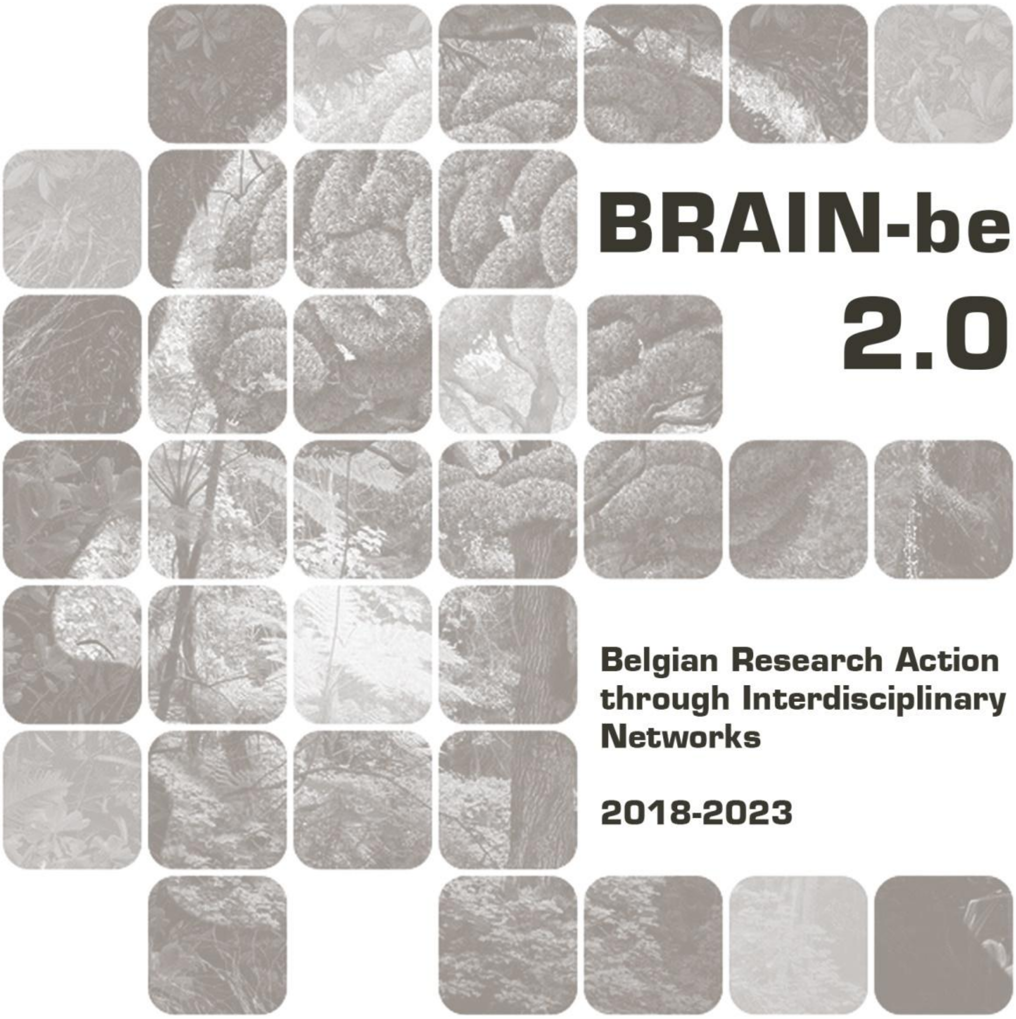

ELLIS

Monitoring and mitigating environmental health inequalities

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2018-2023

NETWORK PROJECT

ELLIS

Monitoring and mitigating environmental health inequalities

Contract - B2/191/P3/ELLIS

FINAL REPORT

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ABSTRACT

Environmental factors, such as pollution and green space availability, play a significant role in public health, affecting disease risk and well-being. However, exposure to environmental stressors is unevenly distributed, disproportionately affecting lower-income and less-educated populations, which contributes to health disparities and reduced life expectancy. The ELLIS project aimed to address these environmental health inequalities in Belgium by developing tools to monitor socioeconomic disparities and evaluate the impact of policy measures. The project developed the Belgian Indices of Multiple Deprivation, and found significant geographical disparities in environmental health, especially in Wallonia, and revealed that poor housing and socioeconomic inequality were major contributors to premature deaths. It also highlighted how environmental stressors, such as air pollution and industrial land use, impact mortality rates, with higher exposure linked to more deprived areas. Traffic interventions, like car-free days, were found to reduce NO_2 exposure and could decrease paediatric asthma rates. To address these health disparities, Belgium must implement stricter air quality regulations, prioritize better urban planning, and expand green spaces. Regularly updating and promoting the newly developed deprivation indices is essential for creating evidence-based policies that effectively target and reduce inequalities.

KEYWORDS

Environmental burden of disease, Environmental health inequalities, Environmental inequalities, Health impact assessment, Health inequalities, Monitoring, Pollution, Social deprivation

1. INTRODUCTION

There is an increasing body of evidence showing that environmental stressors can increase the risk of illness and premature mortality. For example, particulate matter triggers lung cancer (Raaschou-Nielsen et al., 2013) and noise increases the risk of heart attack (van Kempen and Babish, 2012). Conversely, the natural environment can also enhance health, e.g., contact with nature in parks and gardens (green spaces) is associated with increased physical activity, reduced stress and improved well-being. Consequently, governments worldwide aim to mitigate the negative health effects of environmental exposures and secure environmental health benefits. As exposures are not equal among all population segments, it is furthermore important to understand and mitigate inequalities in environmental health. Indeed, some already socially vulnerable population subgroups are more exposed to environmental risks in their living, working, and social environments. This differential exposure can accentuate or attenuate the existing socio-economic health inequalities. For example, in areas where people have easier access to green space, differences in mortality for all causes and cardiovascular diseases are less pronounced than in areas where access to green space is more difficult (Michell & Popham, 2008). **However, discrimination in relation to living environment is a dimension that is often overlooked in practice and has been insufficiently studied.**

2. STATE OF THE ART AND OBJECTIVES

2.1. CONCEPTUAL FRAMEWORK

The conceptual framework for ELLIS is presented in Fig. 1. **Three dimensions** are of interest to studying environmental health inequalities–i.e., socioeconomic deprivation, environmental exposure, and health outcomes. Pairwise integration of these dimensions gives rise to three concepts¬–i.e., **health inequalities, environmental inequalities, and environmental health**. Each of these concepts has been well described in national and international literature; however, the integration of all three, leading to **environmental health inequalities**, has so far received little attention. In what follows, we give a brief overview of the current state of the art regarding each of these concepts, as well as the challenges with integrating them. Finally, we give an overview of existing tools for **health impact assessment**, aiming to quantify the impact of policy measures on any of these concepts.

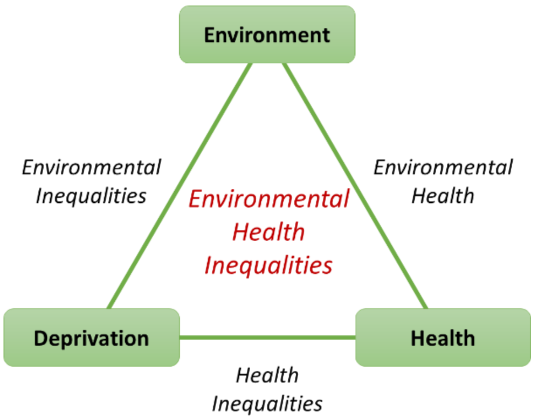

Fig. 1. Environmental health inequalities integrate socioeconomic deprivation, environmental exposure, and health outcomes.

2.2. GUIDING PRINCIPLES: INEQUALITIES, INEQUITIES, AND SOCIOECONOMIC DEPRIVATION

Health inequalities refer to differences in the health status between individuals or groups of people (Kawachi et al., 2002). It is a descriptive term that does not imply any moral judgment on the fairness of the observed differences. In contrast, **health inequities** refer to those inequalities that are considered unfair and potentially avoidable (Kawachi et al., 2002). Inequity in health is therefore a normative concept, relying on prevailing social and ethical values (Whitehead, 1992).

In particular, **socioeconomic health inequalities** are disparities between people grouped according to some features of their underlying socioeconomic position (such as income, wealth, education or occupation). Socioeconomic health inequalities penalising socially disadvantaged groups are one of the most consistent, and persistent, findings in epidemiology (Mackenbach 2012), for almost every health outcome and socioeconomic indicator. They are usually considered unfair and avoidable, and therefore most often qualify as “inequities”; however, socioeconomic inequalities are often easier to measure, and have therefore been the focus of most studies, including the project at hand. In line with the attention drawn to health inequalities, increased attention has been drawn to **environmental inequalities**¬–i.e., (socioeconomic) differences in environmental exposure between individuals or groups. Quite often, this is referred to by its complement, i.e., environmental justice, mirroring its emergence in activist movements (Brulle & Pellow 2006). Just as health inequalities, environmental inequalities are widespread and persistent, as was recently inventoried in the Second Assessment Report on Environmental health inequalities in Europe by the WHO Regional Office for Europe (WHO/EURO 2019). The report concludes with a strong call for action to identify environmental inequalities at country level, and to take action to protect those who carry a disproportionate environmental burden.

When studying socioeconomic health or environmental inequalities, developing a measure of the position of individuals or groups within society is a prerequisite. **Socioeconomic status** refers to the social and economic factors that influence the position of individuals or groups within the fabric of a society. Its measurement includes one or more social characteristics, the more common being occupation, income, wealth, and education. All these domains capture distinct aspects of the socioeconomic position and are correlated to each other, without being interchangeable (Shavers 2007). While most studies focus on one indicator of socioeconomic position, it is increasingly recognised that different indicators may lead to subtle differences in terms of their effects, patterns, and gradients (Gadeyne & Deboosere, 2006). The challenge is therefore to construct a multidimensional socioeconomic indicator. Townsend (1987) discusses the evolution of the concept of **area-based multiple deprivation indices**, introduced in the UK in the 1970s to support selective allocation of (scarce) resources to the more disparate areas. Townsend (1987) defined deprivation as “a state of observable and demonstrable disadvantage relative to the local community or the wider society or nation to which an individual, family or group belongs”, denoting a phenomenon more complex than poverty, associated with an accumulation of disadvantages. Based on 1981 census data, he combined four indicators (unemployment, household overcrowding, non-home ownership and non-car ownership) to create this index at the ecological level, offering a different perspective than that gained by income alone and highlighting the social aspects of deprivation that are relevant for health care planning and resources allocation. Since then, several other countries have developed indices of multiple deprivation (IMD) (e.g., Exeter et al., 2017; Rey et al., 2009). In Belgium, at the individual level, Eggerickx et al. (2018) defined an index of multiple deprivation based on educational level, occupation, and tenure status. Using this indicator, they divided the population into different social groups, and quantified the evolution of social inequalities in mortality. **So far, however, no area-level IMD has been developed or applied in Belgium, nor are IMDs used in policy-making.**

Finally, it is important to note that studying the environmental dimensions of health inequalities comes with specific challenges. Most spatial studies on mortality identify the place of residence and socioeconomic characteristics of individuals at the time of death. However, the place of residence at death is not necessarily the one where the individual has been most exposed to risk factors during his or her lifetime. It would therefore be important to take into account residence times and migratory trajectories, information that is rarely available and mobilised, particularly in the context of cross-sectional and aggregate studies (Norman et al., 2005). Similarly, socioeconomic conditions change over the life course and disease and death are likely to be as much or more related to cumulative effects experienced throughout life than to characteristics observed at the time of death (Coburn, 2004). In other words, an account should be taken of changes in the socioeconomic status of individuals, social mobility, stagnation and accidents along the way.

