Subnational inequalities in years of life lost and associations with socioeconomic factors in pre-pandemic Europe, 2009–19: an ecological study

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Summary

Background Health inequalities have been associated with shorter lifespans. We aimed to investigate subnational geographical inequalities in all-cause years of life lost (YLLs) and the association between YLLs and socioeconomic factors, such as household income, risk of poverty, and educational attainment, in countries within the European Economic Area (EEA) before the COVID-19 pandemic.

Methods In this ecological study, we extracted demographic and socioeconomic data from Eurostat for 1390 small regions and 285 basic regions for 32 countries in the EEA, which was complemented by a time-trend analysis of subnational regions within the EEA. Age-standardised YLL rates per 100 000 population were estimated from 2009 to 2019 based on methods from the Global Burden of Disease study. Geographical inequalities were assessed using the Gini coefficient and slope index of inequality. Socioeconomic inequalities were assessed by investigating the association between socioeconomic factors (educational attainment, household income, and risk of poverty) and YLLs in 2019 using negative binomial mixed models.

Findings Between Jan 1, 2009, and Dec 31, 2019, YLLs lowered in almost all subnational regions. The Gini coefficient of YLLs across all EEA regions was 14·2% (95% CI 13·6–14·8) for females and 17·0% (16·3 to 17·7) for males. Relative geographical inequalities in YLLs among women were highest in the UK (Gini coefficient 11·2% [95% CI 10·1–12·3]) and among men were highest in Belgium (10·8% [9·3–12·2]). The highest YLLs were observed in subnational regions with the lowest levels of educational attainment (incident rate ratio [IRR] 1·19 [1·13–1·26] for females; 1·22 [1·16–1·28] for males), household income (1·35 [95% CI 1·19–1·53]), and the highest poverty risk (1·25 [1·18–1·34]).

Interpretation Differences in YLLs remain within, and between, EEA countries and are associated with socioeconomic factors. This evidence can assist stakeholders in addressing health inequities to improve overall disease burden within the EEA.

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Introduction

In the European Economic Area (EEA) substantial and systemic differences exist in health status between social groups and geographical regions.[1] These avoidable health inequities have been estimated to cost the European Union (EU) approximately €980 billion due to welfare losses annually, equating to 9·4% of the gross EU domestic product (GDP), based on 2004 data.[2,3]

Knowledge about geographical and socioeconomic inequalities is invaluable for public health. The distribution of geographical inequalities across the EEA is remarkably variable and dynamic,[4] relating to differences in political, economic, and social environments. European countries are also at different stages of the epidemiological transition. In part, this implies shifts from a high burden of infectious diseases to degenerative and non-communicable diseases, which are largely preventable and strongly associated with the wider determinants of health, such as environment, health behaviours, and political and socioeconomic circumstances.[5] European countries have heterogenous welfare states[6] and health systems,[7] impacting their ability to address health inequalities. This is a policy challenge prioritised by EU institutions, national and local governments, and the general population.[1,8]

Despite the implementation of policies aiming to reduce mortality and therefore health disparities, substantial geographical and social inequalities persist across EEA countries,[8] and in some contexts, are increasing. In eastern Europe, relative and absolute inequalities in mortality have been exacerbated since the early 1990s.[9]

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Research in context

Evidence before this study

We searched PubMed from database inception to Dec 3, 2023 for articles using the following search terms: "((“years of life lost”) OR (“Mortality”[MeSH])) AND ((((“Social Determinants of Health”[Mesh]) OR “Socioeconomic Factors”[Mesh]) AND ((“Health Inequities”[Mesh]) AND “Europe”[Mesh])) AND (spatial OR area OR regions OR NUTS OR subnational OR “within countries” OR “within country”))”, which yielded 343 results. Our search had no language restrictions. Of the 343 articles identified, 172 were out of scope, and nine articles were reviews. 45 articles were abstracts or had irrelevant methods. 12 papers omitted any regional specification, while 86 articles focused on a single country. 13 studies presented findings from countries outside of the European Economic Area (EEA) exclusively. Six studies focused on health inequalities and socioeconomic factors within the EEA, at the subnational level, although none utilised years of life lost (YLLs). As such, we know a lot about individual-level variations between socioeconomic status groups within and between countries (in many outcomes including YLLs), but a gap remains in the understanding of the impact of socioeconomic factors on social inequalities in YLLs across European regions, which hinders effective policy making and the involvement of local communities.

Added value of this study

This is the first study to determine all-cause premature mortality, measured by age-adjusted and population-adjusted YLLs, across subnational regions in all EEA countries before the COVID-19 pandemic. Our findings indicate a decline in YLLs across most subnational regions between 2009 and 2019. There was marked variation observed within countries and across the EEA. The study highlights that levels of educational attainment, household income, and poverty risk were associated with subnational YLLs, although the strength of these associations varied across different regions of Europe. By determining the association between socioeconomic factors and YLLs at the subnational level, we provide insights into the geographical disparities of key determinants of inequality in health.

Implications of all the available evidence

Our study provides a detailed examination of geographical disparities in premature mortality, offering comparative insights both within and between countries. The incorporation of information on both geographical and socioeconomic inequalities, at both national and subnational levels, contributes to a comprehensive understanding of health disparities. This perspective not only informs targeted interventions but also plays a pivotal role in shaping effective policies and guiding the allocation of resources. Findings related to subnational regions emphasise the importance of developing, implementing, and evaluating small-scale regional policies aimed at addressing health disparities. National estimates, although informative, might mask the nuanced inequalities that exist at the subnational level. Recognising regional disparities and wider health-determining factors can help inform how to distribute health resources, equitably. Careful analysis of all-cause YLLs across the EEA provides policy-relevant insights, identifying European regions requiring targeted resource allocation. This might involve utilising cohesion and structural funds strategically, aligned with both national and subnational priorities. Our research is aligned with the objectives of European Union cohesion policy, which acknowledges health as a crucial factor for regional development and competitiveness. We provide important data on economic and social disparities, contributing to the justification for investing in health as a means of addressing regional imbalances and improving overall wellbeing.

