Research Article

Assessing the Relationship Between Clean Cooking Fuels and Women's Cancer Mortality in the European Union: An Empirical Analysis

Matheus Koengkan[1], José Alberto Fuinhas[2], Negin Entezari[2]

1. University of Coimbra Institute for Legal Research (UCILeR), Universidade de Coimbra, Portugal; 2. Faculty of Economics, Centre for Business and Economics Research (CeBER), Universidade de Coimbra, Portugal

This study investigates the impact of access to clean cooking fuels on cancer mortality among women in the European Union from 2013 to 2021. Using Pooled Ordinary Least Squares (OLS) and Quantile Regression (QREG) statistical models, it identifies key variables such as access to clean fuels, education levels, and air quality that were positively and negatively associated with cancer mortality. The findings provide new insights into the socio-environmental determinants of health, highlighting the potential of clean energy initiatives to reduce cancer mortality and improve public health. Additionally, the study reveals an unexpected association between education levels and cancer outcomes. The research underscores the critical role of air quality, particularly the need to address PM2.5 exposure, and calls for comprehensive pollution reduction policies. Key policy recommendations include prioritising clean energy solutions, implementing targeted healthcare and educational interventions, and enhancing air quality standards. Furthermore, gender-responsive healthcare policies should focus on ensuring equitable access to cancer prevention and care. Public health campaigns should emphasise healthier behaviours and address stereotypes that may hinder women's health. While the study provides valuable insights, it acknowledges certain limitations, including issues with data quality, the study's time frame, and the challenges of generalising findings across diverse EU contexts. Future research should include longitudinal studies, causal analyses, and comparative studies to elucidate further the complex relationships between socio-environmental factors and cancer mortality. Research on socioeconomic determinants and their role in shaping cancer outcomes will be particularly important, as will efforts to ensure the consistency and quality of health data across the EU.

1. Introduction

The consumption of biomass and fossil fuels, such as wood, agricultural waste, and charcoal, has long been recognised for its positive effects on human life. These fuels provide essential energy for cooking and heating. However, household air pollution (HAP) mainly results from inefficient combustion of solid fuels such as wood, coal, and biomass used for cooking and heating. The release of harmful pollutants deteriorates indoor air quality, contributing to a range of respiratory diseases and other health complications. Chen et al.[1] and Chafe et al.[2] established that women exposed to high levels of HAP are particularly vulnerable to various health risks, including chronic diseases and cancer.

This exposure contributes to the global burden of diseases and injuries, emphasising the importance of implementing environmental risk factors for health outcomes, as evidenced by Smith et al.[3]. The global burden of diseases highlights how incomplete burning of solid fuels, including biomass and coal, produces hazardous chemicals. Studies, including Arku[4], have confirmed that (PM2.5), carbon monoxide (CO), and polycyclic aromatic hydrocarbons (PAHs) contribute to respiratory and cardiovascular diseases. Scott[5] indicates that reliance on clean cooking fuels, such as electricity, LPG, and biogas, is linked to reduced exposure to household air pollution (HAP). This contributes to lower rates of respiratory and cardiovascular diseases, as well as improved maternal and child health outcomes. Reduced time spent collecting firewood or other biomass can lead to increased time for education or economic activities.

Reduced mortality rates can be attributed to the decreased dependence on traditional biomass fuels for cooking and heating, coupled with the adoption of renewable energy technologies. These transitions are crucial in reducing greenhouse gas emissions and promoting sustainable development[6].

Moreover, a shift towards clean cooking can empower women and enhance economic opportunities in rural communities by reducing the time and effort required for fuel collection[7]. Increasing access to clean fuels is also a critical goal of intervention strategies aimed at improving air quality and mitigating the health risks associated with high-emission fuels[8].

Despite these substantial improvements in household air quality and a decline in HAP-related deaths, it remains concerning that approximately 3.1 billion people globally still rely on polluting energy sources for cooking, heating, and lighting. Rural areas, in particular, face challenges related to the transition to cleaner cooking methods, with after-sales services often lacking[9]. In urban areas, infrastructure like roads and electricity grids facilitate the distribution of cleaner energy sources. However, high population density in slums and unauthorised communities complicates providing reliable and affordable clean energy to all residents[10]. The lack of access to clean fuels and cooking technologies affects health and exacerbates gender inequality.

Efforts to address this issue must tackle inequalities and prioritise investments to ensure that all urban residents have equal access to opportunities and essential services. Furthermore, targeted initiatives must address the fundamental social and economic factors contributing to urban poverty, such as unemployment and a lack of education.

The involvement of women in this endeavour is pivotal. Their intimate knowledge of cooking and daily experiences with the harmful effects of indoor air pollution stemming from traditional cooking fuels make them invaluable sources of information[11]. Empowering women by providing training and employment opportunities in the electrical appliance sector can contribute to gender equality and sustainable energy practices. By engaging local women in research and decision-making processes, interventions and policies can be more effective and tailored to prioritise their needs, resulting in long-term solutions for reducing household air pollution[12].

Considering the significant health burden and cancer mortality among women, it is crucial to contextualise the availability of clean cooking fuels, particularly within the European Union (EU). This investigation can provide valuable insights into the specific challenges faced by women in accessing clean cooking solutions and their potential impact on health.

This study's main research question is: How does access to clean cooking fuels impact women’s cancer mortality in European member-states? The two following hypotheses were put forward to answer this question:

H1: Access to clean cooking fuels, including natural gas, electricity, and clean cookstoves, is inversely related to cancer mortality among women in European member-states. This hypothesis proposes that increased access to clean cooking fuels significantly reduces women’s cancer mortality by decreasing indoor air pollution levels. Supporting evidence from previous research (e.g., Yu et al.[13]; Wu[14]; Yang et al.[15]; Tian et al.[16]) has demonstrated that switching from solid fuels to clean fuels significantly improved women's self-rated health. This suggests that access to clean cooking fuels can enhance overall health, potentially impacting cancer mortality rates.

The findings from the study in Indonesia underscore the profound socio-economic and health benefits of transitioning to clean cooking fuels, particularly for women. Access to clean cooking fuels reduces exposure to harmful pollutants like PM2.5, carbon monoxide, and other toxins that are prevalent in biomass and kerosene combustion. This reduced exposure decreases the prevalence of respiratory diseases and cardiovascular issues and potentially reduces risks associated with long-term illnesses such as cancer[17].

H2: The prevalence of traditional solid-fuel cooking methods is positively correlated with women’s cancer mortality rates in European member-states. This hypothesis suggests that regions with higher dependence on traditional solid fuels, such as wood, coal, or biomass, experience greater indoor air pollution and, consequently, higher cancer mortality rates among women. Research by Smith and Pillarisetti[18] supports this assertion, highlighting that solid-fuel combustion releases harmful pollutants that contribute significantly to respiratory and cancer-related health risks.

A multicenter case-control study in Eastern/Central Europe and the UK found that the odd ratio of 1.22 suggests a 22% increase in the likelihood of lung cancer among individuals using burning of solid fuels like wood, coal, or biomass generates indoor air pollution, releasing harmful particulate matter (PM2.5), polycyclic aromatic hydrocarbons (PAHs), and other carcinogens. Long-term exposure to these pollutants damages lung tissue and increases the risk of lung cancer[19]. Research in Ethiopia indicated that solid fuel use was responsible for a significant proportion of lung cancer cases among women, with household air pollution leading to a substantial disease burden[20].

This study investigated the connection between clean cooking fuels like natural gas, electricity, and stoves and reduced women’s cancer mortality rates. It tries to raise awareness about the health implications of cooking fuel choices and the potential benefits of clean cooking solutions. The research will also quantify how access to clean cooking fuels reduces cancer mortality and identify regional disparities across European countries.

This innovative regional analysis may reveal whether the effects are consistent across all European countries or if there are variations that can be attributed to regional differences. Furthermore, policymakers can use this information to design effective awareness campaigns and provide financial support for adopting clean cooking technologies among vulnerable populations. Additionally, the study aims to identify any barriers to policy implementation and propose recommendations for improvement. The results of this research have the potential to inform public health strategies and contribute to the global effort towards achieving sustainable development goals related to health and environmental sustainability.

In light of the considerations above, this study utilises time series data from 2013 to 2021, employing pooled ordinary least squares (OLS) and quantile (QREG) model regression and analysing dependent and independent variables to explore the correlation between multiple factors and their influence on the relationship between access to clean cooking fuels and cancer mortality among women in EU countries. The findings of this research hold the potential to assist the EU in promoting sustainable energy policies that minimise air pollution, enhance public health, and protect the environment, emphasising the association between the adoption of clean energy sources and reduced mortality risks. This discovery underscores previously unanticipated connections between educational attainment and cancer mortality, highlighting the necessity of focused medical care and educational initiatives. It calls for concerted efforts to support and promote healthier behaviours and overall well-being.

This paper provides a comprehensive overview of the research data and methodologies employed in the following section. Section 3 delves into the empirical findings, and Section 4 explores their implications. The paper concludes with Section 5, highlighting valuable policy insights from the study's outcomes.

2. Data and method

2.1. Data

The empirical investigation examined the association between the impact of access to clean fuels for cooking and women's cancer mortality in 27 European member-states (Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden) (see **Figure 1** below).

Figure 1. Selection of 27 European Countries. This figure was created by the authors.

The rationale behind choosing these 27 European countries for this investigation is firmly grounded in the quest for a well-rounded understanding of the subject. As we already know, access to clean cooking fuels and their impact on health outcomes is a multifaceted issue that warrants comprehensive study within different global contexts.

While disparities in access to clean cooking fuels and associated health concerns are well-documented, particularly in underserved populations such as Africa, South Asia, or Latin America, this investigation's decision to focus on EU countries was driven by several strategic considerations.

Firstly, the EU presents a unique socioeconomic and policy environment with relatively higher living standards and well-developed infrastructure compared to many regions in Asia, Africa, and Latin America. By concentrating on this study within this context, this investigation can explore the intricate interplay between access to clean cooking fuels and cancer mortality in women within a setting where policies and infrastructure are more established, thus offering insights into the issue's nuances within a developed framework.

doi.org/10.32388/7SWT9Q.2

Additionally, the availability and reliability of data in EU countries provide a solid foundation for rigorous analysis and interpretation of findings. Unlike in regions where data may be scarce or of variable quality, EU countries typically maintain comprehensive datasets on access to clean cooking fuels and health outcomes, allowing for more accurate comparisons and robust conclusions. Furthermore, it enables us to identify disparities within the EU and draw meaningful comparisons between different populations within the region, shedding light on specific factors contributing to variations in health outcomes and access to clean cooking fuels across socio-demographic groups.

Moreover, the policy relevance of our research within the EU context cannot be overstated. EU policies and initiatives often serve as global benchmarks for addressing public health challenges, including those related to clean energy and environmental health. By focusing on EU countries, this empirical study's findings can inform evidence-based policy decisions and interventions to improve access to clean cooking fuels and reduce cancer mortality rates in women within the EU and globally.

This underscores the importance of conducting research within contexts where outcomes can directly influence policy formulation and implementation, thereby maximising the impact of our findings on addressing this critical public health issue.