2.3. HEALTH AND ENVIRONMENTAL INEQUALITIES IN BELGIUM

Despite the effectiveness of the Belgian social security and health care system, **socioeconomic health inequalities in Belgium** persist and even tend to widen over time. Analyses based on mortality data linked to census data highlighted a widening social gap in life expectancy at age 25 by educational level. Men with no education had a life expectancy at age 25 which was 5.2 years lower than men with tertiary education in the period 1991-1994, and this gap had increased to 7.5 years in 2001-2004 (Deboosere et al., 2009). A recent study based on data from the 2011 census showed that this gap has increased even further in recent years, especially among males (Renard et al., 2019). Eggerickx et al. (2018) made the same observation based on their index of multiple deprivation. Furthermore, even within social groups, substantial differences in mortality persist between Flanders and Wallonia and between the districts in Belgium. This suggests that, while spatial variations in mortality can largely be accounted for by differences in the socioeconomic characteristics of their populations, elements related to the physical, social, and institutional environment of populations also contribute. **However, little research has been conducted on the environmental dimensions of these inequalities in Belgium.** The scales of the Belgian regions or districts, which are too large and include very disparate "environments", are certainly not the most appropriate way to measure these effects. A more local approach is therefore warranted.

The exploration of **environmental inequalities in Belgium** is less well-studied. Lejeune et al. (2016), using data from a housing quality survey in the Walloon Region, showed that families with lower incomes are more likely to live in housing of lower quality, in more densely populated neighbourhoods, and exposed to higher levels of air pollution. The Belgian Health Interview Survey, conducted by Sciensano, revealed in 2013 that households with a highly educated reference person and households who own their home are less likely to experience both indoor and outdoor environmental nuisances (Charafeddine, 2015). Finally, the aforementioned WHO Report on Environmental health inequalities in Europe reported, amongst others, that between 2009 and 2016, Belgium showed one of the largest increases in inequality (comparing people below versus above relative poverty level) in self-reported noise annoyance.

2.4. ENVIRONMENTAL BURDEN OF DISEASE—QUANTIFYING "ENVIRONMENTAL HEALTH"

In the previous sections, we focussed on two of the three legs of the conceptual model presented in Fig. 1¬–i.e., health inequalities and environmental inequalities. The key to closing the triangle is to introduce the concept of **environmental burden of disease (EBD)**. EBD aims to quantify the number of illnesses and deaths associated with various environmental stressors, as well as the health benefits of potential prevention and mitigation measures. Current EBD studies commonly use the Disability-Adjusted Life Year (DALY) metric as a common currency for integrating the effects of illness and premature death, thereby facilitating the comparison of the burden of various environmental stressors amongst each other and with other risk factors.

Two main approaches can be distinguished for quantifying EBD (Devleesschauwer et al. 2015). In the **bottom-up, risk assessment approach**, exposure data is combined with dose-response or relative risk functions to obtain a prediction of the number of cases or death that can be expected given current exposure levels. Two WHO projects (REVIHAAP & HRAPIE) have recently revised the dose-response and relative risk values for air pollution in Europe (Anenberg et al. 2016; Malmqvist et al. 2018). Although this approach is often applied in toxicology and environmental sciences, its main drawback is that the predicted number of cases or deaths are not bounded by the actual number of cases/deaths observed. In theory, this approach may even result in an estimate of attributable cases/deaths that exceeds the total number of cases/deaths. This problem can be circumvented using the **top-down, comparative risk assessment approach**. Here, a Population Attributable Fraction (PAF) is calculated from the exposure and dose-response data, corresponding to the proportion of cases/deaths that could have been avoided if no one would have been at risk of exposure. This is the most widely used approach to estimate EBD at global and regional level, as practiced both by the World Health Organization (Prüss-Ustün et al., 2019) and the Institute for Health Metrics and Evaluation, leading the Global Burden of Disease study (GBD 2017 Risk Factor Collaborators, 2018). Few other studies have calculated EBD in Belgium using local data. Hanninen et al. (2014) report the results of the Environmental Burden of Disease in European countries (EBoDE) project, in which the burden from nine environmental risk factors in Belgium was quantified. Stassen et al. (2008) quantified the burden from transportation noise in Flanders. Currently, the Belgian Institute for Health, Sciensano, is conducting a national burden of disease study, calculating DALYs for key diseases and risk factors (Devleesschauwer 2019). **At the moment, however, environmental stressors are not included in the framework, restricting a systematic assessment of the EBD in Belgium.**

2.5. ENVIRONMENTAL HEALTH INEQUALITIES

After having introduced the individual dimensions and pairwise concepts, we can now introduce the concept of environmental health inequalities–i.e., **the socioeconomic inequalities in EBD**.

An increasing number of studies quantify socioeconomic health inequalities in burden of disease. For instance, Newton et al. (2015) and Steel et al. (2018) calculated absolute differences in burden of disease across area deprivation levels in the UK. Mesalles-Naranjo et al. (2018) calculated relative and slope indices of inequality to quantify inequalities in the burden of mortality in Scotland by area deprivation. Ljung et al. (2005) calculated attributable fractions, as well as relative and slope indices of inequality, to quantify inequalities in the burden of disease in Sweden by occupational level. **However, remarkably few studies have explicitly addressed socioeconomic inequalities in EBD.** In a 2016 report on “Environmental Gradients and Health Inequalities in the Americas” compiled by the Pan-American Health Organization, socioeconomic inequalities in EBD across and within the countries of the Americas were assessed at the ecological level. Specifically, they quantified inequalities in the burden of disease attributable to unimproved water and sanitation, using the slope index of inequality and the concentration index.

2.6. INTEGRATING DIMENSIONS AT INDIVIDUAL VS AGGREGATE LEVEL

When studying health disparities, analyses are regularly conducted at the **individual level**, for example by using survival methods to highlight the effect of exposure to certain pollutants or climatic conditions at some point in life on subsequent risks of developing diseases leading to premature death. This individual perspective allows taking into account time lags between exposure and illness or death, and integrating other individual characteristics, such as marital, migratory or professional history (Crowder & Downey, 2010). Integration at the individual level requires linkages between the microdata (i.e., the individual-level records), which exposes the researcher to possible sensitive data of individuals. In particular, when integrating environmental data, which are spatial by nature, researchers would be exposed to address data of the individuals. Linking microdata therefore requires approval from an ethical committee or privacy commission, including provisions to be taken to guarantee anonymity; for instance, the use of a third trusted party to perform the linkages and return the integrated dataset. Such approvals are typically provided for a well-defined project, with a predefined start and end date.

Alternatively, analyses can also be conducted at higher geographical levels, such as neighbourhoods or districts, to cover more “upstream” factors such as local social policies, the supply of public services (transportation, health care) or spatial planning. This aggregate perspective can help identify contextual effects that can attenuate or amplify the compositional effects of neighbourhoods. Integration at the aggregate level furthermore offers substantial practical benefits, since the only requirement is that all variables are available at the aggregate level (e.g., neighbourhoods or districts).

Also, at the aggregate level, cumulative risk assessment can be conducted to study how multiple exposures and vulnerabilities from various sources contribute to shaping health inequalities over time. For example, contextual factors such as residential segregation, wealth distribution, or social capital can affect the ability of local communities to influence public policies related to environmental health stressors (Soobader et al., 2006). While individual-level characteristics can be related to pollution perceptions, pollution health concerns can be associated with characteristics at individual and area level (Reames & Bravo, 2019).

Caution is however warranted when generalising conclusions from aggregated data to the individual level, due to the risk of **ecological fallacy**, especially when the areas considered are large and heterogeneous. Indeed, associations (e.g., between deprivation and environmental exposure) observed at the aggregate level, may differ in magnitude, or even direction, from the true associations that would be observed at individual level. **When integrating information at the aggregate level, the potential impact of ecological bias should therefore be assessed.**

2.7. HEALTH (INEQUALITY) IMPACT ASSESSMENT OF ENVIRONMENTAL STRESSORS

In addition to merely monitoring the extent of environmental health inequalities, governments also require tools that allow them to **define polices aimed at mitigating these inequalities**. Health impact assessment (HIA) is an increasingly important tool for informing public policy decisions that affect environmental conditions, and is actively supported by the World Health Organization (https://www.who.int/health-topics/health-impact-assessment). HIA quantitatively compares alternative policy scenarios with the “business-as-usual” scenario; results are often reported in terms of number of the cases, deaths, or DALYs, or changes in life expectancy, attributable to total exposure (=business-as-usual) or a change in exposure (=alternative policy options) (WHO/EURO 2016).

There are a number of HIA tools available online, each differing in scope (from disease/risk-specific to supposedly generic tools) and usability. Fehr et al. (2012, 2016) reviewed publicly available computational tools for quantitative health modelling. Of the nearly 20 identified tools, only a few were sufficiently mature and available for public use. DYNAMO-HIA (Dynamic Modelling for Health Impact Assessment) is generic in scope, and illustrates the public health tradition in HIA. The HEIMTSA/INTARESE toolkit (Health and Environment Integrated Methodology and Toolbox for Scenario Assessment/Integrated Assessment of Health Risks of Environmental Stressors in Europe), focusses on environmental stressors and illustrates the environmental HIA tradition. Arenberg et al. (2016) reviewed 12 air pollution HIA tools, including the well-known AirQ+, developed and maintained by WHO.

While these tools could in principle be adapted to the Belgian context, they do not allow assessing impacts on health inequalities—highlighted by Fehr et al. (2012, 2016) as a key limitation of many currently available HIA tools. To date, probably the most comprehensive health inequality assessment tool is the Triple I toolkit (Informing Interventions to reduce health Inequalities), used by NHS Health Scotland to compare the potential population impact of interventions on health inequalities in Scotland (McAuley et al., 2016). This tool is however limited to the Scottish context, and currently only includes one environmental intervention–i.e., implementing 20 mph speed limits, modelled to reduce air pollution and road traffic accidents. **To support the mitigation of environmental health inequalities in Belgium, a novel tool is required, able to integrate the three underlying dimensions, and adapted to the local context.**

2.8. PROBLEM STATEMENT AND OBJECTIVES

In Belgium, there is currently no systematic monitoring of environmental health inequalities, nor are there tailored tools to assess the impact of policy measures on the extent of and inequalities in environmental burden of disease. In part, this situation is the result of both the important data needs and the methodological challenges in developing such a system.

The overall objectives of ELLIS were to develop tools to a) monitor the extent of socioeconomic differences in environmental burden of disease; and b) assess the impact of policy measures on environmental health inequalities.