Health across European countries remains geographically divided, despite improvements in heart disease prevention and treatment, with changes in alcohol consumption and road traffic safety improving the situation in countries that emerged out of the dissolution of the Soviet Union.[10]

Although health inequalities are typically addressed as a European or national concern, they also require action at the subnational level. However, comprehensive data on how socioeconomic indicators are associated with health at the EEA regional level are scarce. This insight could enhance our understanding of health disparities within countries and bolster the impact of policies and interventions in regional contexts. Previous research has been concentrated on studies of individual, or a small number of countries,[11,12] or had a narrow focus (eg, survival among older people).[13]

Interventions tackling geographical and social inequalities in many European countries are inefficient and difficulties exist with regard to developing a clear and integrated vision between national and regional levels.[14] Since the release of the 2008 report by the WHO Commission on Social Determinants of Health,[15] local governments have been identified as crucial partners in addressing health inequalities resulting from social determinants.[16]

Through investigating differences between and within countries, policy makers and public health practitioners can develop targeted interventions and governance systems to tackle specific health inequalities and improve population health. Sub-national level insights can also help uncover inequalities that might be overlooked when examining data from larger geographical areas only.[17]

Years of life lost (YLLs) quantify the population-level impact of premature mortality through incorporating the frequency and age-distribution of mortality. YLLs can be used to inform policy strategies aimed at reducing health inequalities.[18] YLLs have been applied in subnational and global contexts and are a key metric of the Global Burden of Disease (GBD) studies.[19] Subnational YLL estimates across wider regions of the EEA permit comparative and consistent analysis of geographical inequality in premature mortality burdens both between and within countries. The aim of this study was to investigate subnational disparities in all-cause YLLs between and within EEA countries in 2019, and to analyse changes in all-cause YLLs between 2009 and 2019. Furthermore, we aimed to examine the associations between several indicators of socioeconomic status and YLLs.

Methods

Study design and setting

We did an ecological study and time-trend analysis of subnational EEA regions, defined using Eurostat Nomenclature of Territorial Units for Statistics (NUTS) 2 (n=285 basic regions with application of regional policies) and NUTS 3 (n=1390 small regions).[20] The EuroVoc classification was used to define broader European geographical regions: central and eastern; northern; southern; and western Europe.[21] The Baltic countries of Estonia, Latvia, and Lithuania were reclassified from northern Europe to central and eastern Europe, based on a closer epidemiological profile to countries in central and eastern Europe. Alternative findings from a sensitivity analysis using the northern Europe classification are in the appendix (p 18). The study was reported in adherence to the STROBE guidelines (appendix pp 3–8).

Data sources and measures

Data on all-cause mortality counts, residential population, and socioeconomic indicators (income, level of education, and risk of poverty), by subnational region from 2009 to 2019 were obtained from Eurostat. Data were extracted at NUTS 3 for assessing YLLs in 2019 and the rural-urban typology association. NUTS 2 data were used for assessing YLL trends from 2009 to 2019 and the socioeconomic indicators association, as NUTS 3 data were unavailable. The GBD 2019 reference life table was used to determine YLLs.[22] More detailed data source specifications can be found in the appendix (p 36). The Eurostat data repository had incomplete mortality data (eg, 6% missing mortality data for NUTS 3 in 2019) and socioeconomic indicators (eg, risk of poverty [44% missing] and household income [15% missing]). Missing data were imputed, with details provided in the appendix (pp 9, 38–39). Imputed data did not alter the interpretation of the main effects, as confirmed by a sensitivity analysis (appendix p 40).

The study outcome was all-cause premature mortality, estimated using age-standardised YLL rates.[23] YLL estimates incorporate the age-distribution of deaths, such that deaths at younger ages contribute a greater weight than deaths at older ages. Age-conditional life expectancy was defined using the aspirational model life table from GBD 2019.[24,25] Direct age-standardised YLLs rates per 100 000 population (referred to as YLLs hereafter) were estimated using the 2013 European Standard Population, which is the preferred approach outlined by Eurostat.[26] Relative geographical inequalities in age-standardised YLLs were evaluated using the Gini coefficient,[27] which capture the average relative difference in YLLs between regions (NUTS 3 and NUTS 2) within countries or across the EEA. Higher Gini coefficients indicates greater geographical inequality in YLLs, with 100% representing complete inequality and 0% indicating complete equality. Absolute geographical inequalities in YLLs were measured using the slope index of inequality (SII).[27] The SII is the average absolute difference in YLLs between the most advantaged and most disadvantaged regions within a country, or the EEA, based on the linear regression of country rankings by YLLs and population distribution across NUTS 2 or NUTS 3-level regions.

We assessed the association of age-standardised YLLs with socioeconomic factors such as educational attainment, household income, and risk of poverty and social exclusion (referred to as risk of poverty hereafter), across NUTS 2-level regions. Household income reflects households' economic capacities, adjusted per inhabitant.[20] Risk of poverty indicates the percentage of people with a disposable income that is 60% of the national median, considering social transfers, social deprivation rate (eg, capacity to face unexpected expenses, ability to keep home adequately warm), and living in households with low work intensity (ie, a working time ≤20% of their total combined work-time potential during the previous year).[28] Educational attainment was measured as the proportion of individuals with upper secondary non-tertiary education or less, based on the international standard classification of education (levels 0–4; International Standard Classification of Education 2011).[29] We used the Eurostat urban–rural typology classification, which classifies each NUTS 3 region either as predominantly rural, intermediate, or predominantly urban.[30]

Ethical approval was not required for this study because it uses aggregated data that were publicly available.

Statistical analysis

From 5-year lifetables (0 to >85 years) of deaths and population (per Jan 1), we calculated sex–year–region–age–specific mortality rates per 100 000 population and corresponding 95% CIs. In this study, sex refers to the biological classification of individuals as male or female. CIs were estimated using the delta method to account for the variance of the estimates.[31] From these mortality rates, we calculated sex-year-region-specific YLLs and corresponding 95% CIs with residual life expectancy based on the GBD 2019 life tables.[32] Sex-specific and country-specific Gini coefficient, SII, and 95% CI estimates of YLLs were calculated based on NUTS 3 for 2019 and NUTS 2 for the period of 2009 to 2019. The average annual percentage

For the **definition of household income used** see https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Households_disposable_income

See Online for appendix

For **mortality data** see https://ec.europa.eu/eurostat/web/products-datasets/-/demo_r_magec

For **data on population size** see https://ec.europa.eu/eurostat/web/products-datasets/-/demo_r_d2jan

For **data on income** see https://ec.europa.eu/eurostat/web/products-datasets/-/nama_10r_2hhinc

For **level of education** see https://ec.europa.eu/eurostat/web/products-datasets/-/edat_lfs_9918

For **data on poverty** see https://ec.europa.eu/eurostat/databrowser/view/tgs00107/default/table?lang=en change (AAPC) from 2009 to 2019 was calculated using sex-specific and NUTS 2-specific linear regression models, with age-standardised YLLs as the dependent variable and year as the independent variable. This was converted to a percentage using the following formula: AAPC=(exponential [β coefficient$_{(LN[X])}$]–1)×100.

To assess within-country geographical inequalities based on the change of age-standardised YLLs for NUTS 2 from 2009 to 2019, we computed the AAPC for the Gini coefficient and SII. Since negative values were present, SII estimates were reported as raw β values instead of percentages. AAPC calculations comprised the time-series analysis of the study.