The study utilised data from 2013 to 2021. This specific timeframe for analysing the impact of access to clean fuels for cooking on women's cancer mortality in 27 diverse European countries is based on the data availability and integrity principle. The study guarantees the full utilisation of entire and consistent data, thus maintaining the comparability of the analysis throughout space and time. This methodology circumscribes the problems of using the latest data, such as data collection methodologies and reporting accuracy. This study aims to provide statistically significant findings while also considering the historical and sociopolitical context of the period. **Table 1** lists the variables that have been selected for this empirical investigation. These variables will be analysed and evaluated to determine their association with the research objective.

doi.org/10.32388/7SWT9Q.2

Variable	Acronym	Description	Frequency	Measure	Source
Explained variable					
Cancer mortality in women	Dc_w	Cancer-related deaths in women (total, under 65 years and 65 years or older)	Annual	Rate	Eurostat[21]
Explanatory variables					
Average years of schooling among women	Mys_w	Mean years of schooling	Annual	Rate	UNDP (United Nations Development Programme)[22]
PM2.5	PM2.5	Exposure to fine particulate matter (PM2.5)	Annual	Rate	OECD Data[23]
Access to clean fuels for cooking	Ac_cfc	Access to clean fuels or technologies such as natural gas, electricity, and clean cookstoves	Annual	Rate	Our World in Data[24]
Gross National Income per capita among women	Gni_pc_w	Gross National Income per capita among women	Annual	Euro (€)	UNDP (United Nations Development Programme)[22]
Screening for breast and cervical cancer in women	Bcc_w	Women's breast cancer and cervical cancer screenings	Annual	Rate	Eurostat[25]
Total healthcare expenditure	Hc_ex	Total healthcare expenditure	Annual	Million euro (€) per capita	Eurostat[25]
Women engaging in daily cooking and/or housework activities	Pdc_w	Women engaging in daily cooking and/or housework activities (%, 18+ population)	Annual	Rate	European Institute for Gender Equality (EIGE) [26]
Women who do not smoke and are not engaged in harmful drinking	Pdsd_w	Women who do not smoke and engaged in harmful drinking (%, 16+ population)	Annual	Rate	European Institute for Gender Equality (EIGE) [26]
Women who engage in physical activities and/or consume fruits and vegetables	Pdpfv_w	Women who engage in physical activities and/or consume fruits and vegetables (%, 16+ population)	Annual	Rate	European Institute for Gender Equality (EIGE) [26]
Women with unmet needs for medical examinations	Pumex_w	Women who have not attended need of health examinations (%, 16+ population)	Annual	Rate	European Institute for Gender Equality (EIGE) [26]
Women who self-perceive their health as good or very good	Sphg_w	Women who self-perceive them as healthy (%, 16+ population)	Annual	Rate	European Institute for Gender Equality (EIGE) [26]
Share of women serving as ministers	Sm_w	The share of women serving as ministers (%)	Annual	Rate	European Institute for Gender Equality (EIGE) [26]
The proportion of women serving as members of regional assemblies	Smra_w	The proportion of women serving as members of regional assemblies (%)	Annual	Rate	European Institute for Gender Equality (EIGE) [26]
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)	Annual	Rate	European Institute for Gender Equality (EIGE) [26]

Table 1. Data description and sources

The dependent and independent variables have been meticulously chosen to assess their influence on the relationship between access to clean cooking fuels and cancer mortality among women in EU countries. Each variable has a scientific rationale based on previous research, as outlined below:

a. Dc_w serves as a tangible and critical indicator of the potential health consequences of indoor air pollution resulting from traditional cooking methods, which is what access to clean fuels seeks to mitigate. This research sheds light on public health disparities by examining the association between clean fuel access and women's cancer mortality throughout 27 European member-states. It has significant policy implications, guiding efforts to reduce cancer-related deaths and enhance the overall well-being of women in diverse regions.
b. Mys_w is linked with high health results and decreased cancer mortality among women. Previous studies by Gedefaw et al.[27], Raghupathi and Raghupathi[28], and Vaccarella et al.[29] have demonstrated a positive link between higher education levels.
c. PM2.5 represents fine particulate matter pollution linked to adverse health effects, including elevated cancer risk. Scientific studies[30][31] have shown the connection between exposure to PM2.5 and increased cancer incidence and mortality rates.
d. Ac_cfc has been associated with reducing cancer mortality (e.g., Yu et al.[13]; Yang et al.[15]; Tian et al.[16]). As is already known, traditional solid-fuel cooking methods release harmful pollutants, contributing to indoor air pollution and raising health concerns, particularly for women who spend significant time in cooking areas[18]. Therefore, access to clean fuels or technologies such as natural gas, electricity, and clean cookstoves is linked to the absence of harmful pollutant emissions, thus reducing indoor air pollution and associated health concerns, including cancer (e.g., Yu et al.[13]; Yang et al.[15]; Tian et al.[16]).
e. Gni_pc_w reflects economic well-being and access to healthcare services among women. Studies[32] have established the relationship between higher gross national income per capita and improved healthcare infrastructure, contributing to better cancer outcomes.
f. Bcc_w focuses on breast and cervical cancer, emphasising the importance of women's early detection and lower mortality rates. Yang et al.[33] have shown that adequate breast and cervical cancer screening programs increase survival rates and decrease mortality.
g. Hc_ex represents healthcare expenditure, underscoring the significance of healthcare services in cancer outcomes. Previous studies[34][35] have demonstrated the role of access to healthcare services in reducing cancer mortality rates.
h. Pdc_w highlights the relationship between daily cooking and/or housework activities and reduced cancer mortality rates among women. Research (e.g., Bevel et al.[36]; Chen et al.[37]; Mills et al.[38]; Lacombe et al.[39]; Yu et al.[40]) consistently shows the benefits of frequent physical activity and a healthy lifestyle in reducing cancer risk and improving survival.
i. Pdsd_w is related to reduced cancer risks through women's lower smoking and harmful drinking rates. Anand et al.[41] and Lugo et al.[42] have shown the link between tobacco and alcohol consumption and increased cancer incidence and mortality.
j. Pdpfv_w emphasises the benefits of frequent physical activity and a healthy diet in reducing women's cancer mortality. Donaldson[43], Schnohr et al.[44], Liu et al. (2015), Kerschbaum & Nüssler[45], and Chan et al.[46] support the benefits of physical activity and a nutritious diet in reducing cancer risks and improving survival.
k. Pumex_w addresses barriers to accessing healthcare services and potential delays in women's cancer diagnosis. Williams et al.[47] and Quintal et al.[48] have emphasised the importance of timely access to healthcare and its impact on cancer outcomes.
l. Sphg_w highlights the association between positive self-perceived health in women and lower cancer mortality rates. Research[49] has shown that individuals with a positive self-perception of health tend to engage in healthier behaviours and have improved health outcomes, including lower cancer mortality.
m. Sm_w reflects women's political representation, which is linked to improved health outcomes and lower cancer mortality rates. Studies[50] have demonstrated the positive impact of gender equality in political representation on various health indicators, including cancer mortality.
n. Smra_w reflects women's political representation, which is linked to improved health outcomes and lower cancer mortality rates. Studies[50] have demonstrated the positive impact of gender equality in political representation on various health indicators, including cancer mortality.
o. Wds_w represents women's engagement in regular physical activity and leisure activities, which have been associated with better overall health, decreased risk of cancer, and improved cancer results, as stressed by Schnohr et al.[44] and Liu et al. (2015).

This investigation has thoughtfully integrated various variables into the study to comprehensively understand the complex relationship between access to clean cooking fuels and cancer mortality among women. Furthermore, it is crucial to acknowledge that this investigation does not address the causality of deaths in women from various types of cancers separately due to the lack of comprehensive macro data in EU countries covering the period between 2013 and 2021. Consequently, this empirical analysis had to concentrate on overall cancer mortality among women rather than delving into the specifics of individual cancer types.

2.2. *Method*

This study adopts a macro-level approach, analysing population data from 27 EU countries to explore associations between access to clean cooking fuels and cancer mortality among women. This design allows us to identify trends and associations across a diverse socio-political landscape, providing insights into how clean fuel access might relate to health outcomes in broad population settings. Given the ecological nature of this study, our findings represent population-level associations and are not intended to imply causation at the individual level. This methodology aligns with similar public health studies where national or regional data reveal significant trends applicable to policy.

This section details the methodology, commencing with initial assessments and culminating in applying Pooled OLS and QREG model regression. After explaining the underlying theoretical framework, the subsequent phase systematically exposes the empirical research procedures to be meticulously carried out. The sequential progression of the empirical inquiry, as illustrated in **Figure 2** below, serves as a blueprint for translating the theoretical underpinnings into practical applications. These methodical steps are thoughtfully designed to translate abstract concepts into concrete data and tangible interpretations from actual experiences.

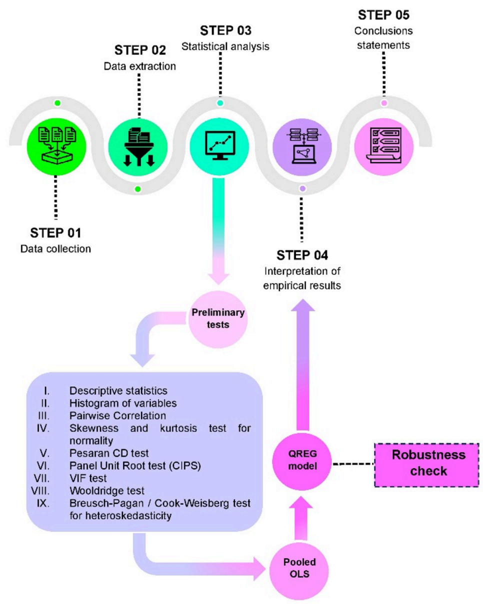

Figure 2. Steps ofempirical research. The authors developed the figure.

Figure 2 visually outlines these stages of the empirical investigation, encapsulating the structured approach. This framework aims to connect the theoretical concepts with their practical implementation, making it easy to understand the subject matter. Each step in the empirical process is performed precisely and seamlessly connects with the previous step to ensure the investigative journey is coherent and progressive.

This meticulous methodology intends to achieve applied insights and substantial inferences, contributing to academic scholarship and a practical understanding of the subject. By rigorously following the prescribed empirical investigation steps, the study seeks to validate its theoretical hypotheses while shedding light on the nuanced complexities that arise in real-world contexts. This methodological transparency reinforces research integrity and provides a roadmap for future replication and extension.

2.2.1. *Pooled Ordinary Least Squares Model*

The Pooled OLS model estimates the relationship between one or more explanatory variables and a dependent variable through statistical methodology. It is stated by Eq. 1.

$$y_{it} = \beta_0 + \beta_1 x_{1it} + \beta_2 x_{2it} + \cdots + \beta_n x_{15it} + \varepsilon_{it}, \qquad (1)$$

where, $x_1, \cdots, x_{15}$ are the explanatory variables, $\beta_1, \cdots, \beta_{15}$ are the regression's parameters, corresponding to the relationship between the explanatory variables and the explained variable, and ε_{it} corresponds to the error term, i.e. the unexplained variation in the explained variable.

The pooled OLS model is well-suited for investigating the impact of access to clean fuels for cooking on cancer mortality across 27 EU countries from 2013 to 2021. Several reasons underpin this choice. Firstly, it adeptly manages extensive datasets by consolidating data from multiple countries, expanding the sample size and enhancing statistical power. This approach facilitates cross-country comparisons, encompassing the EU's diverse socioeconomic, cultural, and healthcare contexts. Secondly, Pooled OLS regression effectively addresses potential confounding factors, permitting a thorough exploration of the link between access to clean fuels for cooking and cancer mortality while considering potential influencing factors. Thirdly, this method provides coefficient estimates that furnish statistical evidence of the relationships between the variables under scrutiny. In conclusion, the Pooled OLS regression method effectively harmonises practicality, statistical robustness, and the ability to unveil meaningful insights concerning the intricate interplay between access to clean fuels for cooking and cancer mortality while maintaining statistical validity.