To achieve this goal, ELLIS integrated the three dimensions of environmental health inequalities – i.e., socioeconomic deprivation, environmental exposures, and health outcomes (Fig. 2). To increase flexibility and sustainability, the integration of these dimensions took place at the level of the statistical sector (i.e., the smallest administrative subdivision of Belgium). In addition to monitoring the situation, ELLIS would also allow simulating the potential impact of alternative policy scenarios on the extent of and inequalities in EBD.

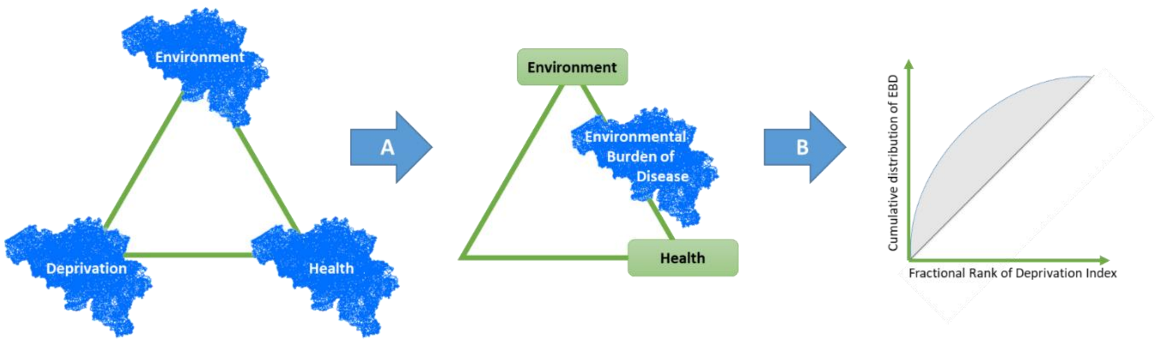

Fig. 2. Integration of environment, health and deprivation dimensions to calculate environmental health inequalities. Step A = calculation of environmental burden of disease; Step B = calculation of population-level inequality indices, such as the population attributable fraction.

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3. METHODOLOGY

To achieve the objectives of ELLIS, we defined 6 work packages (Fig. 3). WP1-3 developed each of the three dimensions of environmental health inequalities. WP4 developed the methodology for integrating them, while WP5 established the scenarios for health impact assessment. WP6 ensured close and explicit interaction with the relevant stakeholders.

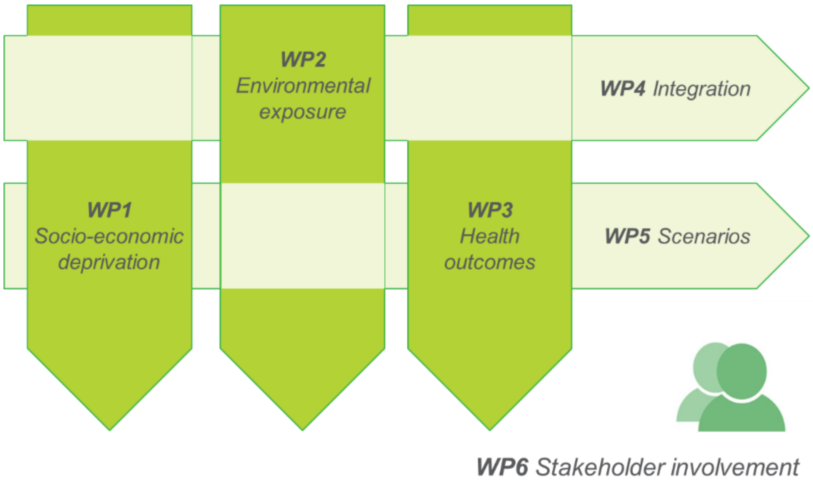

Fig. 3. ELLIS was composed of six work packages.

The ELLIS methodological framework was implemented via two PhD projects, which were defended in academic year 2024-2025:

- **Martina Otavova: Multiple Deprivation and Health Inequalities in Belgium.** Thesis presented in fulfilment of the requirements of the Degree of Doctor of Social and Political Sciences, Specialization in Demography (UCLouvain) and Doctor of Sciences in Statistics (UHasselt). Academic year 2024-2025. Supervisors: Professor Bruno MASQUELIER (UCLouvain) and Professor Christel FAES (Hasselt university), Co-promotor: Professor Brecht DEVLEESSCHAUWER (Sciensano & Ghent University)
- **Bram Vandeninden: Quantifying and Mitigating the Environmental Disease Burden and Health Inequalities in Urban and Transport planning.** Thesis presented in fulfilment of the requirements of the PhD Degree in Public Health (ULB – "Doctorat en sciences de la Santé Publique" and in Sciences – "Doctor of Sciences" (UHasselt). Academic year 2024-2025. Supervisors: Professor Olivier VANDENBERG (Université libre de Bruxelles) and Professor Christel FAES (Hasselt university), Co-promotors: Professor Catherine BOULAND (Université libre de Bruxelles) and Dr. Eva M. DECLERCQ (Sciensano)

ELLIS was coordinated by Sciensano (Prof. Devleesschauwer), while the different partners were responsible for providing specific methodological support and for co-supervision of the PhD students. The knowledge translation activity was supported by the entire consortium, and supervised by the project coordinator. To steer and monitor the progress of the different work packages, all partners formed a steering committee that met four times a year. To ensure impact and uptake, a follow-up committee was established comprising representatives of the concerned federal authorities and experts in the field of environmental health inequalities. Meetings with the follow-up committee were organised at least once a year throughout the project lifespan.

4. SCIENTIFIC RESULTS AND RECOMMENDATIONS

PART I. MULTIPLE DEPRIVATION AND HEALTH INEQUALITIES

Measuring small-area level deprivation in Belgium: The Belgian Index of Multiple Deprivation

Otavova M, Masquelier B, Faes C, Van den Borre L, Bouland C, De Clercq E, Vandeninden B, De Bleser A, Devleesschauwer B (2023) Measuring small-area level deprivation in Belgium: the Belgian Index of Multiple Deprivation. Spat Spatiotemporal Epidemiol 45:100587. doi: 10.1016/j.sste.2023.100587

In the past, deprivation has been mostly captured through simple and univariate measures such as low income or poor educational attainment in research on health and social inequalities in Belgium. The ELLIS project introduced a shift towards a more complex, multidimensional measure of deprivation at the aggregate level, through the development of the first Belgian Indices of Multiple Deprivation (BIMDs) for the years 2001 and 2011. The BIMDs are constructed at the level of the smallest administrative unit in Belgium, the statistical sector. They are a combination of six domains of deprivation: income, employment, education, housing, crime, and health. Each domain is built on a suite of relevant indicators representing individuals who suffer from a certain deprivation in an area. The indicators are combined to create the domain deprivation scores, and these scores are then weighted to create the overall BIMDs scores. The domain and BIMD scores can be ranked and assigned to deciles from 1 (the most deprived) to 10 (the least deprived).

The results reveal geographical variations in the distribution of the most and least deprived statistical sectors in terms of individual domains and overall BIMD, and allow identifying hotspots of deprivation. The majority of the most deprived statistical sectors are located in Wallonia, whereas most of the least deprived statistical sectors are in Flanders.

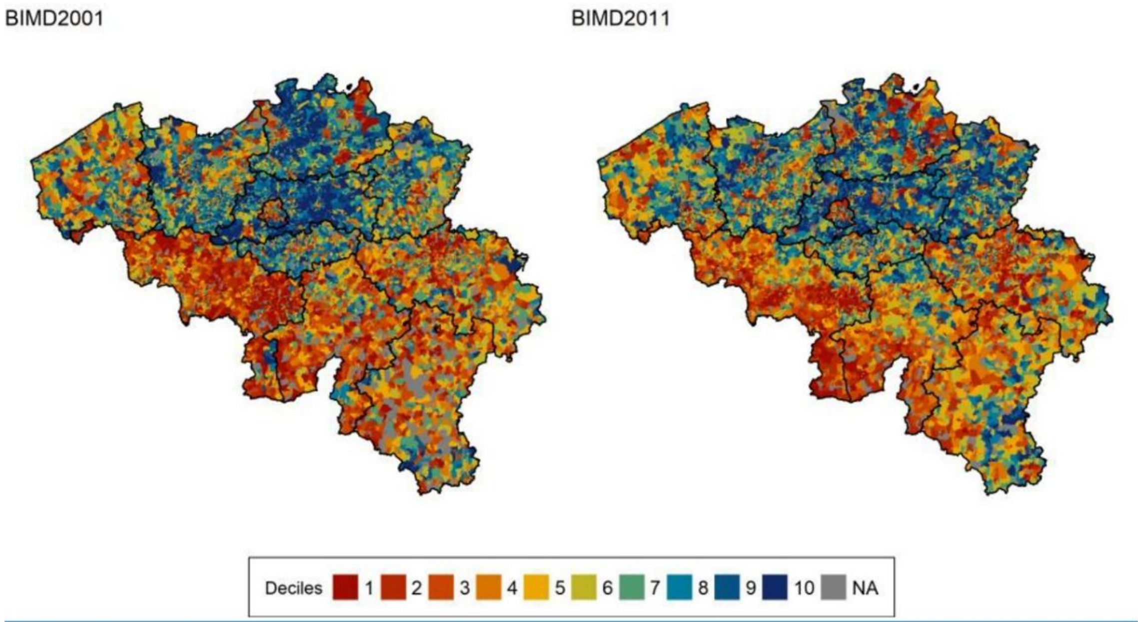

Fig. 4. Distribution of the BIMD2001 and BIMD2011 deprivation deciles across Belgian statistical sectors in 2001 and 2011. The most deprived statistical sectors fall into the first deprivation decile (dark red).

Along with the article, an online tool was launched to allow visualising the BIMD (https://bimd.sciensano.be/tool/). The BIMD tool is available to anyone and by searching an address one can investigate the level of deprivation in the given area. It also provides information on different deprivation domains, such as income, employment, education, health, housing, and crime. The website provides a link to a GitHub (https://github.com/bimd-project/bimd) where the BIMDs can be downloaded for further use. An R package is also available to perform analyses and visualisations in the R programming language (https://github.com/sciensanogit/bimd-pkg). Last but not least, a webinar (which can be replayed via https://bimd.sciensano.be) was organised to introduce the BIMD.

We are currently in the process of updating the BIMD towards the year 2021, based on the latest census data. The tool has proven to be highly relevant, and we therefore remain committed to further updating and promoting the tool.

Inequalities in mortality associated with housing conditions in Belgium between 1991 and 2020

Otavova M, Faes C, Bouland C, De Clercq E, Vandeninden B, Eggerickx T, Sanderson J-P, Devleesschauwer B, Masquelier B (2022) Inequalities in mortality associated with housing conditions in Belgium between 1991 and 2020. BMC Public Health 22:2397. doi: 10.1186/s12889-022-14819-w

Poor housing conditions have been associated with increased mortality. ELLIS investigated the association between housing inequality and increased mortality in Belgium and estimated the number of deaths that could be prevented if the population of the whole country faced the mortality rates experienced in areas that are least deprived in terms of housing. To this end, we used individual-level mortality data extracted from the National Register in Belgium and relative to deaths that occurred between Jan. 1, 1991, and Dec. 31, 2020. Spatial and time-specific housing deprivation indices (1991, 2001, and 2011) were created at the level of the smallest geographical unit in Belgium, with these units assigned into deciles from the most to the least deprived. We calculated mortality associated with housing inequality as the difference between observed and expected deaths by applying mortality rates of the least deprived decile to other deciles. We also used standard life table calculations to estimate the potential years of life lost due housing inequality.