We conducted mixed-effects negative binomial regression models to assess the association between educational attainment, household income, and risk of poverty with the outcome age-adjusted YLL rate. The analyses included random intercepts by country and utilised robust standard errors (appendix p 37). The incident rate ratio (IRR) is estimated with corresponding 95% CIs. Quintiles were calculated for each socio-economic variable by dividing the data into five equal intervals, maintaining equal proportions in each quintile. This was calculated across EEA subnational regions, and then within each EuroVoc region, relative to that region. Additionally, for educational attainment, quintiles were calculated separately by sex. For the association analysis, quintile 1 was defined as the reference group for educational attainment (highest educational attainment) and for risk of poverty (lowest proportion at risk of poverty), whereas quintile 5 was the reference group for household income (highest income). A sensitivity analysis (appendix pp 14–17), assessing the impact of utilising age-standardised YLL rates versus crude YLL rates with mean subnational regional age as a covariate, determined that these models had minimal impact on the findings of the analysis, with the exception of northern Europe, where incorporating age as a separate covariate led to a generally lower effect size for educational attainment. We did general linear model analyses to assess trends in YLLs across socioeconomic quintiles. The β coefficients indicate the estimated change in YLLs for each one-unit-higher value in the percentile group, with corresponding p values. Both the mixed-effects negative binominal regression and linear regression analyses were conducted separately for the main analysis (across all subnational regions of all EEA countries) and by each EuroVoc region, aligning quintiles with the specific region under examination. The method used to generate maps for countries is explained in the appendix (p 41).

Stata (version 17.0) was used to calculate all descriptive statistics and regression estimates. The spmap package was used to produce maps, and Gini coefficients were calculated using the ineqdeco Stata module (version 15.0).

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

In 2019, across all subnational regions, mean age standardised YLLs for males (19 477 per 100 000 [95% CI 19 136–19 817]) were 1·8 times higher than YLLs for females (10 745 per 100 000 [10 575–10 875). Disparities in age-standardised YLL rates for males and females were identified across different NUTS 3 regions (figure 1). Further descriptive statistics of YLLs across subnational regions are presented in the appendix (pp 19–22).

For females, the ten highest YLLs were observed in regions of Bulgaria (Montana [22 771 per 100 000 (95% CI 15 118 to 30 424)], Vidin, Targovishte, Sliven, Pernik, Dobrich, and Vratsa) and Romania (Tulcea, Satu Mare, and Bacau), while the ten lowest YLLs were observed in regions of Greece (Evrytania [4282 per 100 000 (–690 to 9253)], Thesprotia, and Lefkada), Spain (El Hierro, Araba/Álava, Fuerteventura, Burgos, and La Gomera), Italy (Ogliastra), and the UK (Camden and City of London).

For males, the ten regions with the highest YLLs were in Latvia (Latgale [45 726 per 100 000 (95% CI 37 381–54 072]), Romania (Tulcea, Bacau, Vaslui, Galati, and Satu Mare), Lithuania (Utenos Apskritis), and Bulgaria (Pernik, Kyustendil, and Montana). Conversely, the ten regions with the lowest YLLs among males were observed in the UK (Westminster [8389 per 100 000 (4774–12 388)]), Switzerland (Appenzell Innerrhoden, Obwalden, Zug, Uri, and Ticino), Spain (Menorca), Greece (Evrytania), Malta (Gozo and Comino), and Sweden (Hallands county). A complete list of all YLL estimates in 2019 by sex and NUTS 3-level region is in the appendix (pp 42–101).

In general, YLLs across all NUTS 2 regions were lower in 2019 than in 2009 for both sexes. The five largest declines (ie, greatest improvements) for females were observed in Corse, France (AAPC –2·74% [95% CI –3·69 to –1·79]), Hovedstaden, Denmark (–2·57% [–2·86 to –2·29]), Eastern and Midland, Ireland (–2·44% [–2·85 to –2·04]), Sud-Vest Oltenia, Romania (–2·31% [–2·84 to –1·78]), and Syddanmark, Denmark (–2·28% [–2·80 to –1·77]). The smallest improvements for females were observed in Ciudad de Ceuta, Spain (0·94% [–0·51 to 2·41]), Ionia Nisia, Greece (0·37% [–0·78 to 1·53]), Merseyside, UK (0·13% [–0·62 to 0·88]), and the West Midlands, UK (0·08% [–0·38 to 0·54]).

The five largest improvements in YLLs for males were observed in Southern, Ireland (AAPC –2·96% [95% CI –3·33 to –2·60]), Sør-Østlandet, Norway (–2·93% [–3·37 to –2·49]), Eesti, Estonia (–2·91% [–3·36 to –2·47]), Oslo og Akershus, Norway (–2·78% [–3·92 to –1·63]), and Sostines regionas, Lithuania (–2·77% [–3·35 to –2·19]).