2.2.2. Quantile Regression (QREG) Model

This study employs the QREG estimation to evaluate the robustness of the Pooled OLS results. QREG extends the scope of traditional regression by estimating various quantiles of the response variable, offering more profound insights into how predictors influence different segments of the outcome's distribution. Koenker and Bassett[51] introduced this method. Unlike OLS, which focuses exclusively on the mean, QREG investigates how changes in predictors affect different percentiles, making it robust to outliers, adaptable to diverse data patterns, and capable of revealing tail behaviour. A basic linear quantile regression equation is represented as follows:

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

In this equation $Q(y \mid x; \tau)$ represents the conditional quantile of the response variable y given the predictor variable x at quantile level τ. The coefficients $\beta_{0,\tau}$ and $\beta_{1,\tau}$ correspond to the intercept and slope of the regression line at the specified quantile τ, epsilon representing the error term. By estimating these coefficients at various quantile levels, quantile regression offers a holistic view of how the relationship between variables evolves across distinct segments of the response distribution.

Indeed, this empirical investigation employs the 25th, 50th, 75th, and 95th quantiles as a robustness check. This QREG technique ensures reliable analysis by examining relationships across segments of the response distribution, thereby revealing potential asymmetry and heterogeneity. The median provides insights into central tendencies with resistance to outliers, while the 95th quantile scrutinises extreme outcomes, ensuring consistent conclusions across the distribution and enhancing model reliability. Using both QREG and Pooled OLS regression allows for a comprehensive analysis that addresses heterogeneity, outliers, and nonlinear relationships among variables. QREG's capability to estimate different quantiles accommodates data variations, yielding insights into extreme values and tail behaviour. The comparison between QREG and OLS results facilitates robustness assessment, wildly when data deviates from a normal distribution or includes outliers. This approach enriches the understanding of variable relationships and ensures a thorough data evaluation.

Moreover, the choice of Pooled OLS and QREG models is particularly well-suited for this study's analysis of time-series data spanning multiple countries. The Pooled OLS model efficiently consolidates data from 27 EU countries over the 2013–2021 period, leveraging the increased sample size to enhance statistical power and enable cross-country comparisons. This approach accounts for variations in socioeconomic, cultural, and healthcare contexts, which are critical when assessing the relationship between access to clean fuels and cancer mortality. On the other hand, the QREG model is especially advantageous in its ability to accommodate non-normal distributions and examine relationships across different quantiles of the response variable. This feature provides a deeper understanding of how predictors influence various segments of cancer mortality rates, including extreme outcomes. By addressing potential outliers and offering robustness against data heterogeneity, QREG complements the insights gained from OLS. Together, these models ensure a comprehensive and rigorous analysis, effectively capturing the complex interplay between the variables while accommodating the unique characteristics of time series and cross-sectional data.

2.3. Preliminary testing

It is crucial to conduct preliminary tests to understand the variables' characteristics within the economic model before applying Pooled OLS and QREG estimators to the regressions. Thus, we conducted initial tests to evaluate the variables in the model:

I. We computed descriptive statistics for each variable, such as mean, standard deviation, minimum, maximum, and quartiles. These statistics give an overall summary of the variable's characteristics.

II. Histograms were used to visualise the distribution of each variable, identifying any skewness, kurtosis, or potential outliers in the data.

doi.org/10.32388/7SWT9Q.2

III. Pairwise correlation coefficients were calculated to measure the strength and direction of linear relationships between variable pairs, providing insight into their interdependencies (Jolliffe, 2002).
IV. Skewness and Kurtosis Test for Normality (D'Agostino et al.[52]): This test evaluated whether the variables adhered to a normal distribution. The null hypothesis assumed the variables' normality.
V. The Pesaran CD Test (Pesaran, 2004) evaluates cross-sectional dependence in panel data. The test's null hypothesis is the absence of cross-sectional dependence.
VI. Panel Unit Root Test CIPS (Cross-sectionally Augmented IPS) of Pesaran[53] to assess the stationarity of variables within the panel data.
VII. Variance Inflation Factor (VIF) Test[54]: This test examines the presence of multicollinearity among the variables.
VIII. The Wooldridge Test for Autocorrelation in Panel Data[55] scrutinises the error term autocorrelation. The test has as a null hypothesis the nonexistence of autocorrelation.
IX. Breusch-Pagan[56] and Cook-Weisberg[52] Test for Heteroskedasticity. This test was used to check for heteroskedasticity in the error term. The null hypothesis assumed no heteroskedasticity.

After conducting initial tests, we gained insights into variable characteristics and identified non-normality, autocorrelation, and heteroskedasticity issues, which could potentially impact subsequent Pooled OLS and QREG regressions. As stressed by Baltagi[57], Greene[58], and Wooldridge[59], such tests are widely recognised in econometrics for bolstering the robustness and validity of estimations.

Moreover, it is important to note that this research focus and study design did not necessitate explicitly modelling such indirect impacts. The primary aim of this investigation was to investigate the direct association between access to clean cooking fuels and cancer mortality in women within the EU context rather than examining complex interactions and pathways between multiple independent variables.

The decision to use a more straightforward modelling approach such as Pooled OLS and QREG was deliberate, as it offers several advantages, as informed before, such as ease of interpretation, computational efficiency, and robustness to violations of certain assumptions. Given the specific objectives of this study and the nature of the data available, Pooled OLS and QREG regressions can provide a suitable framework for estimating the direct effects of access to clean cooking fuels on cancer mortality in women while controlling for relevant confounding factors.

3. Empirical results

This section presents information on data properties, preliminary variable testing, estimation outcomes, and tests for estimation specifications. **Table 2**, below, provides descriptive statistics for the variables utilised in empirical estimations.

Variables	Obs	Mean	Std. Dev.	Min	Max
Dc_w	243	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
Ac_cfc	225	4.5993	0.0285	4.4441	4.6051
Gni_pc_w	243	32518.08	11339.21	15135.71	71316.82
Bcc_w	243	33.98156	30.50838	0	84.3
Hc_ex	243	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	242	35.1358	14.6471	0	70
Pumex_w	228	1.5657	0.81914	0	3.0910
Sphg_w	243	4.1345	0.1831	3.6375	4.4308
Sm_w	243	26.0493	13.2555	0	59
Smra_w	243	27.1687	10.5611	0	49
Wds_w	242	3.1156	0.6180	1.7917	4.0943

Table 2. Descriptive statistics of variables

Notes: The command "sum" in Stata was employed.

The results from **Table 2** above indicate that the mean value of cancer-related deaths in women (Dc_w), measuring a specific variable, is approximately 200.13, suggesting a central tendency around this figure. This variable exhibits a moderate level of variability, as indicated by its standard deviation of roughly 28.07. The minimum and maximum values of 140.36 and 268.56 demonstrate the range of observations.

Independent variables like average years of schooling among women (Mys_w), PM2.5 exposure, and gross national income per capita among women (Gni_pc_w) exhibit distinct patterns. Mys_w, with a mean of about 2.48 and a narrow standard deviation of 0.10, suggests relatively low variability. In contrast, Gni_pc_w displays substantial income disparities within the dataset, with a broad standard deviation of approximately 11339.21, reflecting significant variation in income per capita. These statistics collectively provide a comprehensive overview of the dataset, aiding in understanding the data's central tendencies, variability, and the extent of disparity or consistency within each variable.

The histograms presented in **Figure 3** unveil the diverse patterns exhibited by the research variables. Notably, these histograms indicate a departure from a normal distribution, potentially impacting the statistical significance of the estimated parameters within the Pooled OLS model. A QREG analysis can be employed to investigate these deviations further to enhance the robustness of the results.

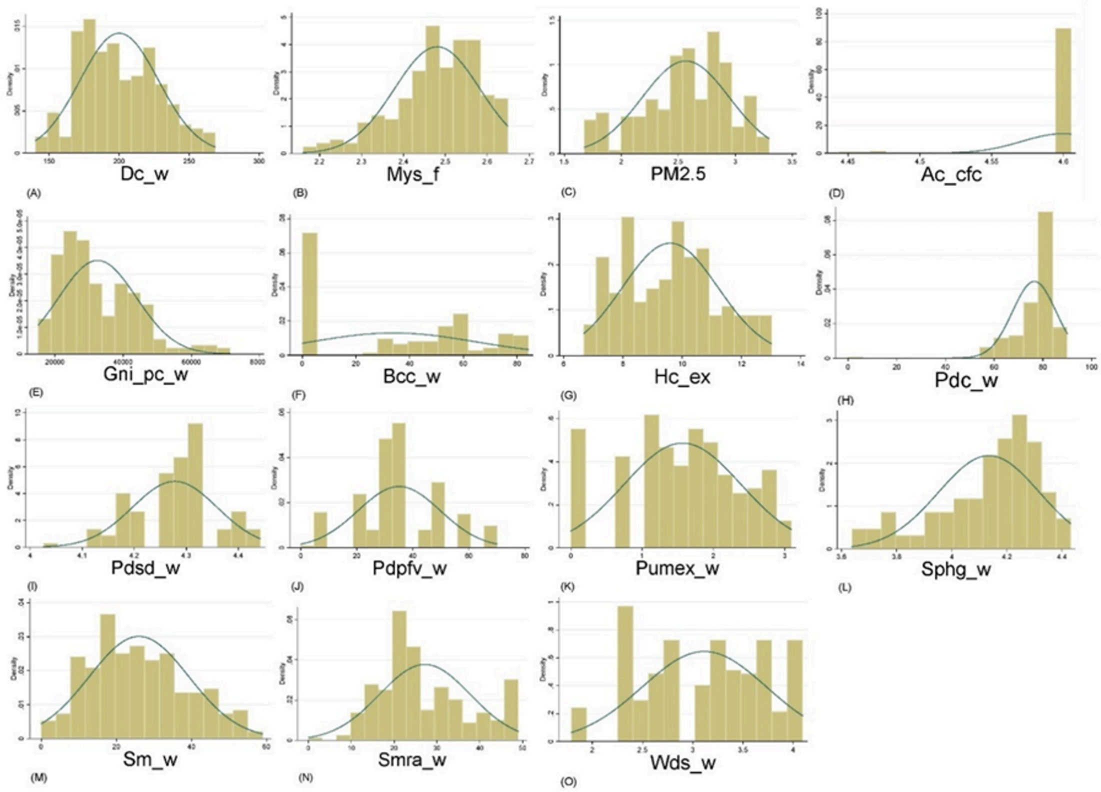

Figure 3. Histogram of variables. The command " histogram" in Stata was employed.