Up to 18.5% (95% CI 17.7–19.3) of all deaths between 1991 and 2020 may be associated with housing inequality, corresponding to 584,875 deaths. Over time, life expectancy at birth increased for the most and least deprived deciles by about 3.5 years. The gap in life expectancy between the two deciles remained high, on average 4.6 years. Life expectancy in Belgium would increase by approximately 3 years if all deciles had the mortality rates of the least deprived decile.

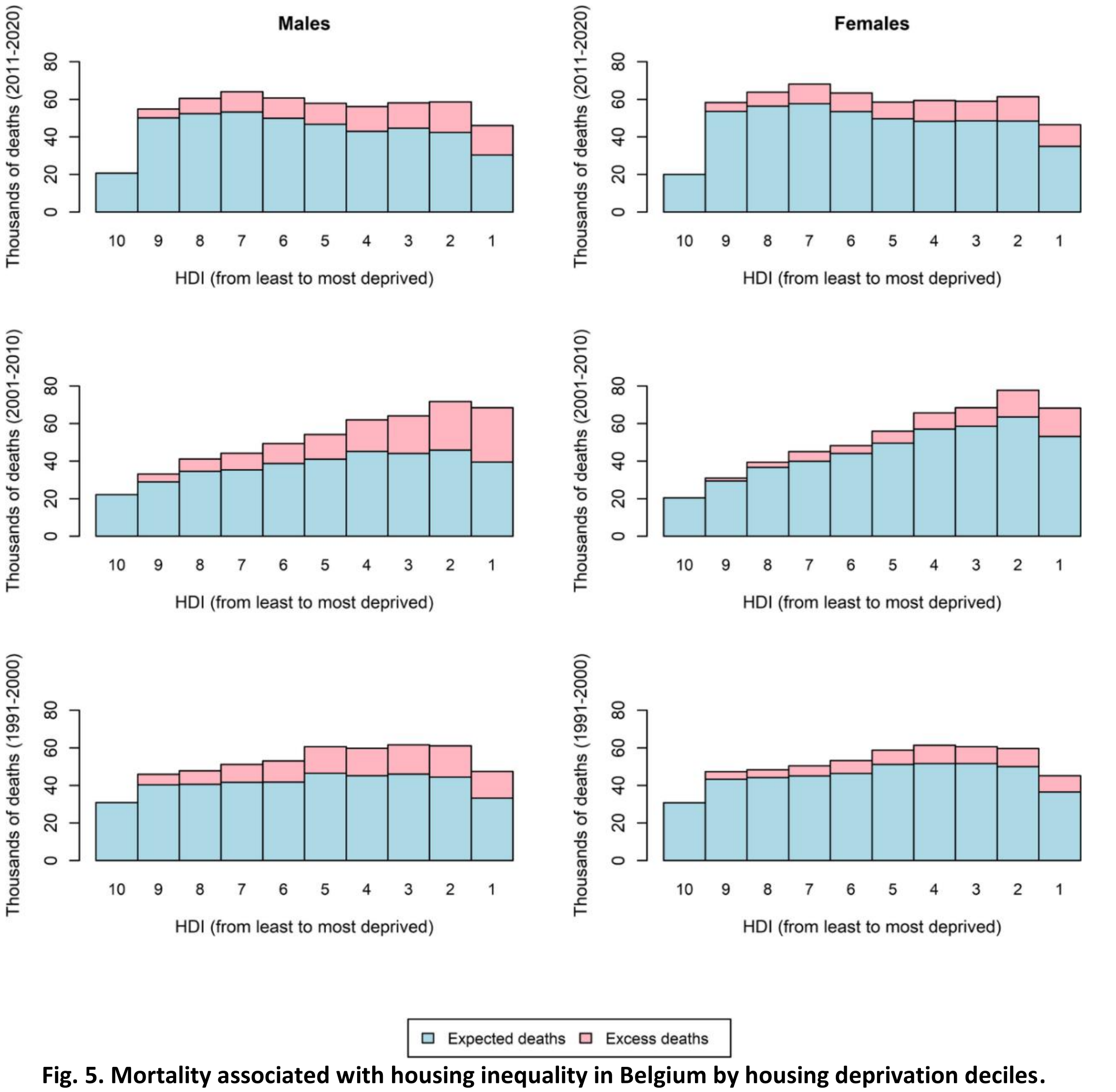

Fig. 5. Mortality associated with housing inequality in Belgium by housing deprivation deciles.

Our findings provide a better understanding of the extent to which housing inequalities are associated with mortality and suggest that important socio-spatial inequalities still exist in Belgium. Using composite housing deprivation indices and multiple measures of health inequality, we showed that every year thousands of deaths in Belgium could be avoided if Belgium had the mortality rate of the least deprived decile. Our findings can help the Belgian government and local politicians to locate hotspots of poor housing and their associated health inequalities for better targeted public action.

Trends in socioeconomic inequalities in cause-specific premature mortality in Belgium, 1998–2019

Otavova M, Masquelier B, Faes C, Van Den Borre L, Vandeninden B, De Clercq E, Devleesschauwer B (2024) Trends in socioeconomic inequalities in cause-specific premature mortality in Belgium, 1998-2019. BMC Public Health 24:470. doi: [10.1186/s12889-024-17933-z](10.1186/s12889-024-17933-z)

Higher levels of socioeconomic deprivation have been consistently associated with increased risk of premature mortality, but a detailed cause-specific analysis is lacking in Belgium. We investigated the association between area deprivation and all-cause and cause-specific premature mortality in Belgium over the period 1998–2019. Specifically, we used the 2001 and 2011 Belgian Indices of Multiple Deprivation to assign statistical sectors, the smallest geographical units in the country, into deprivation deciles. All-cause and cause-specific premature mortality rates, population attributable fraction, and potential years of life lost due to inequality were estimated by period, sex, and deprivation deciles.

Men and women living in the most deprived areas were 1.96 and 1.78 times more likely to die prematurely compared to those living in the least deprived areas over the period under study (1998–2019). About 28% of all premature deaths could be attributed to socioeconomic inequality and about 30% of potential years of life lost would be averted if the whole population of Belgium faced the premature mortality rates of the least deprived areas.

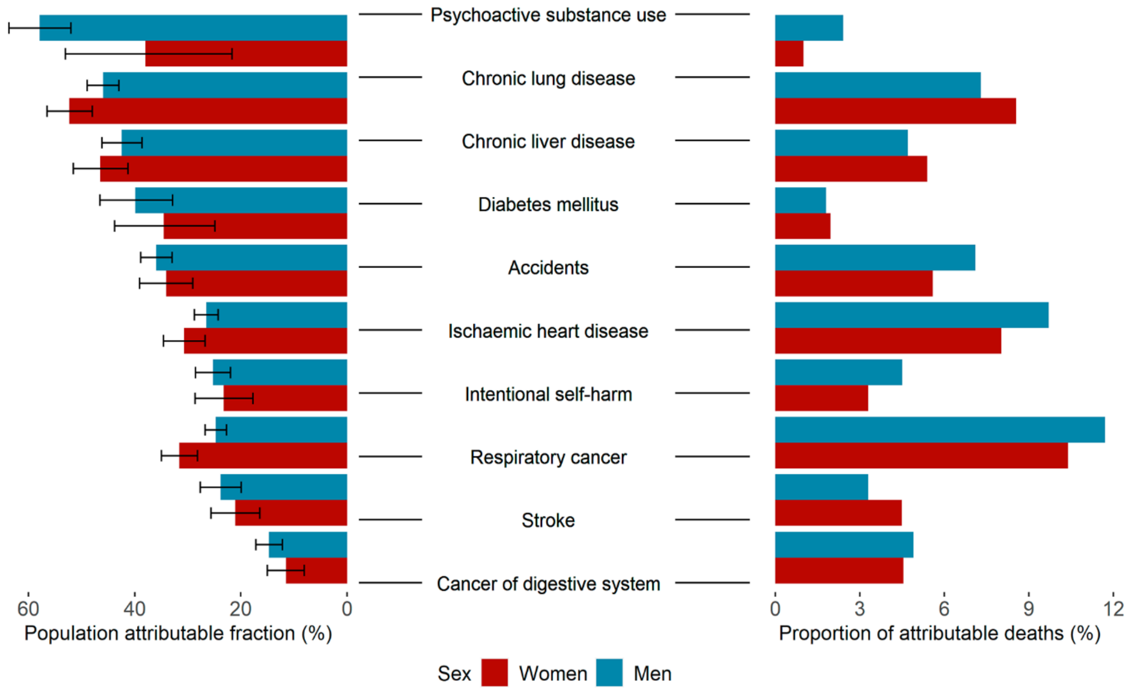

Fig. 6. Causes of death with the greatest proportion of premature mortality attributable to socioeconomic inequality and their contributions to the total number of attributable deaths, 1998–2019.

Premature mortality rates have declined over time, but inequality has increased due to a faster pace of decrease in the least deprived areas compared to the most deprived areas. As the causes of death related to poor lifestyle choices contribute the most to the inequality gap, more effective, country-level interventions should be put in place to target segments of the population living in the most deprived areas as they are facing disproportionately high risks of dying.

Uncovering socioeconomic disparities in modal age at death and its dispersion in Belgium since 2000

Lower mortality at higher ages has led to the aging of populations with increased numbers of centenarians and supercentenarians, a rise in the maximum recorded life span, and the uninterrupted long historical increase in life expectancy. These events increased interest in longevity studies concerning monitoring and analysing longevity trends or differentials by investigating lifespan indicators. Life expectancy at birth has been the most commonly researched longevity indicator and its remarkable increase has been considered one of the greatest human accomplishments of the past century. Although not as well-known and widely used as life expectancy at birth, the modal age at death and its dispersion measure, standard deviation above the modal age at death, represent a relevant set of tools to summarize and monitor mortality changes at older ages over time

In the ELLIS project, we aimed to address a gap in longevity research by examining trends and levels of lifespan indicators, along with their dispersion measures, across varying levels of deprivation. Specifically, we analysed both the all-cause modal age at death and the all-cause standard deviation above the mode. Additionally, we investigated cause-specific modal age at death and cause-specific standard deviation above the mode for six leading causes of death among Belgian men and women: cerebrovascular diseases, heart diseases, and four types of cancer—colorectal, lung, breast (for women), and prostate (for men).

The life expectancy at birth and modal age at death showed improvements over the period, with male life expectancy rising from 74.63 to 79.63 years, and female life expectancy increasing from 80.95 to 83.99 years. Similarly, the modal age at death increased, for men from 81.86 to 87.05 years, and women from 86.66 to 89.76 years. The standard deviation of life expectancy and standard deviation above the modal age at death has decreased, reflecting less variability in both indicators.