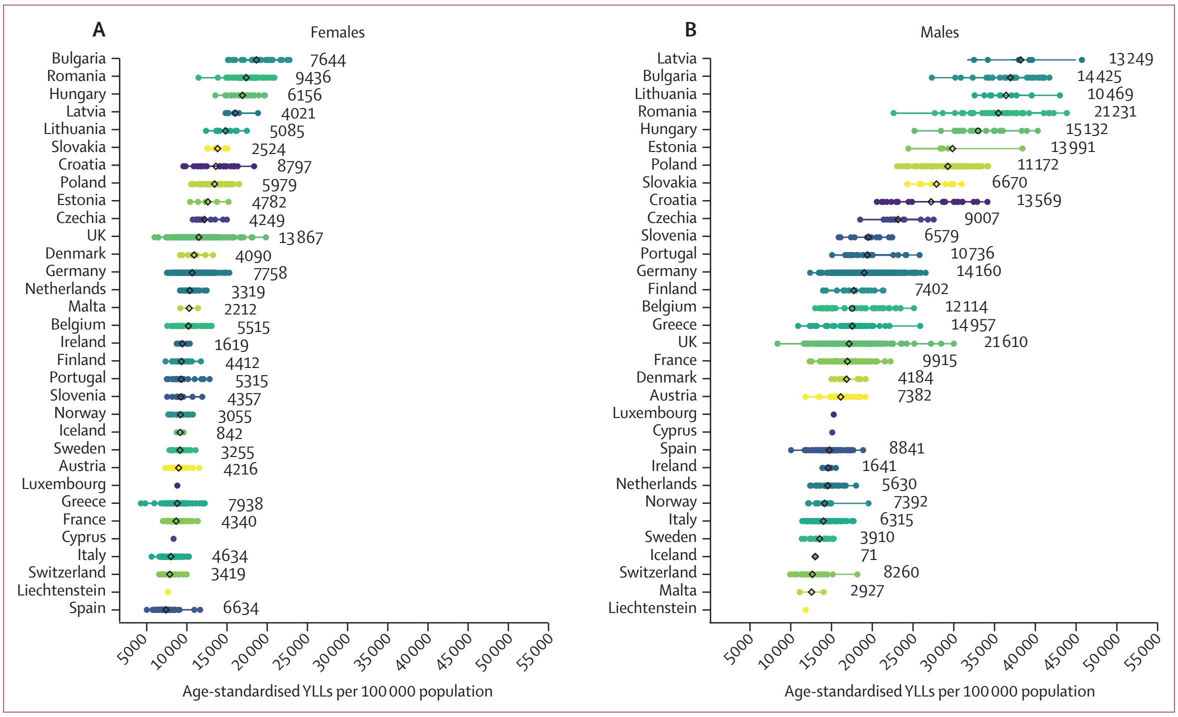

***Figure 1:* Age-standardised YLLs per 100 000 population for each subnational region in 2019, by country for females (A) and males (B)**
Each dot represents a single subnational NUTS 3-level region; the colours in the figure are consistent within a country across sex groups. Black diamonds show mean YLL values. Numbers presented for each country indicate the absolute difference between the lowest and highest region in terms of YLLs. YLLs=years of life lost. NUTS=Nomenclature of Territorial Units for Statistics.

The smallest improvements for males were observed in Lincolnshire, UK (0·05% [–1·03 to 1·14]), Algarve, Portugal (0·02% [–0·62 to 0·66]), Cornwall and Isles of Scilly, UK (–0·08% [–0·83 to 0·68]), Northumberland and Tyne and Wear, UK (–0·17% [–0·80 to 0·47]), and Nord-Est, Romania (–0·22% [–0·80 to 0·37]). However, despite these improvements, YLLs remained relatively high in 2019 in many subnational regions of central and eastern Europe (figure 2). A comparison of YLLs in 2019 with baseline levels in 2009 (appendix pp 21–22) suggests that, for example, while regions in Estonia, Latvia, and Lithuania had substantial reductions in YLLs, baseline YLLs were some of the highest in 2009 in these countries.

The relative within-country geographical inequality in age-standardised YLLs in 2019 by subnational regions (NUTS 3), measured by the Gini coefficient, was generally low. For females, the highest level of inequality was observed in the UK (11·21% [95% CI 10·11–12·30]), followed by Greece (10·14% [7·69–12·59]) and Croatia (9·64% [7·15–12·13]; table 1). On the other hand, the lowest level of inequality for females was observed in Ireland (3·37% [2·26–4·48]), Slovakia (3·80% [2·26–4·48]), and the Netherlands (4·05% [2·32–5·27]). For males, the highest level of inequality was observed in Belgium (10·76% [9·34–12·17]), followed by the UK (10·46% [9·46–11·47]) and Croatia (9·0% [7·21–10·83]). The lowest level of inequality for males was observed in Ireland (1·99% [1·18–2·81]), Lithuania (4·36% [2·42–6·30]) and Slovakia (4·47% [2·85–6·10]). The overall relative geographical inequality in YLLs was larger between EEA countries rather than within EEA countries, and slightly greater for males (16·96% [16·26–17·65]) than for females (14·22% [13·62–14·82]; table 1).

In absolute terms, the largest geographical inequality in YLLs in 2019 among females, as measured by SII, was observed in Germany (16·86% [95% CI 16·28 to 17·44]), followed by Estonia (16·35% [8·47 to 24·23]) and the UK (15·26% [14·52 to 15·99]). In males, the largest absolute geographical inequality was observed in Estonia (36·60% [–10·88 to 84·07]), followed by Latvia (31·07% [14·78 to 47·36]) and Hungary (30·60% [27·39 to 31·48]); however, the 95% CI for Estonia crossed 0, indicating substantial uncertainty about its rank. In females, the lowest absolute geographical inequality was observed in Ireland (3·80% [2·69 to 4·91]), followed by Switzerland (4·24% [3·41 to 5·07]) and the Netherlands (4·66% [4·15 to 5·17]), whereas in males the lowest absolute geographical inequality was observed in Ireland (3·37% [2·44 to 4·30]), followed by Sweden (6·67% [5·81 to 7·54]) and the Netherlands (7·08% [6·25 to 7·90]). The absolute geographical inequality for all NUTS 3-level regions was 20·43% (20·00 to 20·86) for females and 41·3% (40·03 to 42·49) for males (appendix p 23).

Between all EEA subnational regions (NUTS 2-level) between 2009 and 2019, relative georgaphical inequalities were reduced for females (AAPC –0·19% [95% CI