Table 3 below shows an overview of the pairwise correlations between variables. Generally, these corrections are low, indicating a limited degree of association between the variables. Conversely, it is worth noting that the strongest correlation exists between the independent variables women who engage in physical activities and/or consume fruits and vegetables (Pdpfv_w) and PM2.5 exposure, as well as Pdpfv_w and gross national income per capita among women (Gni_pc_w). Even in this instance, the correlation coefficient remains below 0.8, signifying a significant but not overly strong relationship between these variables.

 doi.org/10.32388/7SWT9Q.2

Correlation (A)												
Variable	**(A)**	**B)**	**(C)**	**(D)**	**(E)**	**(F)**	**(G)**	**(H)**	**(I)**	**(J)**	**(K)**	**(L)**
Dc_w (A)	1.000											
Mys_w (B)	0.4063***	1.000										
PM2.5 (C)	0.2215***	-0.0582	1.000									
Ac_cfc (D)	0.0455	0.1962**	-0.1253**	1.000								
Gni_pc_w (E)	-0.0310	0.2766***	-0.5336***	0.2311***	1.000							
Bcc_w (F)	0.3204***	0.2617***	-0.1070*	0.2344***	0.2336***	1.000						
Hc_ex (G)	-0.0929	-0.2193***	-0.1715**	0.0661	0.3552***	-0.0790	1.000					
Pdc_w (H)	-0.2617***	-0.0770	-0.2132***	0.1212**	0.2435***	0.1542**	0.1360**	1.000				
Pdsd_w (I)	-0.1245**	-0.2635***	0.1316**	-0.0258	-0.4516***	-0.0792	-0.2067**	0.2674***	1.000			
Pdpfv_w (J)	0.1493**	0.3677***	-0.5677***	0.4233***	0.6898***	0.2710***	0.2264***	0.2884***	-0.2515***	1.000		
Pumex_w (K)	0.1660**	0.0122	0.0419	-0.2612***	-0.4472***	-0.1655**	-0.2470***	-0.0607	0.2021**	-0.2790***	1.000	
Sphg_w (L)	-0.1653**	-0.1205*	-0.1306**	-0.0431	0.4771***	0.0530	0.3687***	0.1706***	-0.4790***	0.3256***	-0.3386***	1.000
Sm_w (M)	-0.2012***	0.1061*	-0.3709***	0.1525**	0.4619***	-0.0655	0.5050***	0.2956***	-0.1452**	0.4416***	-0.1395**	0.2359***
Smra_w (N)	-0.2641***	0.0685	-0.4963***	0.2142**	0.4052***	-0.0037	0.4764***	0.3889***	-0.0762	0.4231***	-0.1585**	0.2219***
Wds_w (O)	0.1168**	0.2802***	-0.5081***	0.4442***	0.6735***	0.4130***	0.3331***	0.3592***	-0.4034***	0.7026***	-0.2550***	0.3936***
Pairwise Correlation Matrix (B)												

doi.org/10.32388/7SWT9Q.2

Correlation (A)												
Variable	(A)	B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)

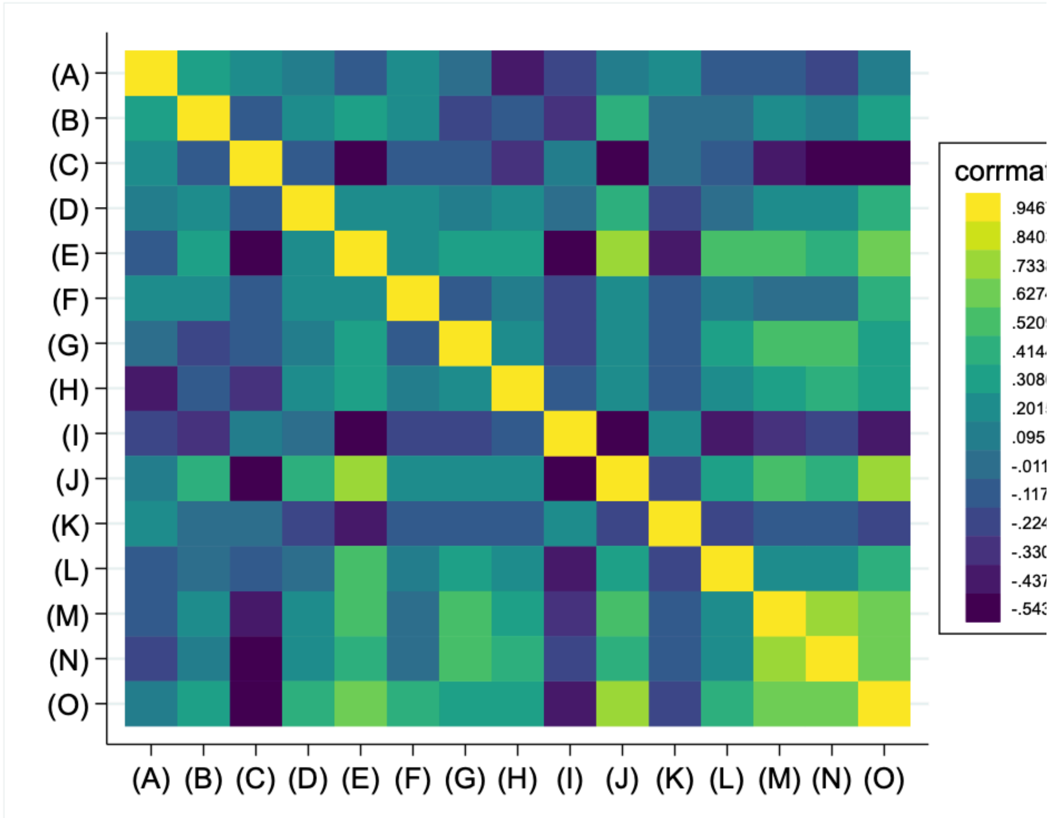

Table 3. Matix of Correlations

Notes: *In the context of statistical significance, the symbols ***, **, and * correspond to significance levels of 1%, 5%, and 10%, respectively. The command "pwcorr" in Stata was employed.*

Table 4. below shows the results from the Skewness and kurtosis test for normality in all variables in the model.

doi.org/10.32388/7SWT9Q.2

Variables	Skewness/Kurtosis tests for Normality					Obs
	Pr(Skewness)	Pr(Kurtosis)	adj chi2(2)	Statistic		
Dc_w	0.0609	0.0105	9.12	0.0105	**	243
Mys_w	0.0000	0.4952	16.21	0.0000	***	243
PM2.5	0.0027	0.1707	9.74	0.0077	**	243
Ac_cfc	0.0000	0.0000	n.a.	0.0000	***	225
Gni_pc_w	0.0000	0.0605	25.28	0.0000	***	243
Bcc_w	0.7310	n.a.	n.a.	n.a.	243	
Hc_ex	0.2182	0.0000	19.92	0.0000	***	243
Pdc_w	0.0000	0.0000	n.a.	0.0000	***	243
Pdsd_w	0.1503	0.6871	2.25	0.3246		242
Pdpfv_w	0.0421	0.8557	4.20	0.1227		242
Pumex_w	0.0193	0.0225	9.58	0.0083	*	228
Sphg_w	0.0000	0.5561	21.79	0.0000	***	243
Sm_w	0.0367	0.0058	10.61	0.0050	**	243
Smra_w	0.0010	0.0236	13.65	0.0011	**	243
Wds_w	0.2197	0.0000	32.16	0.0000	***	242

Table 4. Skewness and kurtosis test for normality

Notes: *In the context of statistical significance, the symbols ***, **, and * correspond to significance levels of 1%, 5%, and 10%, respectively. The command " sktest" in Stata was employed; n.a. denotes unavailable.*

The results from **Table 4** above show that several of the examined variables significantly deviate from a normal distribution. Variables like cancer mortality rate among women (Dc_w), average years of schooling among women (Mys_w), access to clean fuels for cooking (Ac_cfc), PM2.5 exposure, gross national income per capita among women (Gni_pc_w), healthcare expenditure (Hc_ex), self-perceived health as good or very good among women (Sphg_w), share of women serving as ministers (Sm_w), and share of women serving in regional assemblies (Smra_w) exhibit clear departures from normality, with both skewness and kurtosis tests yielding very low p-values, signifying substantial non-normality.

On the other hand, independent variables like women engaging in daily cooking/housework activities (Pdc_w), women who do not smoke and are not engaged in harmful drinking (Pdsd_w), women who engage in physical activities and/or consume fruits and vegetables (Pdpfv_w), and women with unmet needs for medical examinations (Pumex_w) present somewhat mixed results, with significant kurtosis deviations but missing or less significant skewness information, implying potential distribution irregularities. The independent variable screening for breast and cervical cancer in women (Bcc_w) poses a unique challenge; it displays significant right skewness but lacks kurtosis information, making it harder to determine overall distribution characteristics. **Table 5.** below are the results of the Pesaran CD test, which must be conducted before confirming the presence of unit roots in the variables.

 doi.org/10.32388/7SWT9Q.2

Variables	CD-test	p-value		Obs
Dc_w	26.22	0.000	***	243
Mys_w	39.02	0.000	***	243
PM2.5	36.55	0.000	***	243
Ac_cfc	n.a.	225		
Gni_pc_w	35.70	0.000	***	243
Bcc_w	n.a.	243		
Hc_ex	53.17	0.000	***	243
Pdc_w	0.71	0.475		243
Pdsd_w	n.a.	242		
Pdpfv_w	n.a.	242		
Pumex_w	n.a.	228		
Sphg_w	4.16	0.000	***	243
Sm_w	8.55	0.000	***	243
Smra_w	13.19	0.000	***	243
Wds_w	n.a.	242		

Table 5. Pesaran CD test

***Notes:** In the context of statistical significance, the symbol *** corresponds to a significance level of 1%. The command "xtcd" in Stata was employed; n.a. denotes unavailable.*

The results of **Table 5** above reveal substantial evidence of cross-sectional dependence among several variables in the dataset, as indicated by highly significant p-values. Notably, variables such as cancer-related deaths in women (Dc_w), average years of schooling among women (Mys_w), exposure to fine particulate matter (PM2.5), gross national income per capita among women (Gni_pc_w), total healthcare expenditure (Hc_ex), self-perceived health as good or very good among women (Sphg_w), share of women serving as ministers (Sm_w), and share of women serving in regional assemblies (Smra_w) all exhibit strong cross-sectional dependence, emphasizing the interrelatedness of observations across different cross-sectional units.

On the other hand, independent variables like daily cooking and/or housework activities (Pdc_w) do not show significant cross-sectional dependence, suggesting relative independence among observations. However, it is essential to acknowledge that for some independent variables, such as access to clean fuels for cooking (Ac_cfc), women who do not smoke and are not engaged in harmful drinking (Pdsd_w), women who engage in physical activities and/or consume fruits and vegetables (Pdpfv_w), unmet needs for medical examinations (Pumex_w), and engagement in sporting, cultural, or leisure activities outside of the home at least daily or several times a week (Wds_w), the CD test results are not available due to the existence of few observations for these variables to conduct a reliable CD test. The test requires a minimum number of observations to produce meaningful results. **Table 6** below brings out the unit root tests.

Variables	Pesaran[53] Panel Unit Root test (CIPS)				
	Without trend			With trend	
	Lags	Zt-bar		Zt-bar	
Dc_w	0	-3.483	***	-3.833	***
	1	0.993		12.468	
Mys_w	0	-4.934	***	-0.079	
	1	-0.009		12.048	
PM2.5	0	-8.163	***	-4.986	***
	1	-3.036	***	12.468	
Ac_cfc	0	16.04		12.468	
	1	16.045		12.468	
Gni_pc_w	0	-0.193		0.196	
	1	-1.980	**	12.468	
Bcc_w	0	5.190		5.026	
	1	6.243		12.468	
Hc_ex	0	-4.370	***	-2.334	**
	1	-1.584	**	12.468	
Pdc_w	0	2.953		3.491	
	1	-0.531		12.468	
Pdsd_w	0	15.012		12.009	
	1	16.199		12.768	*
Pdpfv_w	0	14.889		12.011	
	1	15.939		12.367	*
Pumex_w	0	n.a.			
	1	n.a.			
Sphg_w	0	-0.068		0.486	
	1	-7.153	***	12.957	
Sm_w	0	-1.089		-1.255	
	1	-8.452	***	12.957	
Smra_w	0	-0.578		3.408	
	1	-4.858	***	12.957	
Wds_w	0	14.948		11.952	
	1	16.037		12.602	*

Table 6. Pesaran[53] Panel Unit Root test (CIPS)

Notes: *In the context of statistical significance, the symbols ***, **, and * correspond to significance levels of 1%, 5%, and 10%, respectively. The Stata command "xtunitroot" was employed; n.a. denotes unavailable.*

Data presented in **Table 6** uncovers a nuanced pattern among variables, with cancer-related deaths in women (Dc_w), average years of schooling among women (Mys_w), gross national income per capita among women (Gni_pc_w), women who do not smoke and are not engaged in harmful drinking (Pdsd_w), women who engage in physical activities and/or consume fruits and vegetables (Pdpfv_w), self-perceived health as good or very good among women (Sphg_w), share of women serving as ministers (Sm_w), share of women serving in regional assemblies (Smra_w), and engagement in sporting, cultural, or leisure activities outside of the home at least daily or several times a week (Wds_w) displaying a borderline behavior between I(0) and I(1), suggesting a possible threshold effect in their stationarity.