Deprivation-specific results showed that the life expectancy at birth and modal age at death increased for men and women across all deprivation deciles. The trend was similar but the pace of increase differed - with those in the least deprived areas showing slightly greater increase. As a result, the gap between the most and least deprived groups widened in both indicators.

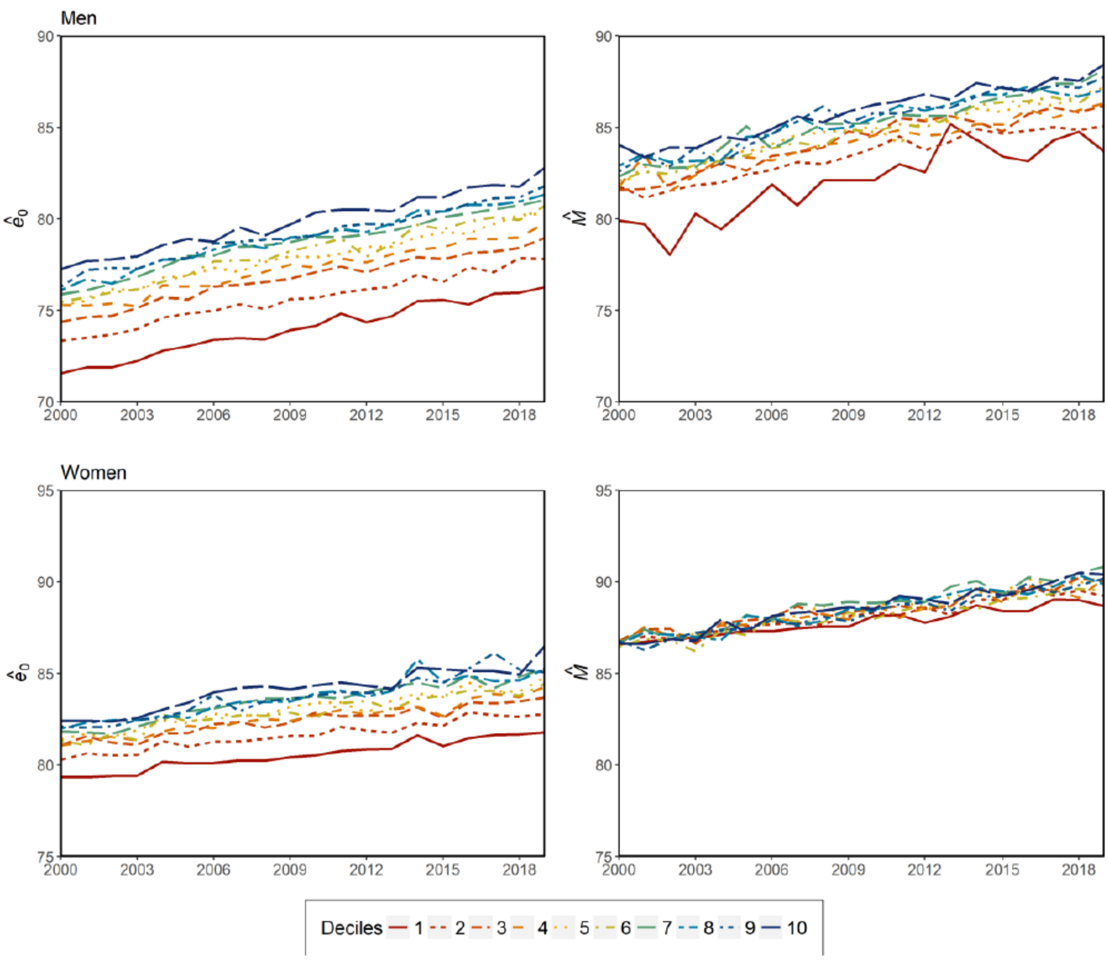

Fig. 7. Estimated life expectancy at birth and modal age at death by deprivation deciles and sex in Belgium, 2000 to 2019. The most deprived are located in the first (full red line) and the least deprived in the tenth decile (full blue line).

Cause-specific modal age at death also showed notable trends. For both sexes, the most common age at death of studied causes of death increased over time. The results showed that not all cause-specific modal ages were greater in men and women living in the least deprived areas as expected. In women, we observed a reversed pattern – a lower modal age at death among those living in the least deprived areas compared to the most deprived areas – for breast cancer and cerebrovascular diseases.

The standard deviation of all-cause or cause-specific modal age at death decreased over time across all deprivation deciles for men and women, but stayed greater in the most deprived areas, suggesting greater inequalities the dispersion around the modal age at death in this deprivation group.

Overall, while life expectancy at birth and modal age at death increased over time for men and women across all deprivation deciles and their dispersion measures decreased, the inequality between the most and least deprived areas persisted and increased.

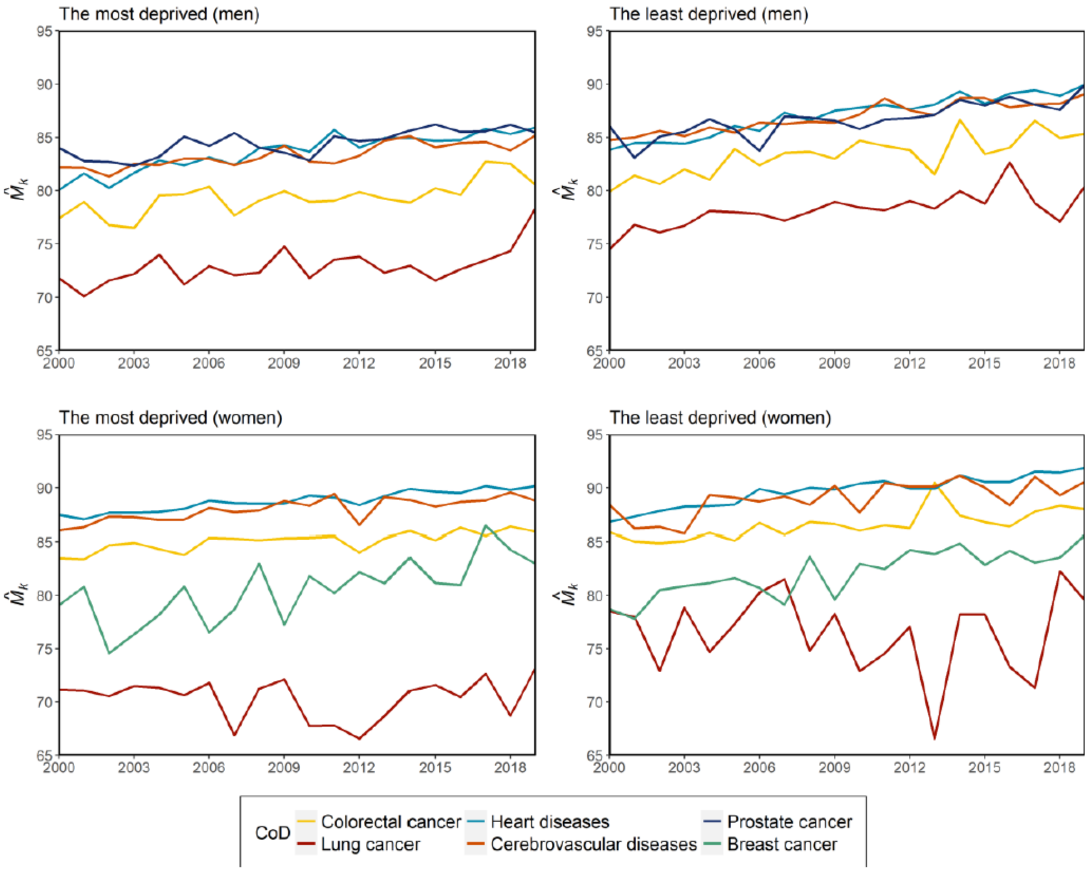

Fig. 8. Estimated modal age at death for leading causes of death among Belgian men and women living in the most and least deprived areas, 2000-2019.

Spatial variation in cause-specific premature mortality and association with deprivation in Belgium since the 2000s

Otavova M, Masquelier B, Faes C, Bouland C, De Clercq EM, Vandeninden B, Devleesschauwer B, Schluter BS. Spatial variation in cause-specific premature mortality and its association with socioeconomic deprivation in Belgium from 2000 to 2019. Arch Public Health. Under review

Population-level premature mortality risks vary in space and time between subpopulations and are influenced by numerous factors, including levels of socioeconomic deprivation. In the ELLIS project, we investigated the impact of overall and domain-specific deprivation on the spatio-temporal variation of cause-specific premature mortality in all 589 municipalities in Belgium, aggregated into 5-year periods, between 2000-2019. The average deprivation score, the measure of socioeconomic deprivation in this study, was based on the Belgian Index of Multiple Deprivation 2011 and its domains. We estimated relative risks (RR) of cause-specific premature death using a Bayesian hierarchical model, the Besag-York-Mollié (BYM) model.

Our findings showed that with a unit increase in the average deprivation score, the RR of dying prematurely increases by 13.3% and 12.5% in men and women. The employment and housing average deprivation scores showed the greatest impact on almost all RRs investigated. The greatest effect of overall and domain-specific deprivation is observed for RRs of alcohol-related deaths, and deaths due to COPD and diabetes mellitus in both sexes. The spatial pattern differs by cause, with the most common pattern being the North-South gradient with the greatest RRs distributed in Wallonia, but a notably different pattern for breast cancer in women (Fig. 9-11). Furthermore, increasing heterogeneity of the RR of dying prematurely reflects an increase in spatial inequality over time.