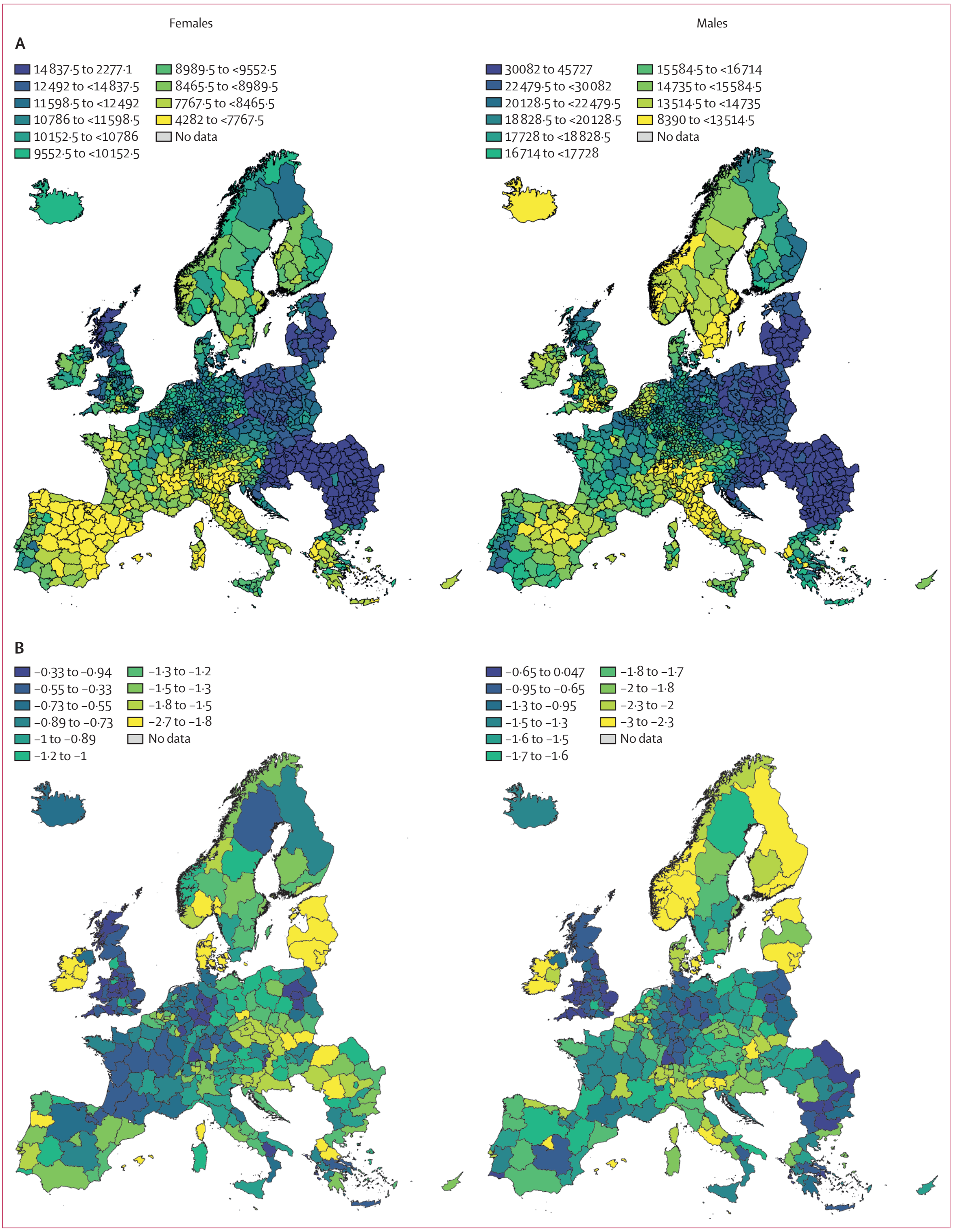

Figure 2: **Age-standardised YLLs per 100 000 population for each NUTS 3-level subnational region in 2019 by sex (A) and annual percentage change in age-standardised YLL rates per 100 000 per NUTS 2-level subnational region, between 2009 and 2019 by sex (B)**
Comparisons of baseline YLLs in 2009 versus 2019 and overall change values are in the appendix (pp 21–22, 27–30). YLLs=year of life lost. NUTS=Nomenclature of Territorial Units for Statistics.

–0·60 to 0·22]), while it increased for males (0·54% [0·19 to 0·89]). Among females, no significant change in the absolute differences was identified, as measured by the SII; however, for males, the absolute geographical inequality was lower over this period (β_{SII}=–0·0037 [95% CI –0·0053 to –0·0021]). At the NUTS 2 level, change in the Gini coefficient of YLLs was reduced within countries between 2009 and 2019, although the Gini coefficient was higher for females in Hungary (3·69% [2·05 to 5·37]) and Germany (1·76% [0·83 to 2·70]), and in absolute terms, for the UK (0·0026 [95% CI 0·0015 to 0·0036]), Hungary (0·0023 [0·0009 to 0·0037]), and Germany (0·0005 [0·00005 to 0·0010]). Between 2009 and 2019, among females, absolute geographical inequality was reduced slightly in Poland (–0·0023 [–0·0041 to –0·0006]) and Romania (–0·0024 [–0·0045 to –0·0004]). Among males, between 2009 and 2019, inequalities increased in Romania (AAPC 5·13% [95% CI 2·70 to 7·62]) and Belgium (1·55% [0·83 to 2·27]), whereas inequality was significantly reduced in Poland (–1·30% [–2·23% to –0·36]) and Denmark (–4·82% [–8·82 to –0·65]). In absolute terms, geographical inequality increased between 2009 and 2019 among males in Romania (β_{SII} 0·0059 [0·0021 to 0·0097]), and reduced slightly in several countries, with the most substantial reduction observed in Portugal (–0·0063 [–0·0122 to –0·0003]). Details of the time-trend analysis of geographical inequalities are in the appendix (pp 25–30).

In NUTS 2-level regions of the EEA, age-standardised YLLs rates were 19% (IRR 1·19 [95% CI 1·13–1·26]) higher for females and 22% (1·22 [1·16–1·28]) higher for males among people living in quintile 5 regions (ie, lowest educational attainment) than in quintile 1 regions (ie, highest educational attainment) with a dose–response relationship (p=0·0002 for females, p<0·0001 for males). A statistically significant trend in the inverse association of educational attainment and age-standardised YLL was observed across quintiles for all EuroVoc regions, except in northern Europe for women and southern Europe for men. Compared with NUTS 2-level regions with the highest average household income exceeding €28 118 (quintile 5), higher age-standardised YLL rates were observed across all other lower household income quintiles (quintiles 1–4). A dose–response relationship was evident across all EEA regions (p<0·0001), whereby the IRR (1·35 [95% CI 1·19–1·53]) was highest for the lowest quintile (household income <€11 100). A statistically significant trend in the inverse association between income and YLL rates was observed across quintiles for all EuroVoc regions except northern Europe. Among individuals living in a NUTS 2-level region with the highest risk of poverty (ie, >28%, quintile 5), age-standardised YLLs rates were on average 25% (IRR 1·25 [95% CI 1·18–1·34]) higher than for individuals living in NUTS 2-level regions with the lowest risk of poverty (ie, <13%), with a dose–response relationship across quintiles (p<0·0001) and for all EuroVoc regions, with the exception of northern Europe. YLLs were slightly higher among individuals living in predominantly rural areas when compared with individuals living in predominantly urban areas (IRR 1·03 [95% CI 1·00–1·07]). No differences were observed in age-adjusted YLL rates between urban and intermediate areas. Subgroup analysis showed that YLL rates for people living in central and eastern European regions classified as predominantly rural were on average 12% (1·12 [1·04–1·21]) higher than for people living in predominantly urban regions, and 9% higher than for people living in intermediate regions. In western Europe, YLL rates for people living in rural areas were 4% (1·04 [1·00–1·09]) higher than for those living in predominantly urban areas; however, no differences in YLL rates were observed for northern and southern Europe (table 2, appendix pp 10–13). Linear models by subnational regions highlight the regional variations within and across EuroVoc regions (figure 3). Generally, YLLs were higher