Conversely, the independent variables exposure to fine particulate matter (PM2.5) and total healthcare expenditure (Hc_ex) are firmly established as stationary. Notably, the independent variables access to clean fuels for cooking (Ac_cfc), daily cooking and/or housework activities (Pdc_w), and women who do not smoke and are not engaged in harmful drinking (Pdsd_w) emerge as non-stationary, albeit it is essential to acknowledge that the short temporal dimension in longitudinal data may have strongly influenced this lack of stationarity, primarily attributed to short-run events.This characteristic may not significantly impact pooled OLS estimation but could introduce some reservations when conducting robustness analysis using the quantile regression model. **Table 7** below discloses the multicollinearity tests.

Variable	Variance Inflation Factor tests	Mean-Variance Inflation Factor test
Dc_w	n.a.	2.85
Mys_w	1.79	
PM2.5	3.35	
Ac_cfc	2.01	
Gni_pc_w	3.86	
Bcc_w	1.45	
Hc_ex	1.93	
Pdc_w	1.41	
Pdsd_w	2.51	
Pdpfv_w	4.71	
Pumex_w	1.52	
Sphg_w	1.85	
Sm_w	4.15	
Smra_w	4.55	
Wds_w	4.78	

Table 7. Multicollinearity tests

Notes: n.a. means "not applicable"; the command "vif" in Stata was employed.

The findings in **Table 7** demonstrate that VIF and mean VIF values are not a concern. The results show that VIF values are below 10, and the mean VIF value is below 5[60][61][62][63][64]. As a result, it can be confidently concluded that multicollinearity is unlikely to be a concern for both pooled OLS and QREG estimations, affirming the stability and reliability of the regression models. **Table 8** below presents the outcomes of the Wooldridge and Breusch-Pagan/Cook-Weisberg tests.

Panel autocorrelation test of Wooldridge	Heteroskedasticity test of Breusch-Pagan/Cook-Weisberg
F(1,24) = 1.608	chi2(1) =7.74***

Table 8. Tests of panel autocorrelation and heteroskedasticity

*Notes: In the context of statistical significance, the symbol **o corresponds to significance levels of 1%. The commands "xtserial" and "hettest" in Stata were employed.*

Table 8. above provides results from the Wooldridge autocorrelation test (H0: no first-order autocorrelation) and the Breusch-Pagan/Cook-Weisberg heteroskedasticity test (H0: constant variance). There are no indications of autocorrelation issues. However, due to heteroskedasticity, employing the "robust" option in estimation is advisable, ensuring the reliability of the regression model results.

After conducting a series of initial assessments to detect potential concerns related to non-normality, unit roots, multicollinearity, autocorrelation, or heteroskedasticity that might influence the subsequent model regressions, this study proceeds to implement the Pooled OLS regression. As previously noted, this regression is the core model in our empirical analysis. Consequently, the results of both the Pooled OLS and Pooled OLS robust approaches are displayed in **Table 9**.

Independent variables	Explained variable (Dc_w)						
	Pooled OLS				Pooled OLS Robust		
	Param.	t	P > |t|	Signif.	t	P > |t|	Signif.
Mys_w	43.3254	2.47	0.014	**	2.64	<0.001	***
PM2.5	21.0829	3.16	<0.001	***	3.55	<0.001	***
Ac_cfc	-126.2829	-1.92	0.056	**	-3.19	<0.001	***
Gni_pc_w	-0.0002	-1.03	0.303		-1.09	0.278	
Bcc_w	0.1140	2.08	0.039	**	1.93	0.055	**
Hc_ex	3.6832	3.08	<0.001	***	2.40	0.017	**
Pdc_w	-80.2508	-5.38	<0.001	***	-6.31	<0.001	***
Pdsd_w	-0.7193	-2.02	0.045	**	-1.99	0.048	**
Pdpfv_w	0.5258	2.54	0.012	**	2.48	0.014	**
Pumex_w	7.2768	3.45	<0.001	***	3.30	<0.001	***
Sphg_w	-42.2525	-4.02	<0.001	***	-4.14	<0.001	***
Sm_w	-0.2949	-1.40	0.163		-1.40	0.163	
Smra_w	-0.8526	-3.17	<0.001	***	-3.12	<0.001	***
Wds_w	22.6169	4.74	<0.001	***	3.91	<0.001	***
Const	1093.871	3.62	<0.001	***	5.69	<0.001	***
Number of obs		209			209		
F(14, 194)		16.59			30.13		
Prob. F		0.001***			<0.001***		
R^2		0.5448			0.5448		
Adj R^2		0.5120			n.a.		
Root MSE		19.801			19.801		

Table 9. Pooled OLS models

*Notes: In the context of statistical significance, the symbols *** and ** correspond to 1% and 5% significance levels, respectively. The Stata commands "reg" and "reg robust" were employed; n.a. means not applicable.*

The results presented in **Table 9** reveal key associations derived from the Pooled OLS and OLS Robust estimators. Several independent variables exhibit significant relationships with women's cancer mortality in the EU. Notable positive associations were observed for variables such as average years of schooling among women (Mys_w), exposure to fine particulate matter (PM2.5), screening for breast and cervical cancer (Bcc_w), total healthcare expenditure (Hc_ex), engagement in physical activities and/or consumption of fruits and vegetables (Pdpfv_w), unmet needs for medical examinations (Pumex_w), and participation in sporting, cultural, or leisure activities (Wds_w). The corresponding coefficients for these variables were 43.33, 21.08, 0.11, 3.68, 0.53, 7.28, and 22.62, respectively, suggesting that increases in these factors are linked to higher cancer mortality rates among women, with each coefficient representing cancer-related deaths per 100,000 women.

For instance, Exposure to Fine Particulate Matter (PM2.5) is associated with a 21.08 increase in cancer-related deaths per 100,000 women. An increase of 1 $\mu g/m^3$ in PM2.5 exposure is associated with a rise of 21.08 cancer-related deaths per 100,000 women.

Conversely, several variables demonstrated statistically significant negative associations with cancer mortality. These include Access to Clean Fuels for Cooking (Ac_cfc), Daily Cooking and/or Housework Activities (Pdc_w), Self-perceived Health as Good or Very Good (Sphg_w), and The Share of Women

doi.org/10.32388/7SWT9Q.2

Serving in Regional Assemblies (Smra_w). The corresponding coefficients were -126.28, -80.25, -42.25, and -0.85, respectively, suggesting that improvements in these factors are associated with lower cancer mortality rates among women, with each coefficient representing cancer-related deaths per 100,000 women.

It is worth noting that two variables, Gross National Income per Capita Among Women (Gni_pc_w) and The Share of Women Serving as Ministers (Sm_w), were statistically insignificant. This lack of significance suggests that these variables do not have a discernible impact on women's cancer mortality in the EU context.

To enhance model simplicity and interpretability, we developed a parsimonious econometric model by excluding statistically insignificant variables. This approach balances explanatory power with reduced model complexity, thereby minimizing overfitting and improving the model's generalizability. Based on these criteria, Gni_pc_w was excluded from the final model due to its low statistical significance and comparatively small coefficient relative to Sm_w, which, while also insignificant, had a higher coefficient.

The resulting parsimonious model, presented in **Table 10**, provides a streamlined yet robust representation of the key relationships within the data. This approach enhances the model's interpretability while maintaining its essential explanatory power, allowing for clearer insights into the factors influencing women's cancer mortality in the EU.

Independent variables	**Explained variable (Dc_w)**						
	Pooled OLS				**Pooled OLS Robust**		
	Param.	**t**	**P > |t|**	**Signif.**	**t**	**P > |t|**	**Signif.**
Mys_w	39.9054	2.32	<0.001	***	2.44	<0.001	***
PM2.5	23.2982	3.69	<0.001	***	3.96	<0.001	***
Ac_cfc	-126.2197	-1.92	<0.001	***	-3.17	<0.001	***
Bcc_w	0.1194	2.19	<0.001	***	2.01	<0.001	***
Hc_ex	3.6475	3.05	<0.001	***	2.37	<0.001	***
Pdc_w	-83.62998	-5.75	<0.001	***	-6.66	<0.001	***
Pdsd_w	-0.6109	-1.80	<0.001	***	-1.69	<0.001	***
Pdpfv_w	0.5260	2.54	<0.001	***	2.47	<0.001	***
Pumex_w	8.2074	4.31	<0.001	***	4.20	<0.001	***
Sphg_w	-43.9824	-4.24	<0.001	***	-4.35	<0.001	***
Sm_w	-0.3641	-1.83	<0.001	***	-1.80	<0.001	***
Smra_w	-0.7624	-2.99	<0.001	***	-2.78	<0.001	***
Wds_w	21.4218	4.63	<0.001	***	3.75	<0.001	***
Const	1103.974	3.65	<0.001	***	5.64	<0.001	***
Number of obs		209			209		
F(13, 195)		17.78			33.42		
Prob. F		0.001***			0.001***		
R^2		0.5423			0.5423		
Adj R^2		0.5118			n.a.		
Root MSE		19.804			19.804		

Table 10. Pooled OLS - Parsimonious Model

doi.org/10.32388/7SWT9Q.2

*Notes: In the context of statistical significance, the symbol *** corresponds to significance levels of 1%. The Stata commands "reg" and "reg robust" were employed; n.a. means not applicable.*

The results from the Parsimonious Model, presented in **Table 10**, reveal significant associations identified through both the Pooled OLS and Pooled OLS Robust estimators. Several independent variables, including average years of schooling among women (Mys_w), exposure to fine particulate matter (PM2.5), screening for breast and cervical cancer (Bcc_w), total healthcare expenditure (Hc_ex), engagement in physical activities and/or consumption of fruits and vegetables (Pdpfv_w), unmet needs for medical examinations (Pumex_w), and participation in sporting, cultural, or leisure activities outside the home (Wds_w), show a positive correlation with women's cancer mortality in the EU. These variables exhibit statistically significant effects, with coefficients of 39.91, 23.30, 0.12, 3.65, 0.53, 8.21, and 21.42, respectively. This suggests that increases in these factors are associated with higher cancer mortality rates, with each coefficient representing cancer-related deaths per 100,000 women.

For instance, Exposure to Fine Particulate Matter (PM2.5) is associated with a 23.30 increase in cancer-related deaths per 100,000 women. An increase of 1 $\mu g/m^3$ in PM2.5 exposure is associated with a rise of 23.30 cancer-related deaths per 100,000 women.