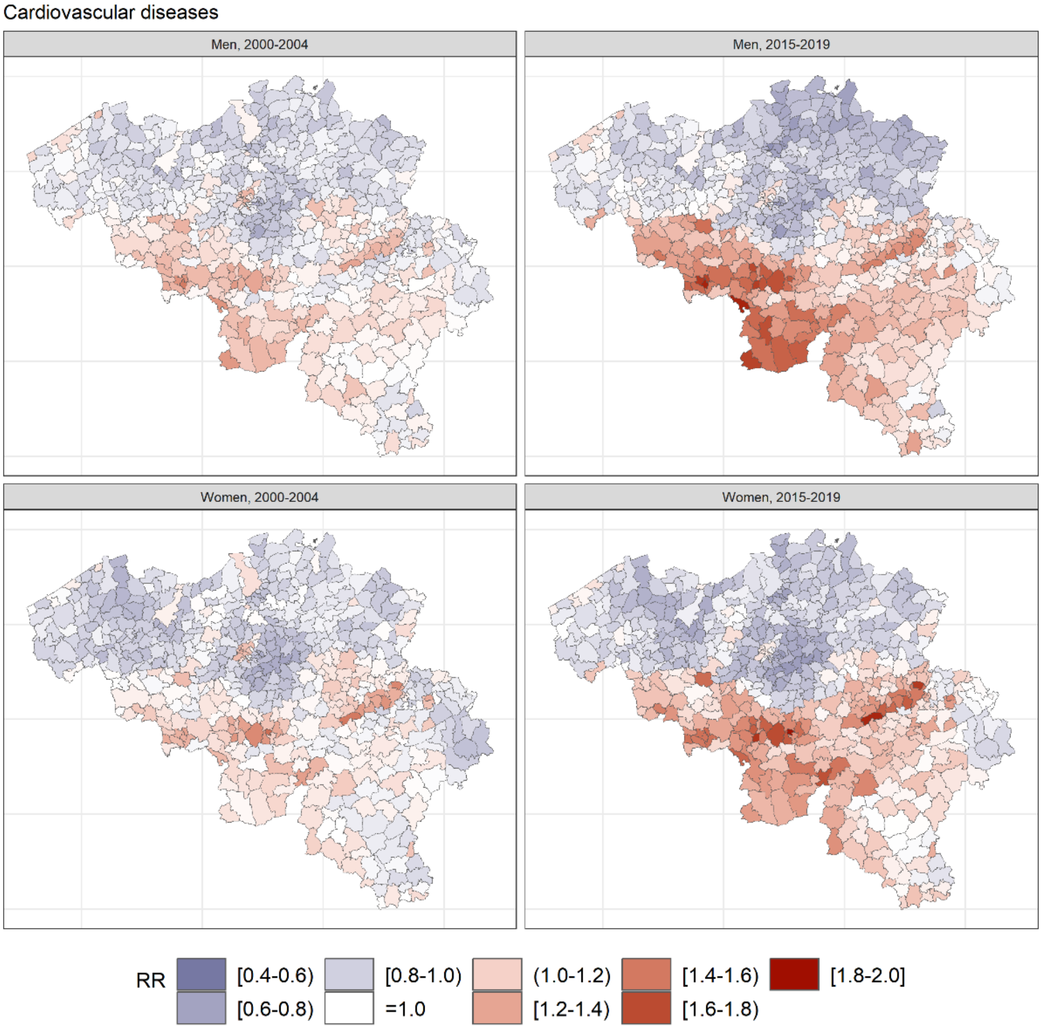

Fig. 9. Spatial and temporal distribution of RR of premature mortality due to cardiovascular diseases in Belgium in the first (2000-2004) and last period (2015-2019) studied.

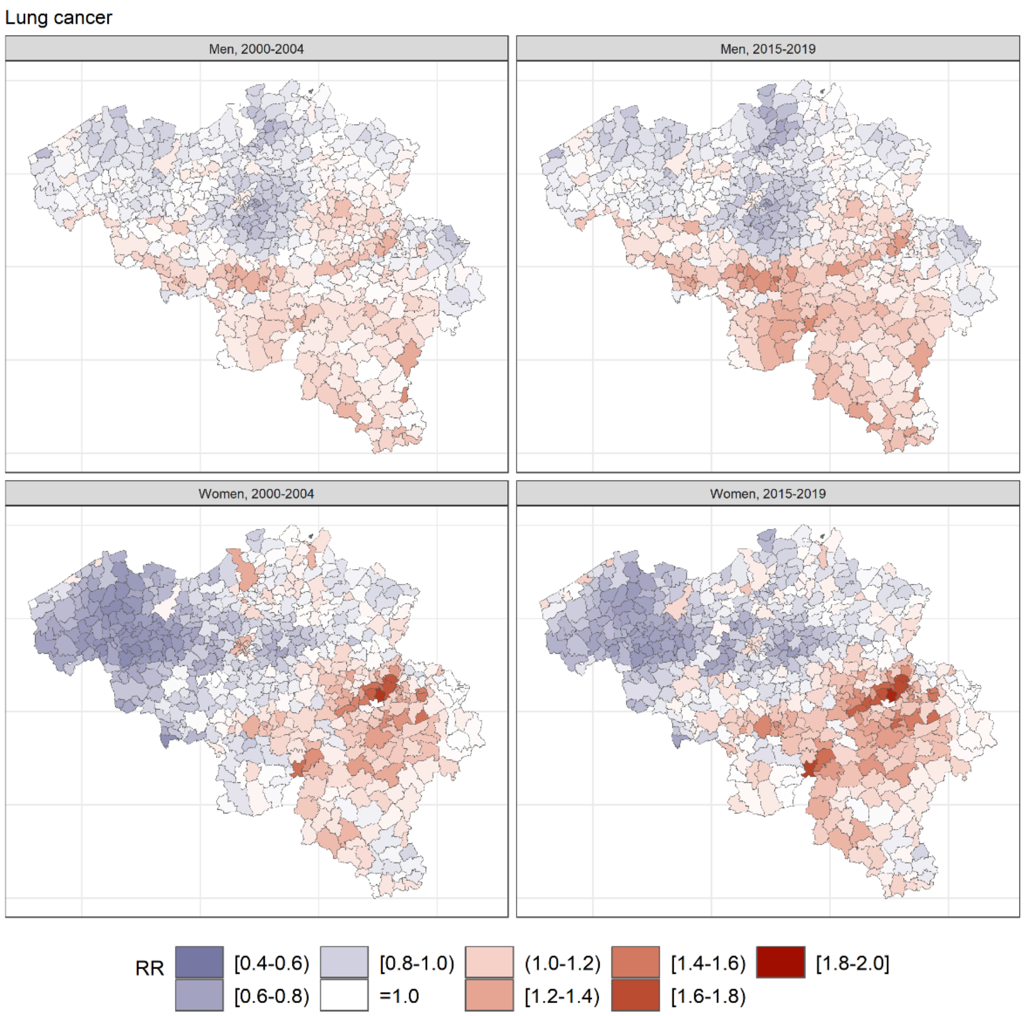

Fig. 10. Spatial and temporal distribution of RR of premature mortality due to lung cancer in Belgium in the first (2000-2004) and last period (2015-2019) studied.

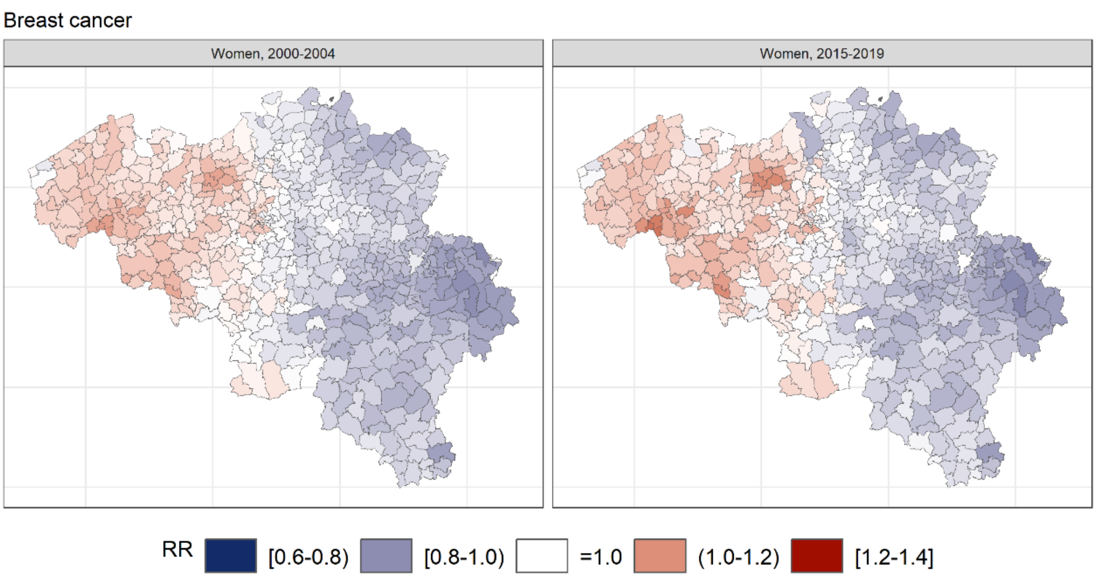

Fig. 11. Spatial and temporal distribution of RR of premature mortality due to breast cancer in Belgium in the first (2000-2004) and last period (2015-2019) studied.

PART II. ENVIRONMENTAL HEALTH AND HEALTH INEQUALITIES

Cluster pattern analysis of environmental stressors and quantifying their impact on all-cause mortality in Belgium

Vandeninden B, De Clercq E, Devleesschauwer B, Otavova M, Bouland C, Faes C (2024) Cluster pattern analysis of environmental stressors and quantifying their impact on all-cause mortality in Belgium. BMC Public Health 24:536. doi: [10.1186/s12889-024-18011-0](10.1186/s12889-024-18011-0)

Environmental stress represents an important burden on health and leads to a considerable number of diseases, hospitalisations, and excess mortality. In the ELLIS project, we studied exposure to various stressors, considering a representative sample drawn from the Belgian population in 2016 (n = 11.26 million, with a focus on n = 11.15 million individuals). The analysis was conducted at the geographical level of statistical sectors, comprising a total of n = 19,794 sectors, with a subset of n = 18,681 sectors considered in the investigation. We integrated multiple parameters at the finest spatial level and constructed three categories of environmental stress through clustering: air pollution, noise stress, and stress related to specific land-use types. We observed identifiable patterns in the spatial distribution of stressors within each cluster category. We assessed the relationship between age-standardised all-cause mortality rates (ASMR) and environmental stressors. Our research found positive associations between ASMR and very high air pollution values in areas where traffic is the dominant local component of air pollution (ASMR + 14.8%, 95% CI: 10.4–19.4%), and the presence of industrial land in the neighbourhood (ASMR + 14.7%, 95% CI: 9.4–20.2%). Cumulative exposure to multiple sources of unfavourable environmental stress (simultaneously high air pollution, high noise, presence of industrial land or proximity of primary/secondary roads and lack of green space) is associated with a large increase in ASMR (ASMR + 26.9%, 95% CI: 17.1–36.5%).

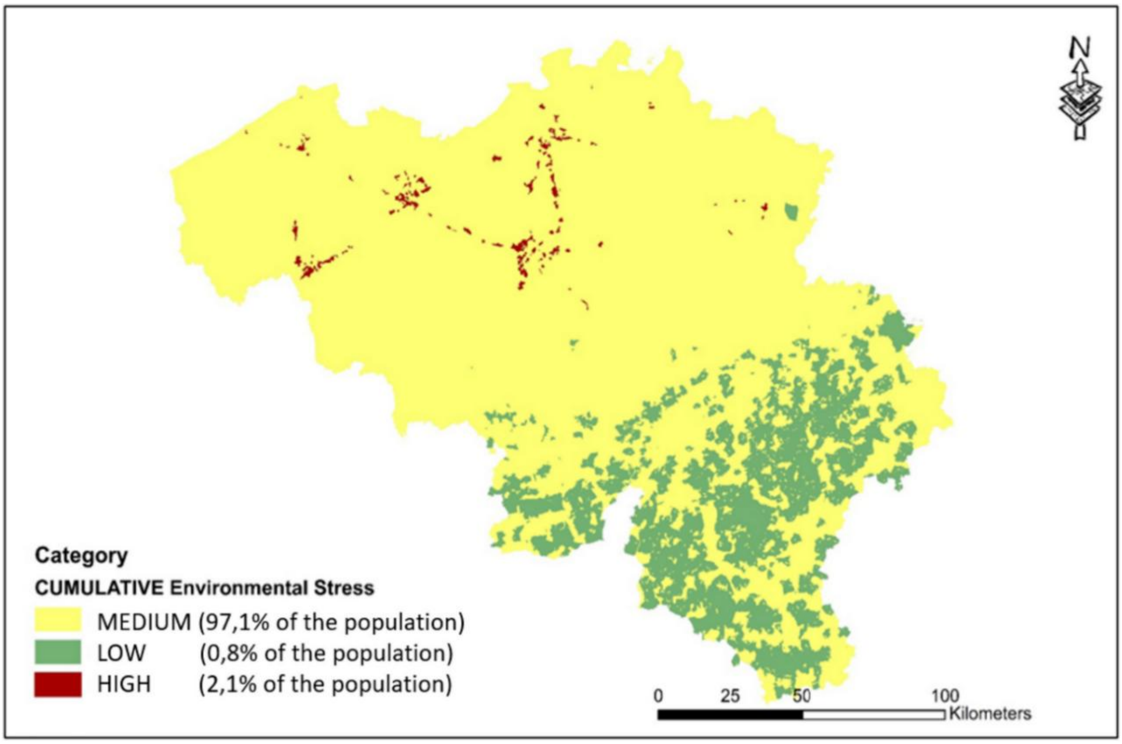

Fig. 12. Cumulative exposure to average vs. very high simultaneous (elevated air pollution + high industry/roads + high noise) and very low simultaneous (abundant green space, low air pollution and low noise) environmental stress

Implications of sectorial spatial-seasonal air pollution patterns for source allocation and public health policy making

Vandeninden B, Bouland C, Devleesschauwer B, Vanpoucke C, Hooyberghs H, Otavova M, Faes C, De Clercq EM. Implications of spatial and seasonal air pollution patterns, socioeconomic disparities, and 15-minute communities for achieving WHO air quality guidelines. Sci Rep, under review.