	Females		Males	
	Country	Gini coefficient, % (95% CI)	Country	Gini coefficient, % (95% CI)
1	UK	11·21% (10·11–12·30)	Belgium	10·76% (9·34–12·17)
2	Greece	10·14% (7·69–12·59)	UK	10·46% (9·46–11·47)
3	Croatia	9·64% (7·15–12·13)	Croatia	9·02% (7·21–10·83)
4	Belgium	8·38% (7·31–9·45)	Greece	7·84% (5·99–9·70)
5	Spain	7·66% (6·01–9·31)	Estonia	7·75% (2·39–13·11)
6	Estonia	7·56% (4·35–1·77)	Germany	7·62% (7·11–8·12)
7	Portugal	7·14% (4·57–9·70)	Portugal	7·30% (5·12–9·49)
8	Germany	7·03% (6·58–7·48)	Finland	7·11% (5·39–8·83)
9	Bulgaria	6·56% (5·16–7·97)	France	6·99% (6·09–7·88)
10	Finland	6·30% (4·38–8·22)	Switzerland	6·92% (4·57–9·26)
11	Poland	6·16% (5·25–7·06)	Romania	6·58% (5·19–7·97)
12	Slovenia	6·10% (3·24–8·96)	Spain	6·55% (5·24–7·86)
13	Italy	5·98% (5·17–6·78)	Slovenia	6·43% (4·49–8·36)
14	Switzerland	5·97% (4·32–7·63)	Hungary	6·15% (4·51–7·79)
15	Romania	5·74% (4·27–7·21)	Latvia	6·10% (3·43–8·77)
16	France	5·63% (4·68–6·58)	Italy	5·94% (5·23–6·65)
17	Norway	5·57% (4·26–6·88)	Bulgaria	5·38% (3·83–6·94)
18	Denmark	5·49% (3·02–7·97)	Czechia	5·21% (2·92–7·51)
19	Czechia	5·43% (3·11–7·74)	Norway	5·20% (2·44–7·95)
20	Lithuania	5·45% (3·38–7·51)	Poland	5·18% (4·37–5·99)
21	Hungary	5·33% (3·65–7·02)	Austria	5·11% (3·74–6·48)
22	Austria	5·02% (3·48–6·56)	Denmark	4·61% (3·39–5·83)
23	Sweden	4·91%(1·68–7·08)	Sweden	4·73% (3·70–5·76)
24	Latvia	4·38% (3·13–4·97)	Netherlands	4·51% (3·56–5·47)
25	Netherlands	4·05% (2·32–5·27)	Slovakia	4·47% (2·85–6·10)
26	Slovakia	3·80% (2·26–4·48)	Lithuania	4·36% (2·42–6·30)
27	Ireland	3·37% (2·26–4·48)	Ireland	1·99% (1·18–2·81)
EEA	All regions	14·22% (13·62–14·82)	All regions	16·96% (16·27–17·65)

Countries ranked by Gini coefficient (highest to lowest). Countries with four or less subnational regions (classified as per Eurostat Nomenclature of Territorial Units for Statistics level 3[19]) were excluded. EEA=European Economic Area.

Table 1: **Relative geographical inequalities in age-standardised YLL rate per 100 000 population within subnational regions and across all regions, by sex and country, 2019**

	Comparison quintile	IRR (95% CI)	β_{trend}	p_{trend}
Females with upper secondary education or less* (%)				
EEA (all regions)	Quintile 5 (highest) *vs* quintile 1 (lowest; ref)	1·19 (1·13–1·26)	585	0·0002
Central and eastern Europe	Quintile 5 (highest) *vs* quintile 1 (lowest; ref)	1·20 (1·14–1·28)	693	<0·0001
Northern Europe	Quintile 5 (highest) *vs* quintile 1 (lowest; ref)	1·08 (0·93–1·25)	179	0·23
Southern Europe	Quintile 5 (highest) *vs* quintile 1 (lowest; ref)	1·29 (1·06–1·57)	688	0·043
Western Europe	Quintile 5 (highest) *vs* Quintile 1 (lowest; ref)	1·15 (1·09–1·20)	437	0·0054
Males with upper secondary education or less* (%)				
EEA (all regions)	Quintile 5 (highest) *vs* quintile 1 (lowest; ref)	1·22 (1·16–1·28)	1037	<0·0001
Central and eastern Europe	Quintile 5 (highest) *vs* quintile 1 (lowest; ref)	1·24 (1·12–1·36)	1626	<0·0001
Northern Europe	Quintile 5 (highest) *vs* quintile 1 (lowest; ref)	1·09 (1·06–1·13)	340	<0·0001
Southern Europe	Quintile 5 (highest) *vs* quintile 1 (lowest; ref)	1·26 (1·07–1·47)	1204	0·010
Western Europe	Quintile 5 (highest) *vs* quintile 1 (lowest; ref)	1·20 (1·13–1·27)	861	<0·0001
Annual household income (€)				
EEA (all regions)	Quintile 1 (lowest) *vs* quintile 5 (highest; ref)	1·35 (1·19–1·53)	–1109	<0·0001
Central and eastern Europe	Quintile 1 (lowest) *vs* quintile 5 (highest; ref)	1·16 (1·05–1·28)	–934	<0·0001
Northern Europe	Quintile 1 (lowest) *vs* quintile 5 (highest; ref)	1·08 (0·99–1·18)	–254	0·082
Southern Europe	Quintile 1 (lowest) *vs* quintile 5 (highest; ref)	1·18 (1·06–1·31)	–761	<0·0001
Western Europe	Quintile 1 (lowest) *vs* quintile 5 (highest; ref)	1·16 (1·11–1·23)	–648	<0·0001
Risk of poverty (%)				
EEA (all regions)	Quintile 5 (highest) *vs* quintile 1 (lowest; ref)	1·25 (1·18–1·34)	839	<0·0001
Central and eastern Europe	Quintile 5 (highest) *vs* quintile 1 (lowest; ref)	1·22 (1·12–1·34)	1014	0·026
Northern Europe	Quintile 5 (highest) *vs* quintile 1 (lowest; ref)	1·05 (0·99–1·11)	205	0·094
Southern Europe	Quintile 5 (highest) *vs* quintile 1 (lowest; ref)	1·17 (1·09–1·26)	594	<0·0001
Western Europe	Quintile 5 (highest) *vs* quintile 1 (lowest; ref)	1·32 (1·17–1·49)	1007	<0·0001
Location (urban *vs* rural)†				
EEA (all regions)	Rural *vs* urban (ref)	1·03 (1·00–1·07)	..	..
Central and eastern Europe	Rural *vs* urban (ref)	1·12 (1·04–1·21)	..	..
Northern Europe	Rural *vs* urban (ref)	1·07 (0·99–1·16)	..	..
Southern Europe	Rural *vs* urban (ref)	0·96 (0·89–1·04)	..	..
Western Europe	Rural *vs* urban (ref)	1·04 (1·00–1·09)	..	..

IRR indicate the association between each socioeconomic quintiles with age-standardised YLL rate per 100 000 population compared to the reference quintile and was based on subnational regions (classified as per Eurostat NUTS 2[33]). β values indicate the trend across quintile groups in socioeconomic factors. Quintile ranges were calculated relative to each region. A comprehensive version of the table with ranges and estimates for each quintile is in the appendix (pp 10–13). NUTS=Nomenclature of Territorial Units for Statistics. YLLs=years of life lost. EEA=European Economic Area. IRR=incident rate ratio. β=beta coefficient. *As per the International Standard Classification of Education. †Eurostat NUTS 3-level.

Table 2: **The association between the lowest and highest quintiles for educational attainment by sex, annual household income (adjusted per inhabitant), and risk of poverty by subnational NUTS 2-level regions with age-standardised YLLs per 100 000 population for all EEA regions and by EuroVoc regions in 2019**

for men in central and eastern Europe and lower for women in southern Europe (figure 3). The top five regions with the highest educational attainment and income, and lowest risk of poverty generally had lower YLLs than the five regions with the opposite socioeconomic conditions (figure 3).