In contrast, another set of independent variables demonstrates significant negative associations with cancer mortality. These include access to clean fuels for cooking (Ac_cfc), daily cooking and/or housework activities (Pdc_w), self-perceived health as good or very good (Sphg_w), the share of women serving in regional assemblies (Smra_w), and the share of women serving as ministers (Sm_w). These variables also yield statistically significant effects, with coefficients of -126.22, -83.63, -43.98, -0.61, and -0.76, respectively. These findings suggest that improvements in these factors are linked to reductions in cancer mortality among women in the EU, with each coefficient representing cancer-related deaths per 100,000 women.

A comparative analysis of the results in **Tables 9** and **10** highlights an increase in the coefficient values of independent variables after removing gross national income per capita among women (Gni_pc_w) from the model. Furthermore, in this refined model, all included variables achieve statistical significance at the 1% level. This outcome validates the decision to exclude statistically insignificant variables with low coefficients, reinforcing the model's enhanced performance and precision.To further ensure the stability and reliability of the results, the study employed Quantile Regression (QREG) models for robustness checks. These models, detailed in the methodology, provide insights across the 25th, 50th, 75th, and 95th quantiles. The findings from this robustness assessment are presented in **Table 11**, offering a comprehensive evaluation of the relationships between the variables and cancer mortality rates across different quantiles.

Independent variables	Explained variable (Dc_w)											
	Quantiles											
	.25Q			.5Q			.75Q			.95Q		
Mys_w	59.2516	<0.001	***	38.6941	0.098	**	2.0866	0.927		6.6830	0.647	
PM2.5	26.8654	<0.001	***	26.1738	<0.001	***	31.6462	<0.001	***	52.9553	<0.001	***
Ac_cfc	-63.1345	0.369		-77.8609	0.382		-168.7658	0.054	*	-136.1914	<0.001	***
Bcc_w	0.01695	0.771		0.0291	0.694		0.3301	<0.001	***	0.2589	<0.001	***
Hc_ex	1.6778	0.189		1.7558	0.279		4.7761	<0.001	***	0.7876	0.437	
Pdc_w	-1.3627	<0.001	***	-1.6285	<0.001	***	-1.0912	<0.001	***	-0.3400	0.050	**
Pdsd_w	-0.5950	0.102		-0.3598	0.435		-0.2236	0.620		-0.3751	0.194	
Pdpfv_w	0.3209	0.147		0.4255	0.130		0.5904	0.032	**	1.0076	<0.001	***
Pumex_w	10.0182	<0.001	***	9.8589	<0.001	***	10.8997	<0.001	***	9.3933	<0.001	***
Sphg_w	-54.6203	<0.001	***	-51.9469	<0.001	***	-38.0213	<0.001	***	-37.3136	<0.001	***
Sm_w	-0.22897	0.283		-0.3522	0.193		0.0088	0.973		-0.0948	0.575	
Smra_w	-0.0962	0.723		-0.3833	0.267		-1.4306	<0.001	***	-1.0287	<0.001	***
Wds_w	10.7633	0.030	**	19.6644	<0.001	***	33.56417	<0.001	***	30.0458	<0.001	***
Const	569.6967	0.078	*	668.0946	0.103		1001.103	<0.001	***	782.7262	<0.001	***

Table 11. QREG model- Robustness check

*Notes: In statistical significance, the symbols ***, **, and * correspond to significance levels of 1%, 5%, and 10%, respectively. The command "qreg, quantile (.25.5.75.95)" in Stata was employed.*

The findings presented in **Table 11** detail the outcomes of the Quantile Regression (QREG) analysis, offering nuanced insights into the factors influencing cancer-related deaths in women (Dc_w). The results indicate that average years of schooling among women (Mys_w) positively impacts cancer-related deaths in the 25th and 50th quantiles. Similarly, exposure to fine particulate matter (PM2.5) consistently demonstrates a positive association with cancer-related deaths across all quantiles, highlighting its pervasive influence.

In contrast, access to clean fuels for cooking (Ac_cfc) is associated with a reduction in cancer-related deaths in the 75th and 95th quantiles. Conversely, screening for breast and cervical cancer (Bcc_w) shows a positive association with cancer-related deaths in the same quantiles. Total healthcare expenditure (Hc_ex) is positively associated with cancer-related deaths in the 75th quantile, while daily cooking and/or housework activities (Pdc_w) consistently demonstrate a negative association across all quantiles. Interestingly, women who do not smoke and are not engaged in harmful drinking (Pdsd_w) does not exhibit a measurable impact on cancer-related deaths.

Additional results indicate that women engaging in physical activities and/or consuming fruits and vegetables (Pdpfv_w) positively impact cancer-related deaths in the 75th and 95th quantiles. Unmet needs for medical examinations (Pumex_w) exhibit a positive association across all quantiles, while self-perceived health as good or very good among women (Sphg_w) is consistently linked to a reduction in cancer-related deaths across all quantiles. The share of women serving as ministers (Sm_w) does not demonstrate a significant effect, but the share of women serving in regional assemblies (Smra_w) shows a negative association in the 75th and 95th quantiles. Additionally, engagement in sporting, cultural, or leisure activities outside the home at least daily or several times a week (Wds_w) consistently correlates with increased cancer-related deaths across all quantiles.

These QREG results broadly corroborate the findings obtained from the Pooled OLS regression, affirming the robustness of the model across diverse analytical methodologies. **Figure 4** provides a comprehensive summary of these empirical results, contextualized within the outcomes presented in **Table 10**.

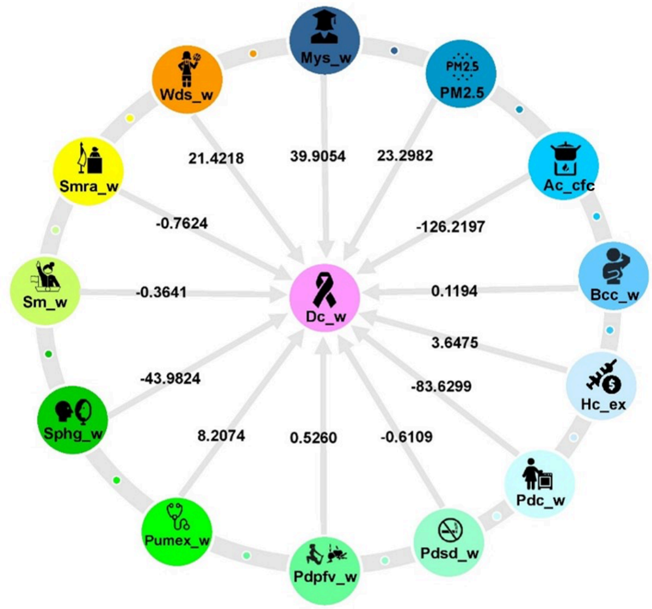

Figure 4. Summary of empirical results: This figure has been derived from the outcomes presented in **Table 10** above. The authors created this figure.

In analysing the relationship between access to clean cooking fuels and cancer mortality, we observed a statistically significant negative association between greater access to clean fuels (e.g., natural gas, electricity) and cancer mortality rates among women across the EU. Specifically, regions with higher adoption of clean fuels demonstrated lower cancer mortality rates. In contrast, exposure to elevated levels of particulate matter (PM2.5) and limited access to healthcare were associated with higher cancer mortality rates. These findings underscore the critical role of environmental quality and healthcare infrastructure in shaping public health outcomes, highlighting the need for policies aimed at improving both environmental conditions and healthcare accessibility to reduce cancer mortality.

The following section will provide potential explanations for the empirical results presented in **Table 10** above.

4. Discussion

In this section, they offer potential explanations for the observed empirical results. Nevertheless, it is imperative to underscore that further studies may be necessary to confirm these findings definitively. They are building upon the findings presented in **Table 10** in the previous section.

This study uses population-level data to assess the relationship between access to clean fuels and cancer mortality among women in the European Union. This approach allows for a broad examination of the socio-environmental factors influencing health at the population level. Ecological studies are widely accepted in public health research for identifying general trends and informing policy, especially when individual-level data is not feasible or available. Thus, while our findings suggest trends that could inform public health policy, they should be seen as indicative rather than definitive of individual-level effects.

The primary independent variable in this empirical study, access to clean fuels for cooking, is associated with decreased women's cancer mortality in the EU. Some literature has reported a correlation between access to clean fuels or technologies, such as natural gas, electricity, and clean cookstoves, and decreased cancer mortality[65][13][15][16]. In the study conducted by Yu et al.[65], a positive association was identified between the use of solid fuels and an increased risk of cardiovascular mortality and all-cause mortality, which includes cancer-related mortality. Conversely, participants who had transitioned to clean cooking fuels in the past exhibited a lower risk of both cardiovascular and all-cause mortality. The reduced risk is linked to decreased indoor and outdoor air pollution caused by using clean energy sources.

This concept is further corroborated by Yu et al.[13], where the individuals who use clean cooking fuels experience substantially lower mortality risks, making a compelling case for promoting their widespread adoption. Compared to persistent solid fuel users, persistent clean fuel users had notably reduced all-cause mortality (with a hazard ratio of 1.19), cardiovascular mortality (HR 1.24), and respiratory mortality (HR 1.43). Furthermore, the study demonstrated that transitioning from solid fuels to clean fuels led to a swift and substantial reduction in excess mortality risks by cancer, with the data revealing a decrease of more than 60% within five years of making this transition.

Yang et al.[15] provide a comprehensive perspective on the critical health im-plications of solid fuel usage. Their analysis underscores that solid fuels are associated with some of the most significant risk factors for various diseases, notably including pneumonia, chronic obstructive pulmonary disease (COPD), ischemic cardiovascular and cerebrovascular diseases, lung cancer, and cognitive decline. These health risks collectively impose substantial social and healthcare burdens worldwide. Conversely, adopting clean fuels and technologies is linked to decreasing these disease risk factors, positively impacting public health. Furthermore, the authors emphasise that promoting the transition from solid to clean fuels enhances global public health, upholding human rights and protecting the environment. This holistic view reinforces the notion that advancing clean fuel solutions is a multifaceted approach that can yield profound benefits by improving health outcomes, respecting individual rights, and contributing to environmental preservation. In the study conducted by Tian et al.[16], a noteworthy conclusion emerges: Individuals who made the transition from biomass to clean fuels experienced a significant decrease in their risk of cancer-related mortality (HR: 0.81, 95% CI: 0.72-0.95) as well as a lowered risk for mortality from all causes (HR: 0.76, 95% CI: 0.64-0.93). Similarly, those who switched from fossil fuels to clean fuels significantly reduced their overall mortality risk (HR: 0.77, 95% CI: 0.62-0.93). In other words, this research highlights a compelling association between using clean cooking fuels and a diminished risk of cancer and all-cause mortality within the elderly population, underscoring the potential health benefits of clean energy adoption in cooking practices.

Furthermore, these findings are intricately linked to the notable prevalence of households with access to clean fuels and advanced technologies, including natural gas, electricity, and clean cookstoves within the EU. In most EU member states, access to such clean energy sources has achieved remarkable levels, with nearly all countries reaching 100% adoption (% of the population) during the period under analysis. Notably, even in the case of Romania, where adoption rates are slightly lower, clean fuel access stood at a commendable 87.7% in the year 2021[24]. Indeed, the high level of access to clean energy sources in most EU countries is closely related to several efficiency initiatives implemented by the EU to enhance energy efficiency in households and buildings, promote the consumption of clean energy sources, and reduce indoor and outdoor air pollution[66]. Several EU nations have implemented various strategies and mechanisms to work towards this objective, aligning with the guidelines outlined in the European Parliament and the Council's Directive (2010/31/EU). These initiatives encompass building performance standards, informative resources, building energy codes, and financial incentives, such as subsidies and tax credits[67].