Long-term exposure to nitrogen dioxide (NO_2) and particulate matter < 2.5µm ($PM_{2.5}$) significantly increases the risk of various diseases, including cardiovascular conditions, asthma, Alzheimer's, and cancer, contributing to hospitalizations and mortality. Both long- and short-term exposure to these pollutants worsen respiratory infections, including influenza and COVID-19. Seasonal patterns show higher occurrences of cardiovascular events and infectious diseases during winter, with air pollution levels peaking in colder months. However, research on the health impacts of spatial and seasonal variations in air pollution remains limited. We therefore explored the spatial-seasonal variations of air pollution in Belgium, focusing on understanding the source allocation of pollutants, especially from motorised road traffic and residential heating (e.g., wood burning).

We found distinct seasonal variations in NO_2 and $PM_{2.5}$ concentrations, with NO_2 showing minimal seasonal differences near traffic sources (10-20%) and higher concentrations close to roads year-round. Further from traffic, NO_2 concentrations dropped more significantly in summer. $PM_{2.5}$ exhibited stronger seasonal variation due to a mix of sources and atmospheric processes. Overall, concentrations of NO_2, $PM_{2.5}$, and Black Carbon (BC) were 35-55% lower in summer compared to winter for 2016-2019.

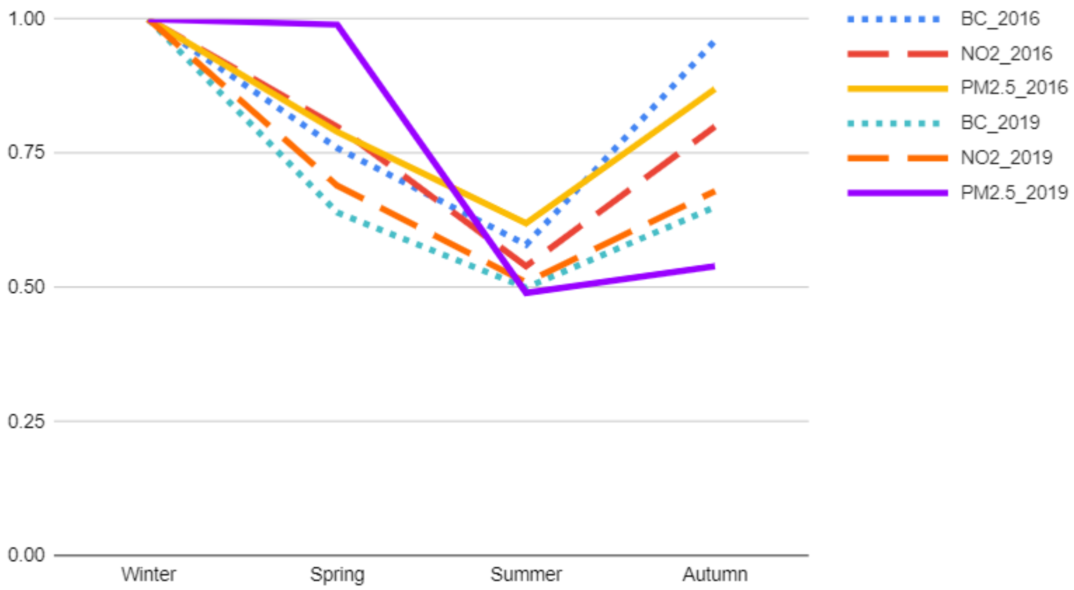

Fig. 13. Relative BC, NO_2 and $PM_{2.5}$ concentrations in spring, summer and autumn compared to winter for the calendar years 2016 and 2019.

Land cover and urbanization also influenced seasonal variations in air pollution. NO_2 ratios (compared to winter) remained close to 1.0 near major roads, urban areas, and transport infrastructure, while areas like forests and peat bogs showed more substantial summer dilution. In urban areas, seasonal differences in NO_2 and $PM_{2.5}$ were less pronounced compared to rural areas. Additionally, both pollutants decreased with distance from roads, with NO_2 diluting more slowly in winter, and $PM_{2.5}$ showing a similar but slower pattern, reflecting the diversity of $PM_{2.5}$ sources.

Urban and transport planning's health burden: a study of three Belgian cities

Vandeninden B, Devleesschauwer B, Otavova M, Faes C, Bouland C, De Clercq EM. Quantifying the urban and transport planning related disease burden in three Belgian cities. Journal of Public Health. Under review.

Urban and transport planning substantially impacts public health through environmental factors like air pollution and green space availability. We quantified the combined disease burden attributable to $PM_{2.5}$, NO_2, and insufficient green space in Brussels, Liège, and Mechelen using a multiplicative Population Preventable Fraction (PF) approach with WHO exposure target values as counterfactual scenario. The analysis focused on key health outcomes linked to urban and transport planning, including total mortality, cardiovascular mortality, diabetes, asthma and depression.

Our findings indicate that by reducing exposure to WHO-recommended levels for $PM_{2.5}$ and NO_2, while also ensuring adequate green space, in Brussels, Mechelen, and Liège, on average (population-weighted, average for city as a whole) 14.7% (95% CI: 9.4 – 19.8%), 11.7% (95% CI: 7.5 – 16.3%), and 12.0% (95% CI: 7.7 – 16.3%) of total premature mortality could be prevented if these factors were addressed. Our findings further indicate that achieving the counterfactual values of 5 µg/m³ for $PM_{2.5}$ exposure, 10 µg/m³ for NO_2 exposure, and city-specific target NDVI values could prevent 10.3% (95% CI: 4.1 – 16%), 11.0% (95% CI: 5.1 – 16.6%), and 13.4% (95% CI: 5.8 – 21.0%) of cardiovascular mortality in Liège, Mechelen, and Brussels, respectively. Similarly, reaching these targets could prevent 21.6% (95% CI: 7.2 – 37.0%), 19.9% (95% CI: 6.7 – 33.9%), and 25.4% (95% CI: 7.0 – 40.3%) of diabetes prevalence in these cities.

When specifically examining traffic-related air pollution and green space at measurement station locations in these cities, up to 22% (95% CI: 15 – 29%) of total mortality could be prevented by the combination of those factors (Fig. 14).

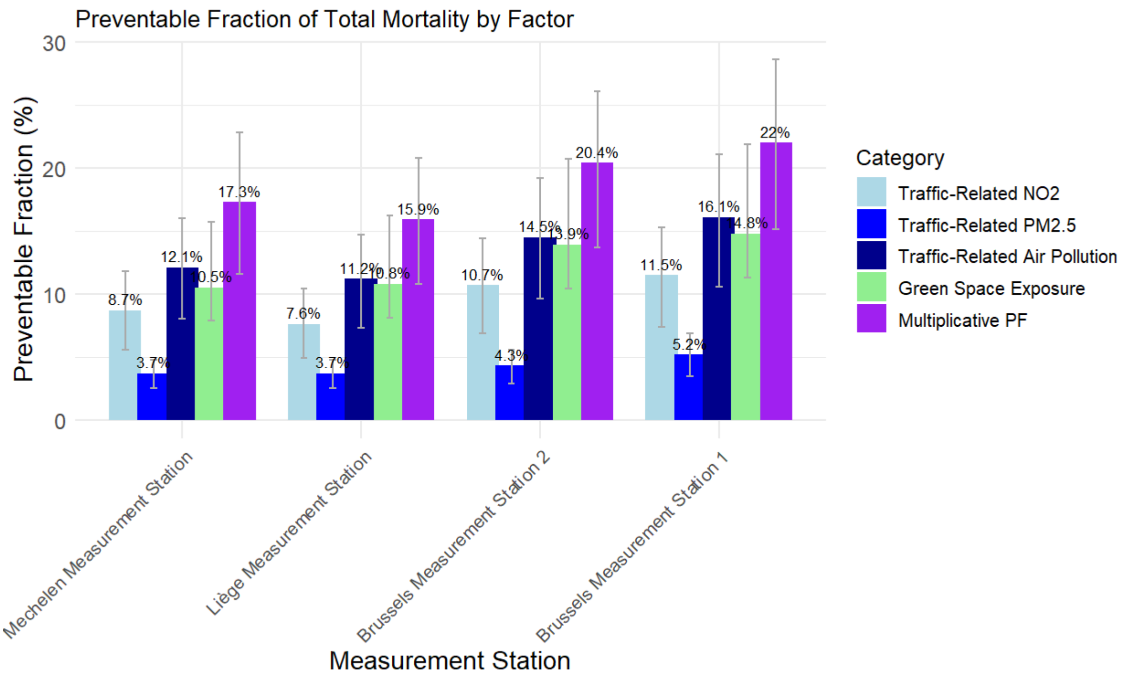

Fig. 14. Integrated assessment of Preventable Fraction (PF) of total mortality from traffic-related air pollution and insufficient green space exposure in the analysed air pollution measurement stations.

Our study also found inadequacies of current pollution assessment tools like SHERPA due to suboptimal source allocation of air pollution, which may underestimate the combined health impacts of traffic-related pollution. We found that 73.2 to 78.6% of NO_2 originates from traffic, with the local traffic component, omitted in analysis relying on background levels responsible for 40.9% to 55.0% of NO_2 concentrations in measurement stations in Brussels, Mechelen and Liège.

These results underscore the necessity for comprehensive urban planning strategies that integrate air quality improvement and green space expansion to substantially reduce the public health burden in urban environments.

Environmental health inequalities in Flanders

Based on the ELLIS methodological framework, we examined social inequalities in the health impact of air pollution by linking disease burden estimates to socio-economic deprivation at a local level, focusing on mortality from $PM_{2.5}$ and NO_2 in 2019.