Discussion

Our study assessed YLLs in 32 EEA countries from 2009 to 2019, assessing subnational geographical inequalities and associations between age-adjusted YLLs and socioeconomic factors. Across the EEA, YLLs were higher in regions of central and eastern Europe and generally lower in southern European regions when compared with the mean YLL across countries. Although YLLs were lower in 2019 than 2009 in almost all subnational regions, small geographical relative and absolute inequalities persisted in YLLs across the EEA. Low educational attainment, low household income, and high risk of poverty in subnational regions were associated with higher age-adjusted YLL rates in the EEA.

YLL reductions from 2009 to 2019, consistent with previous research, are likely attributed to fewer premature deaths from cardiovascular disease.[34] However, improvements in mortality in the past 10 years have been smaller than the improvements of mortality in previous decades in continental Europe.[35] Between 2009 and 2019, GDP per inhabitant has increased in European regions. Generally, the greatest reductions were observed in northern Europe and central and eastern Europe, possibly linked to

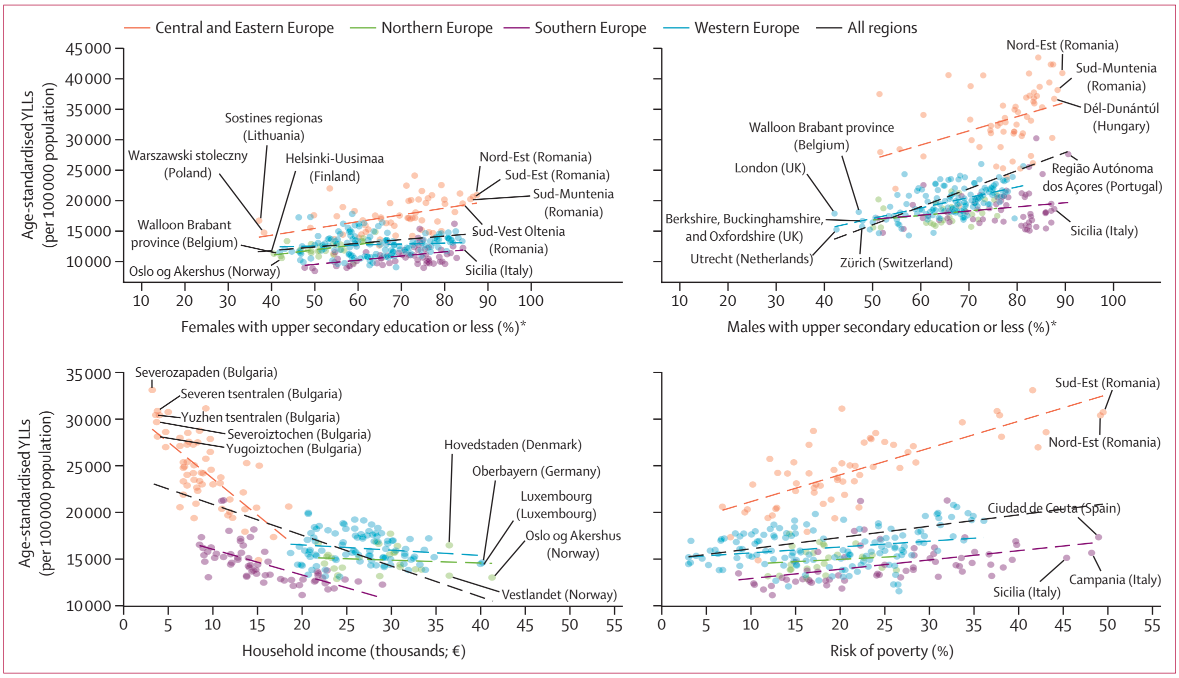

Figure 3: **Age-standardised YLLs per 100 000 population by proportion of people with upper-secondary education or less by sex, annual household income (adjusted by inhabitant), and risk of poverty by subnational NUTS 2-level regions and EuroVoc regions, in 2019**

Lines represent linear fit values for each EuroVoc region and EEA overall. Dots represent observed values at NUTS 2-level. NUTS 2-level regions with the five highest and lowest values are labelled, with the exception of the lower bounds of at risk of poverty, since the five values were imputed and not observed. YLLs=years of life lost. EEA=European Economic Area. NUTS=Nomenclature of Territorial Units for Statistics. *Based on the based on the international standard classification of education (levels 0–4; International Standard Classification of Education 2011[29]).

favourable changes in risk factors. For example, reduced tobacco smoking in Norway due to stringent regulations and changing cultural norms in Nordic countries has been attributed to longer life expectancy.[19] Improvements in eastern European countries might be explained by favourable changes in health care, living standards, and risk reduction efforts following a challenging period in the 1990s.[36] Specifically, considerable reductions in YLLs were observed in the Baltic states, which are likely to have resulted from economic growth and radical health-care reforms;[37] however, YLLs in 2019 remained high, reflecting an elevated baseline level. In larger western European countries, such as France (excluding Corsica), Germany, and the UK, and many regions of southern Europe, modest reductions in YLLs were observed in our study. Potential explanations could be severe flu seasons in Germany[38] and a slowdown in cardiovascular death reductions in Germany, UK, France, and the Netherlands.[39] Other factors could be related to changes in risk factors, such as regional differences in onset of the smoking pandemic and changes in dietary patterns,[40] which could have have slowed YLL reductions in certain countries such as Italy, Greece, and Spain.[40,41]

Previous GBD studies exploring subnational geographical inequalities in Europe highlighted substantial inequalities in YLLs between countries within the UK and between counties in England,[42] with smaller inequalities observed among Norwegian counties.[19] However, to our knowledge no previous studies have comprehensively investigated subnational inequalities across the entire EEA. Geographical disparities in YLLs are influenced by socioeconomic and environmental factors (eg, income and pollution), and health-care accessibility.[43–45] Differences in culture and policies between regions might also impact exposure levels to behavioural risk factors such as alcohol, diet, and smoking.[46] High absolute geographical inequalities are generally evident in countries with higher overall YLLs. Absolute inequalities generally reduce with lower YLLs because the overall impact of YLL is reduced. Conversely, relative inequalities seem more pronounced or prominent in comparison to absolute inequalities, especially when YLL levels are lower. Thus, even when the overall impact of YLLs is reduced, relative inequalities can persist and be significant. Although reducing absolute geographical inequalities aligns with national policies enhancing population health, strategies targeting relative geographical inequalities should focus on subnational regions to achieve comprehensive and equitable improvements in YLLs.[47,48]

In all subnational regions, YLLs were higher in areas with lower levels of educational attainment, household income, and higher risk of poverty. The association was less clear in northern Europe, with associations only identified for educational attainment among males, possibly due to stronger social protections and lower poverty rates.[49] This indicates that northern Europe has implemented exemplary policies addressing inequalities at the regional level. Our findings contrast with research done between 1990 and 2004 showing weaker associations between education and death rates in southern Europe.[50] Possible explanations include temporal changes such as the impact of the smoking pandemic and regional dietary shifts, or differences in study design (area-level *vs* individual-level inequality).