These initiatives might be connected to an increased representation of women in ministerial and regional assembly roles. Such a scenario often leads to a stronger focus on policies that promote clean energy and sustainability[68]. Governments striving for gender equality tend to be more attuned to public health, family well-being, the environment, and gender disparities. Consequently, they are more inclined to implement regulations and initiatives that expand access to clean energy resources. This potential explanation supports the outcomes of the independent variables' share of women serving as ministers and the proportion of women serving as members of regional assemblies.

Follows the explanation of results for the other independent variables within the econometric model, which comprise average years of schooling among women, PM2.5, screening for breast and cervical cancer in women, total healthcare expenditure, women engaging in daily cooking and/or housework activities, women who do not smoke and are not engaged in harmful drinking, women who engage in physical activities and/or consume fruits and vegetables, women with unmet needs for medical examinations, women who self-perceive their health as good or very good, share of women serving as ministers, the proportion of women serving as members of regional assemblies, and women who engage in sporting, cultural, or leisure activities outside of their home at least daily or several times a week. An unexpected finding has emerged regarding the variable average years of schooling among women's impact on women’s cancer mortality in Europe. These findings reveal an unexpected increase in cancer mortality rates by 39.9054, as indicated by Gedefaw et al.[27], Raghupathi and Raghupathi[28], and Vaccarella et al.[29]. This result challenges the conventional belief that higher education levels lead to reduced cancer mortality.

The EU has a notably high proportion of highly educated women, but significant educational disparities persist within the EU. For instance, Romania has the lowest percentage of women aged 25-34 with tertiary education at 25%, while Ireland stands out with the highest rate at 62%, according to Eurostat[69]. These disparities result from a complex interplay of factors, including historical gender norms, economic disparities, and cultural beliefs that limit women's educational opportunities.

The surprising impact on cancer mortality rates can be linked to the lower proportion of highly educated women in most EU countries. Prior research consistently shows that lower educational levels in women are associated with higher cancer mortality rates, as indicated by Bahk et al.[70], Barcelo et al.[71], and Vaccarella et al.[29]. Women with limited education often face barriers to healthcare access, increased exposure to cancer risk factors, and limited awareness of cancer prevention. This result is supported by findings related to key independent variables, such as screening for breast and cervical cancer

doi.org/10.32388/7SWT9Q.2

in women, women who engage in physical activities and/or consume fruits and vegetables, women with unmet needs for medical examinations, and women who engage in sporting, cultural, or leisure activities outside of their home at least daily or several times a week.

In summary, the unexpected relationship between education and cancer mortality in European women suggests that the lower proportion of highly educated women in most countries may play a significant role. This conclusion aligns with prior research that consistently establishes an association between lower education levels in women and increased cancer mortality rates, as seen in the studies by Bahk et al.[70], Barcelo et al.[71], Vaccarella et al.[29], and Koengkan et al.[66].

The influence of PM2.5, a type of air pollution, on women's cancer-related mortality rates in the EU is substantial, denoted by a coefficient of 23.2982. Exposure to PM2.5 is established as a cancer risk factor, and women in EU urban areas typically encounter higher PM2.5 levels than those residing in rural regions[72][73]. These findings heightened that exposure contributes significantly to the increased women's cancer mortality rates[72][73].

In 2019, Bulgaria (19.6 μg/m3) and Poland (19.3 μg/m3) reported elevated PM2.5 levels in urban areas within the EU, followed by Romania (16.4 μg/m3) and Croatia (16 μg/m3). In contrast, Estonia (4.8 μg/m3), Finland (5.1 μg/m3), and Sweden (5.8 μg/m3) recorded lower PM2.5 concentrations in urban areas[74]. Various studies have solidified the connection between PM2.5 exposure and cancer mortality in women (e.g., Dehghani et al.[75]; Guo et al.[76]; Turner et al.[73]; Prada et al.[30]; Dehghani et. al.[77]; Liu et al.[31]), as it amplifies cancer risk by inducing inflammation and lung damage, rendering the lungs more susceptible to cancer-causing agents. This association may also be influenced by lower educational levels and income, which can lead women to reside in areas with subpar air quality due to housing constraints or financial limitations, increasing their exposure to PM2.5[78]. Additionally, limited access to healthcare for women can create substantial barriers to timely cancer screening, diagnosis, and treatment[79]. This situation often results in the detection of cancer at a more advanced and less treatable stage, ultimately contributing to the heightened cancer mortality associated with PM2.5 exposure.

Empirical findings show that the independent variable screening for breast and cervical cancer in women significantly raises cancer mortality among women by 0.1194, contrary to the expected link between screening participation and lower mortality[33]. In specific EU countries, breast and cervical cancer screening rates have been inadequate, notably falling below 70% for breast cancer and under 50% for cervical cancer[80].

This limited screening rate is due to a lack of awareness, financial constraints, transportation issues, language barriers, and cultural beliefs discouraging participation. Improving rates necessitates raising awareness, affordability, accessibility, language support, and cultural sensitivity[80][33].

The impact of screening for breast and cervical cancer in women on increased cancer mortality may also be linked to insufficient investments in screening services in select EU countries[81]. Inadequate healthcare investments are evident, with subsequent findings indicating a connection between healthcare expenditure and increased women's cancer mortality.

Constraints of time and demanding workloads also play a role in these patterns. Kamanga and Stones[79] note that busy schedules and family commitments hinder women's health prioritisation, causing delayed medical appointments and work-related stress that leads to postponing screenings. Furthermore, low screening rates are associated with the underrepresentation of educated women in certain EU countries, with limited awareness and education about early detection contributing to these rates. Access limitations, cultural norms, personal beliefs, and healthcare system inefficiencies further deter screenings[79]. Eurostat[80] and Yang et al.[15] support these findings, highlighting the hindrances of long wait times and rigid scheduling.

As in Starfield et al.[34] and Akinyemiju et al.[35], the empirical findings point to the influence of the independent variable total healthcare expenditure, associated with a notable increase of 3.6475 in cancer mortality among women. This unexpected effect on cancer mortality rates may be linked to low per capita healthcare expenditures in specific EU countries.

Surprisingly, contrary to expectations, Eurostat[82] point out that several EU countries reported relatively modest healthcare expenditure levels in 2020 (Lithuania, Slovakia, Latvia, Hungary, Poland, Croatia, Bulgaria, and Romania). McKee et al.[83], Allemani et al.[84], and Jemal et al.[85] support that this low expenditure can contribute to elevated cancer mortality rates through a variety of mechanisms, including restricted healthcare services, overdue diagnosis and treatment, limited screening and prevention investments, and low quality and insufficient caring services. The impact of the independent variable total healthcare expenditure on the rise in cancer mortality among women indicates healthcare expenditure patterns.

The results demonstrate that the variable women engaging in daily cooking and/or housework activities are associated with a decrease of -83.62998 in cancer mortality among women[36][37][38][39][40]. Engaging in daily cooking and household activities among women in the EU can potentially contribute to lower cancer mortality rates through various mechanisms. These activities promote healthier diets by allowing control over ingredients and cooking methods, resulting in well-rounded and nutritious meals. Additionally, housework involves physical activity, which is linked to reduced risks of cancers like breast, colorectal, and endometrial cancer. Furthermore, these activities may serve as stress-relievers, potentially reducing chronic stress levels associated with increased cancer risk[86]. Significantly, the impact of daily cooking and household activities on cancer mortality rates is influenced by multiple factors.

The empirical findings indicate that the independent variable, women who do not smoke and are not engaged in harmful drinking, is linked to a significant reduction of -0.6109 in the EU's women's cancer mortality. This reduction can be attributed to the low prevalence of "women who neither smoke nor engage in harmful drinking" behaviours. As Anand et al.[41] and Lugo et al.[42] point out, it is well-established that refraining from smoking and excessive alcohol consumption significantly reduces the risk of women's cancer mortality. However, concerning trends are observed in the EU, with a decrease in the proportion of "women who neither smoke nor engage in harmful drinking" behaviours. EU countries have implemented policies and campaigns to reduce alcohol and tobacco consumption[87][88]. Continued efforts in promoting healthy behaviours and raising awareness about the risks associated with smoking and harmful drinking are essential to reduce women's cancer mortality rates in the EU.

Empirical results indicate that the independent variable, women who engage in physical activities and/or consume fruits and vegetables, is associated with a 0.5260 increase in cancer mortality among women. The surprising link between "women engaging in physical activities and consuming fruits and vegetables" and increased "cancer mortality" may be linked to the low levels of physical activity and insufficient fruit and vegetable consumption among women in the EU. For example, Eurostat[89], European Commission[90], Eurofound[91], and Baskin and Galligan[92] point out that various factors contribute to these patterns, including socio-cultural norms, gender conventions, inadequate access to amenities, temporal restrictions, lack of awareness, and body image concerns.

This outcome could also be attributed to lower education levels, as highlighted by Pem and Jeewon[93] and Assari and Lankarani[94]. Individuals with less education often lack proper nutrition knowledge and may encounter misinformation about healthy dietary habits, particularly concerning fruits and vegetables. This educational disparity might contribute to the observed fruit and vegetable intake patterns among women in certain EU countries. Droomers et al.[95] also stressed that lower education levels are linked to decreased physical action engagement.

Income can also be expected to contribute to the problem. Limited economic conditions frequently lead people to prioritise cheaper and more caloric food over fresh food, as noted by Assari and Lankarani[94]. Fruits and vegetables are generally costly, relatively cheaper, and more caloric than other foods. The gender pay gap in the EU could make it harder for women to afford healthy food.

Furthermore, time constraints and workloads could be influencing these results. As Palmer et al.[96] mentioned, women often juggle multiple roles, including paid employment and caregiving responsibilities. This situation can make meal preparation and planning more challenging, resulting in a preference for convenience foods over cooking with fruits and vegetables. Additionally, these responsibilities might limit their capacity to prioritise their nutritional needs.

Moreover, time constraints and workloads also impact women's engagement in physical activities[97]. The link between lower engagement in physical activities among women in the EU and its potential influence on cancer mortality is supported by the variable women who engage in sporting, cultural, or leisure activities outside their homes at least daily or several times a week.

The empirical results reveal a significant association between the independent variable women with unmet medical examination needs and an 8.2074 increase in women's cancer mortality in the EU. Collins et al.[98] support that this increase is linked to unmet medical examination needs, inadequate access to healthcare, waiting lists, economic difficulties, distance, and derisory perception. Various EU age groups reported unfilled health needs. Eurostat[99] points out that older age groups frequently cited reasons such as expenses, distance, and waiting lists.

The justifications behind the lack of satisfied health needs differ in different EU member states. The primary issue was the expense in several member states, including Belgium, Bulgaria, Greece, France, Italy, Cyprus, Latvia, Luxembourg, Austria, Portugal, and Romania. For example, waiting lists occurred extensively in Estonia, Ireland, Spain, Lithuania, Poland, Slovenia, Slovakia, Finland, Sweden, and Norway. Some countries, such as Czechia, Denmark, Germany, Croatia, Hungary, Malta, the Netherlands, and Switzerland, Eurostat[99] point out that reign in a cautious approach of delay and do. Besides, this outcome could likewise be connected to low rates of the aged 50 to 69 women undertaking screenings for breast and cervical cancer. Obstacles to screening and previously identified low healthcare investments might contribute to this phenomenon.