Rural and urban YLL associations varied: YLLs were higher in rural or intermediate regions than urban regions overall and in central and eastern Europe. Similar findings have been reported in Poland[51] and Lithuania.[52] Contemporary advantages, such as better access to health care, emergency services, and education, and improved economic conditions, are likely to have contributed to lower YLLs, especially in urban centres. Although, as observed, such dynamics might be regionally dependent. Further EEA studies should explore the role of rural and urban typology as a covariate or modifier of socioeconomic factors on mortality.

Policy makers should target regions with high YLLs, particularly in central and eastern Europe, with focused interventions, resource allocation, and strengthened health infrastructure to decrease both absolute and relative geographical inequalities. Tailored policies addressing unique subnational characteristics would be effective. Addressing persistent geographical inequalities in YLLs across the EEA requires targeting socioeconomic factors linked to premature mortality. The findings of this study regarding socioeconomic factors suggest that initiatives improving access to education, measures to reduce poverty, and economic opportunities are vital in reducing mortality in affected regions. Social and economic policies must prioritise support for subnational regions with the greatest levels of deprivation. Long-term, sustainable strategies, rather than short-term solutions, are needed to reduce YLLs. The EU has limited legislative competence in the field of health-care provision; however, cross-border cooperation should be explored for sharing best practices and resources in tackling common health challenges. Conversely, the EU can enact policies tackling health determinants, including the socioeconomic factors in our study. These regional inequalities could be addressed through policies and funding mechanisms that promote regional cohesion, improved education, food systems, and exposure to risk factors. Additionally, EU-level public health policies and funding focusing on health promotion and disease prevention could further benefit disadvantaged areas.

For our study, we obtained mortality and population data from Eurostat, legislated under EU law, which relies on robust vital registration systems in European countries, although data quality might vary. The study covers the period before the COVID-19 pandemic and might not be generalisable to post-2019. By focusing on all-cause YLLs, we avoided limitations associated with competition between cause-specific mortality. Missing data were imputed using regression methods, which had no major impact on the results in a sensitivity analysis (appendix p 40). However, a substantial amount of data were missing for poverty risk, which might have influenced the results obtained and hence comparability with existing literature. Stratifying mortality rates by various administrative geographies with varying population sizes might result in larger populations concealing variations in YLL rates within their respective NUTS 2-level or NUTS 3-level regions, therefore, making country-specific geographical inequalities seem less pronounced. Our study utilised geographies with linked health outcome data, providing insights into within-country mortality geographical inequality, albeit conservatively. Although small-area indices were available for some countries to describe mortality geographical inequalities at a granular level, these are context-specific and not available across all countries. NUTS 2-level and NUTS 3-level regions correspond to political and administrative entities, making our findings, although less sensitive, more relevant for local government-level policies. The analysis on socioeconomic factors and YLLs was correlational, and unmeasured confounding cannot be excluded. The causal pathways between socioeconomic factors and YLLs are complex, and factors such chronic conditions might, under certain situations, lead to confounding. However, due to scarcity of high-quality subnational data on chronic diseases in Europe, we did not include these confounders in our analysis. The investigation of subnational associations between lifestyle factors and YLLs was not possible due to data unavailability. The analysis of the YLLs by groups of diseases might provide even more evidence on differences and associations in future studies. Furthermore, due to the ecological design of the study, measured confounding only partially adjusts at the group level. Using group-level data prevents establishing direct links between individual deprivation and premature mortality or determining individual confounder levels. Before identifying causal mechanisms, validation through longitudinal, individual-level linked data is necessary. It is also important to note that YLLs from our study should not be directly compared with GBD estimates, since we used European-specific population weights for age-standardisation, whereas global weights were used in the GBD study.[24]

Our findings underline the importance of subnational organisation, policies, and action in promoting health within EEA countries, alongside EU policies and funding that promote regional cohesion and tackle socioeconomic factors. Efforts should prioritise reducing social inequality and poverty within the most deprived subnational regions. Furthermore, effective subnational initiatives require national-level commitment to promote health equity, such as assigning local governments vital roles in public health through national legislation or mobilising EU and EEA funds towards regional inequalities. Geographical and social health inequalities represent national challenges that must be tackled not only at regional levels, but also at the EU and EEA levels, through defined priorities and dedicated resources and funding.

Contributors

CMB, EvdL, OV, and JC-X conceptualised the study. The data included in this Article were retrieved by JC-X, OV, CMB, AB, PC, JH, RH, and NM. CMB, NM, JCX, and DAG carried out the data analysis. CMB, NM, JC-X, EvdL, and OV provided critical feedback on methods and results. JH, TAE, RH, GMAW, MB, ME, and BU provided critical feedback on discussion and revision. CMB, OV, JC-X, NM, GMAW, TAE, DAG, JH, PC, AB, MB, ME, RH, EAM, BU, and EvdL contributed to interpretation of data for the work. CMB, OV, JC-X, and NM contributed to managing the overall research enterprise. CMB, OV, and JC-X had full access to all the data in the study and had final responsibility for the decision to submit for publication. CMB, TAE, OV, JC-X, NM, DAG, GMAW, JH, PC, AB, MB, ME, RH, EAM, BU, and EvdL were involved in writing the original draft and revising the Article critically for important intellectual content. CMB, TAE, OV, JC-X, NM, GMAW, DAG, JH, PC, AB, MB, ME, RH, EAM, BU, and EL approved the final version of the manuscript. All authors are accountable for all aspects of the work. JC-X, OV, and CMB directly accessed and verified the underlying data.

Declaration of interests

We declare no competing interests.

Data sharing

No individual participant-level data were used in this study. Data on all-cause mortality counts, residential population, and socioeconomic indicators (income, level of education, and risk of poverty) by subnational region from 2009 to 2019 were obtained from Eurostat.

For **mortality data** see https://ec.europa.eu/eurostat/web/products-datasets/-/demo_r_magec

For **data on population size** see https://ec.europa.eu/eurostat/web/products-datasets/-/demo_r_d2jan

For **data on income** see https://ec.europa.eu/eurostat/web/products-datasets/-/nama_10r_2hhinc

For **data on level of education** see https://ec.europa.eu/eurostat/web/products-datasets/-/edat_lfs_9918

For **data on poverty** see https://ec.europa.eu/eurostat/databrowser/view/tgs00107/default/table?lang=en

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