The empirical results demonstrate a significant reduction in cancer mortality among women in the EU due to the independent variable women who self-perceive their health as good or very good, with a substantial decrease of -43.9824. This reduction is associated with women's health self-perception as good or excellent. Positive self-perceived health is linked to the adoption of healthy behaviours, seeking timely medical care, and better adherence to medical recommendations, ultimately leading to early cancer detection and improved treatment outcomes (e.g., Chida et al.[100]; World Cancer Research Fund/American Institute for Cancer Research[86]).

In the EU, 66% of women self-perceive their health as good or very good. Countries with the highest percentages of women reporting positive self-perceived health include Ireland, Greece, Cyprus, Luxembourg, Belgium, the Netherlands, Italy, Norway, Iceland, Austria, and Sweden. Conversely, countries with the lowest percentages of women reporting positive self-perceived health are Lithuania, Latvia, Estonia, Hungary, Germany, Slovakia, and Croatia[101]. Previous research by Korn et al.[49] also supports the finding that individuals with a positive self-perception of health tend to engage in healthier behaviours and have improved health outcomes, including lower cancer mortality.

The empirical results reveal that the independent variables share of women serving as ministers and the proportion of women serving as members of regional assemblies significantly reduce cancer mortality among women in the EU, with reductions of -0.3641 and -0.7624, respectively. This reduction can be attributed to the influence of women serving as parliament and regional assembly members. Gender-responsive policies and healthcare decision-making led by women in positions of power prioritise gender-specific health issues, including cancer prevention and healthcare access[50].

Having women in political leadership can result in policy initiatives supporting cancer prevention programs, early detection strategies, and improved healthcare infra-structure. This case promotes awareness, education, and access to cancer screening and treatment services for women, ultimately leading to better health outcomes and potentially reducing cancer mortality rates. Gender equality and women's empowerment also influence women's healthcare-seeking behaviours, as empowered women prioritise their health, engage in preventive measures, and make informed healthcare decisions[26]. In the EU, women comprised approximately 40% of the European Parliament in 2021[102]. The representation of women in national parliaments varies among EU countries, with higher proportions in Sweden, Finland, Belgium, and Spain and lower proportions in Malta, Cyprus, Hungary, and Greece[103].

Furthermore, this reduction in air pollution may also be associated with a more excellent representation of women in ministerial and regional assembly positions. Women in such roles tend to prioritise policies that support clean energy and sustainability. Salamon[68] corroborates this explanation, finding that women typically know more about climate change, environmental concerns, and pro-environmental behaviour than men. As a result, women in ministerial and regional assembly positions are more inclined to enact regulations and initiatives that promote access to clean energy resources.

According to the same author, higher levels of women's participation in parliamentary activities are associated with increased renewable energy consumption. This situation, in turn, leads to reduced air pollution (indoor and outdoor), including PM2.5 and CO2 emissions, which are significant contributors to various diseases and fatalities. These diseases notably include pneumonia, chronic obstructive pulmonary disease (COPD), ischemic cardiovascular and cerebrovascular diseases, lung cancer, and cognitive decline.

The variable women who engage in sporting, cultural, or leisure activities outside of their home at least daily or several times a week significantly raises cancer mortality among EU women by 21.4218. This increase is tied to their infrequent participation in outdoor activities like sports, culture, or leisure, leading to a sedentary lifestyle and higher cancer risk. Factors including community patterns, education, temporal restrictions, limitations of entry, safety concerns, and gender stereotypes that contribute to this reduced engagement are relevant, as stressed by authors like Park et al.[104], World Cancer Research Fund/American Institute for Cancer Research[86], Euro-found[91], and the European Commission[105]. These challenges involve promoting gender equality, offering affordable recreation, improving facility access, challenging stereotypes, and creating safe spaces for women's activities. Other factors, such as time constraints and workloads, may influence these results, as Palmer et al.[96] highlighted in the preceding discussion concerning the variable women who engage in physical activities and/or consume fruits and vegetables.

5. Conclusions and Policy Implications

This investigation delved into the impact of access to clean cooking fuels on cancer mortality across 27 EU countries from 2013 to 2021. The empirical results of Pooled OLS and QREG models revealed several independent variables that significantly correlate with increased cancer mortality among EU women. Notably, variables such as (i) average years of schooling among women, (ii) PM2.5, (iii) screening for breast and cervical cancer in women, (iv) total healthcare expenditure, (v) women who engage in physical activities and/or consume fruits and vegetables, (vi) women with unmet needs for medical examinations, and (vii) women who engage in sporting, cultural, or leisure activities outside of their home at least daily or several times a week, showed positive associations with cancer mortality.

Conversely, an alternative set of independent variables, including (i) access to clean fuels for cooking, (ii) women engaging in daily cooking and/or housework activities, (iii) women who self-perceive their health as good or very good, (iv) the proportion of women serving as members of regional assemblies, and (v) share of women serving as ministers, displayed negative associations with cancer mortality.

This in-depth investigation into the factors affecting cancer mortality among European women advances our understanding of public health and epidemiology. It highlights the connection between public health, sustainable energy practices, and air quality. Additionally, the study explores the complex relationships between socio-environmental determinants and health outcomes, adding to existing knowledge and guiding future research.

The research presents groundbreaking findings about the connection between clean energy adoption and reduced mortality risks, highlighting the importance of clean energy initiatives in improving health and protecting the environment. It also uncovers unexpected links between education levels and cancer mortality, emphasising the necessity for targeted healthcare and educational interventions. Additionally, the study stresses the urgent need to address PM2.5 exposure and improve air quality to lower cancer risk, reinforcing the importance of comprehensive pollution reduction policies.

The unexpected consequences of low breast and cervical cancer screening rates, combined with limited healthcare investments in cancer mortality, highlight the urgent need for improved screening programs. The study alsoemphasises the significant role of women in positions of power—such as members of parliament and regional assemblies—in shaping gender-responsive healthcare policies, underscoring the importance of equitable representation. Additionally, it offers valuable insights into how physical activity, lifestyle choices, and self-perceived health interact, pointing out the influence of societal norms and gender stereotypes on health behaviours. Overall, the study calls for collective efforts to promote healthier behaviours and enhance well-being.

5.1. Policy implications

The results of this study emphasize urgent policy priorities for enhancing women's health outcomes in the EU, especially regarding cancer mortality. Clean energy policies are vital for reducing exposure to environmental carcinogens. By promoting clean cooking fuels and renewable energy sources while phasing out harmful solid fuels, we can decrease the incidence of respiratory cancers and other diseases linked to poor air quality. Additionally, healthcare interventions must address educational and socio-economic disparities that lead to worse cancer outcomes. Increasing access to health education and cancer prevention programs can bridge knowledge gaps, resulting in earlier detection and improved treatment. It is also important to prioritize initiatives aimed at improving air quality to reduce exposure to pollutants that contribute to cancer mortality, particularly particulate matter (PM2.5) and CO2 emissions. Expanding enhanced cancer screening programs and implementing gender-responsive healthcare policies will ensure timely and equitable access to preventative and diagnostic services, thereby improving early detection rates. Lastly, public health campaigns should encourage healthy behaviours, such as physical activity, better nutrition, and the cessation of tobacco and alcohol use, while also challenging gender stereotypes that restrict women's participation in these activities. Collaborative efforts among governments, healthcare providers, and advocacy groups are essential to developing strong, evidence-based policies. When adopted, these comprehensive policy measures have the potential to significantly reduce cancer mortality among women in the EU while improving overall public health outcomes.

5.2. Limitations of study and future research

This study highlights a significant link between access to clean cooking fuels and a decrease in cancer mortality among women in the European Union, underscoring the potential public health benefits of increasing access to clean energy. However, several limitations should be noted. The reliance on existing data may impact its quality and completeness, and the study's time frame (2013–2021) may not capture the most recent trends. Additionally, the lack of data on specific cancer types and varying age distributions restricts the ability to conduct a more in-depth analysis. Furthermore, the cross-sectional design of the study does not allow for insights into long-term trends or causal relationships.

The study primarily focused on identifying correlations. The next step should involve developing research that incorporates individual-level data, which is essential for validating these findings and understanding the underlying mechanisms. While these results provide valuable insights for EU countries, caution is needed when generalizing to other regions due to differences in healthcare systems and socio-environmental contexts. Despite these limitations, the findings highlight trends that could inform energy and public health policies, supporting evidence-based strategies to address cancer mortality and health disparities through clean energy initiatives.

To suppress some of the study's limitations identified above, future research on cancer mortality among European women should include broad and specific investigations. For example, longitudinal studies are essential for tracking trends over extended periods and identifying evolving patterns. Causal analyses will be critical in understanding the mechanisms behind observed associations, offering insights into how various factors directly influence cancer mortality. Comparative studies between European countries can help pinpoint region-specific factors, thereby guiding the development of tailored public health strategies. A key focus should be on the socioeconomic determinants of cancer mortality, alongside assessing the effectiveness of interventions—especially those related to clean energy and air quality—to ensure they achieve optimal outcomes.

Furthermore, investigating the impact of gender and the role of women in positions of power on healthcare policies, as well as exploring behaviour-focused interventions, can deepen our understanding of cancer mortality. Strengthening the quality and consistency of data across the EU is essential for conducting robust analyses. In conclusion, comprehensive and interdisciplinary research efforts will enhance our understanding of the factors influencing cancer mortality and contribute to more effective public health measures at the regional level.

5.3. Contribution to SDG goals

This research contributes to the United Nations Sustainable Development Goals (SDGs) by deepening our understanding of the factors affecting cancer mortality among European women. It directly supports SDG 3 (Good Health and Well-Being) by providing insights to improve public health outcomes and SDG 5 (Gender Equality) by emphasising the critical role of women in healthcare decision-making. Furthermore, it advances SDG 7 (Affordable and Clean Energy) by highlighting the importance of clean energy initiatives for better health outcomes.

The study also aligns with SDG 10 (Reduced Inequalities) by addressing health disparities, SDG 11 (Sustainable Cities and Communities) through its advocacy for improved air quality, and SDG 13 (Climate Action) by promoting clean energy as a climate-resilient practice. These contributions underscore the study's alignment with global sustainability priorities and its relevance to fostering equitable, health-conscious, and environmentally sustainable societies.

Statements and Declarations

Author Contributions: M.K: Conceptualisation, Methodology, Writing, original draft preparation, Supervision, Validation, Data curation, Investigation, Formal analysis, Visualisation. J.A.F: Reviewing, Editing, and Investigation. N.E: Investigation. All authors have read and agreed to the published version of the manuscript.

Declaration of generative AI in scientific writing: During the preparation of this work, the author(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) reviewed and edited the content as needed and take(s) full responsibility for the final publication.

Funding: UCILeR is an R&D Unit accredited and funded by FCT—Portugal National Agency within the scope of its strategic project: UIDB/04643/2020. CeBER: R&D unit funded by National Funds through FCT—Fundação para a Ciência e a Tecnologia, I.P., project UIDB/05037/2020.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data is available on request from the corresponding author.

Acknowledgements: UCILeR is an R&D Unit accredited and funded by FCT—Portugal National Agency within the scope of its strategic project: UIDB/04643/2020. CeBER: R&D unit funded by National Funds through FCT—Fundação para a Ciência e a Tecnologia, I.P., project UIDB/05037/2020.

Conflicts of Interest: The authors declare no conflicts of interest.

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Declarations

Funding: UCILeR is an R&D Unit accredited and funded by FCT—Portugal National Agency within the scope of its strategic project: UIDB/04643/2020.

CeBER: R&D unit funded by National Funds through FCT—Fundação para a Ciência e a Tecnologia, I.P., project UIDB/05037/2020.

Potential competing interests: No potential competing interests to declare.

doi.org/10.32388/7SWT9Q.2