Social inequality was measured using the Belgian Index of Multiple Deprivation (BIMD), as described above. For this study, an adjusted BIMD2011 for Flanders was created, excluding Brussels and Wallonia and omitting the health domain to focus on health inequalities (Fig. 15).

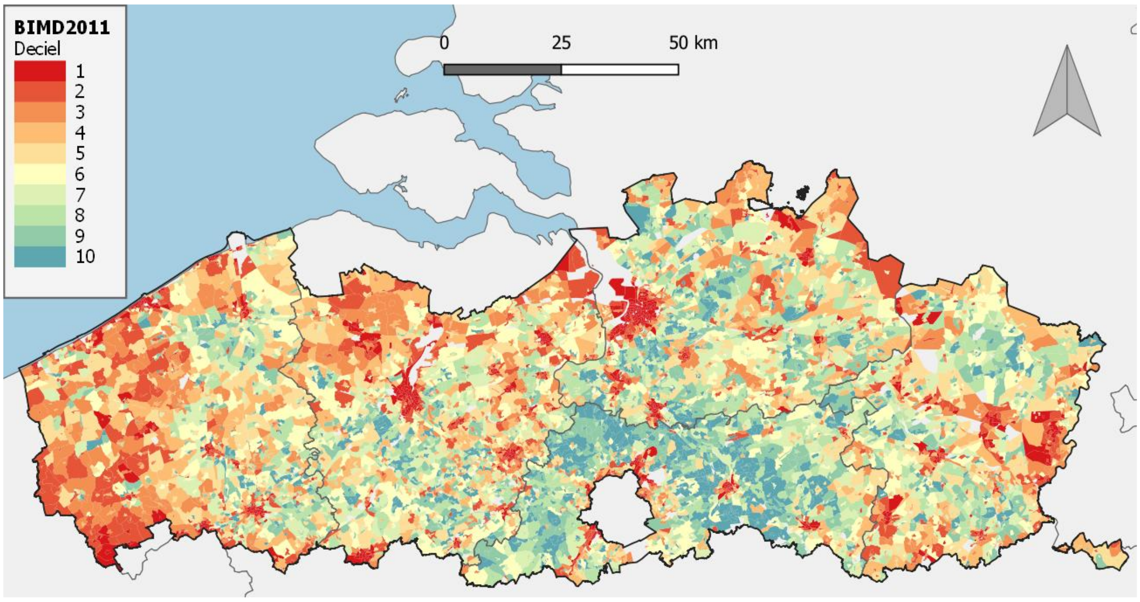

Fig. 15. Adapted version of the BIMD2011 for Flanders, excluding the health domain.

Population exposure to $PM_{2.5}$ and NO_2 was determined using modeled air quality data. High-resolution maps generated by the ATMO-Street model, provided by the Interregional Environment Agency (IRCEL-CELINE), were used for this purpose (Fig. 16). Exposure was calculated per statistical sector as the average concentration of $PM_{2.5}$ and NO_2 within the area.

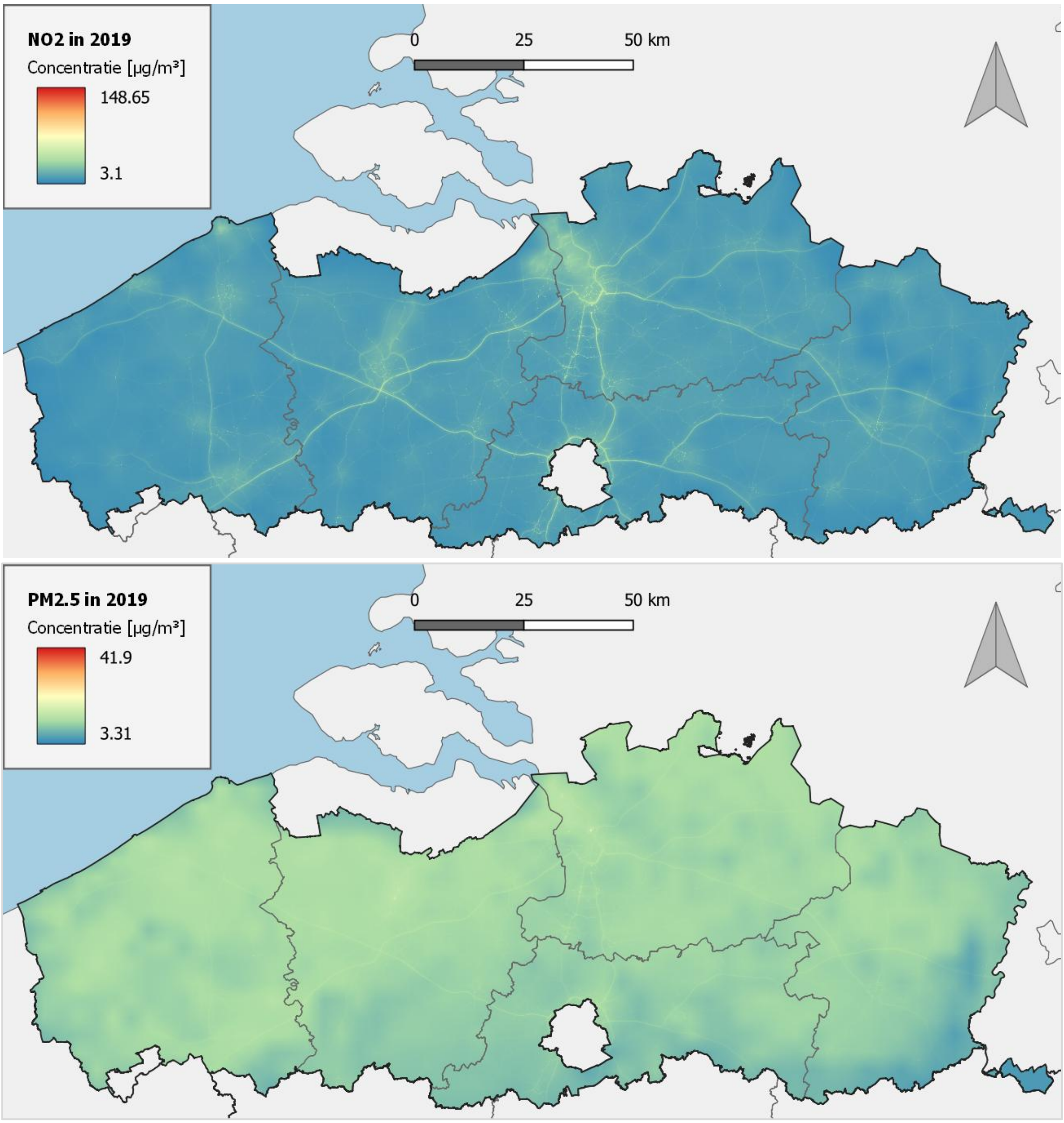

Fig. 16. Annual average concentration of NO_2 (top) and $PM_{2.5}$ (bottom) in Flanders, 2019. Results of the ATMO-Street model, provided by the Interregional Environment Agency.

The health outcome considered in this study was all-cause mortality. The relative risks (RRs) applied were based on the WHO's 2021 air quality guidelines (reference needed), derived from a meta-analysis of the available evidence at the time (https://apps.who.int/iris/handle/10665/345329). The RR for all-cause mortality due to $PM_{2.5}$ exposure is 1.08 per 10 µg/m³ increase in annual average concentration, while for NO_2, it is 1.02 per 10 µg/m³. The dose-response relationships have been adjusted for socio-economic status (SES) differences. The 2019 all-cause mortality figures were sourced from Statbel. They include the statistical sector of the deceased person's last residence, allowing for aggregation of deaths per statistical sector (Fig. 17).

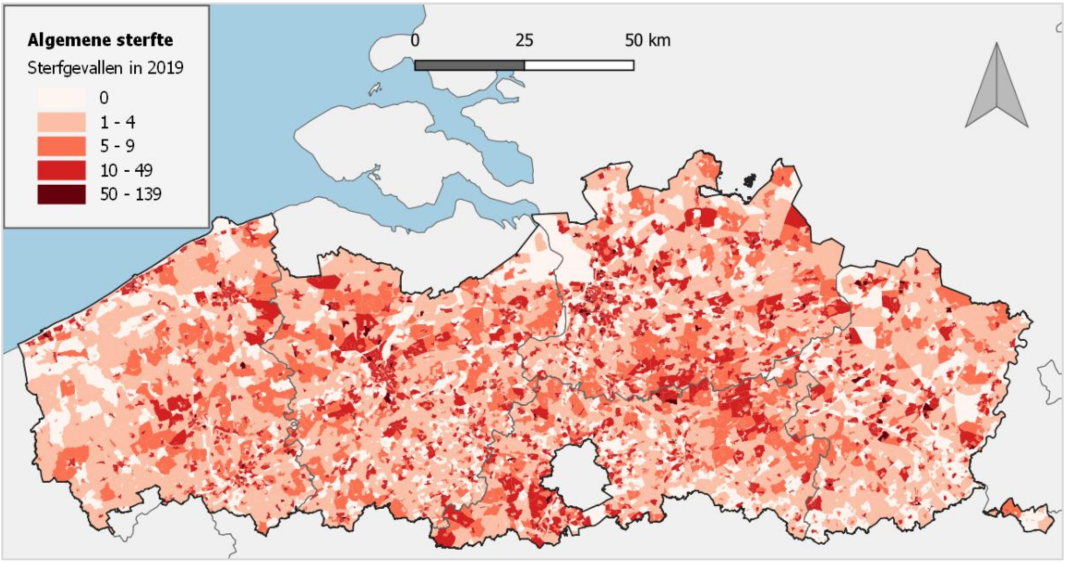

Fig. 17. All-cause mortality by statistical sector, 2019, Flanders.

Exposure to $PM_{2.5}$ and NO_2, as well as the attributable mortality figures, can be linked to the BIMD of the corresponding sector. This enables the calculation of average exposure and aggregated attributable disease burden per deprivation decile. Based on this stratified exposure and environmental disease burden, several indicators can be calculated to quantify inequality, including:

- Absolute difference $D_1 - D_{10}$: the absolute difference between exposure or environmental disease burden in the most and least deprived deciles (D_1 and D_{10})
- Relative difference = D_1/D_{10} : the relative difference between exposure or burden in the most vs least deprive deciles
- Population attributable fraction (PAF) = $\frac{\bar{D}-D_{10}}{\bar{D}}$: the PAF expresses which percentage of all exposure of burden could be avoided if the entire population would belong to the least deprived decile

Our results showed that exposure decreases with decreasing deprivation for both pollutants (Fig. 18). The difference between decile 1 (most deprived) and decile 10 (least deprived) is most pronounced for NO_2, both in absolute and relative terms (Table I). The relationship between deprivation and exposure is weaker for $PM_{2.5}$. This can partly be explained by the spatial distribution of these pollutants: $PM_{2.5}$ concentrations vary more gradually, whereas NO_2 levels can be locally high, particularly in disadvantaged neighbourhoods. The population attributable fraction (PAF) for average exposure compared to the least deprived decile is 5.7% for NO_2 and 1.9% for $PM_{2.5}$, indicating that deprivation has a stronger influence on NO_2 exposure.

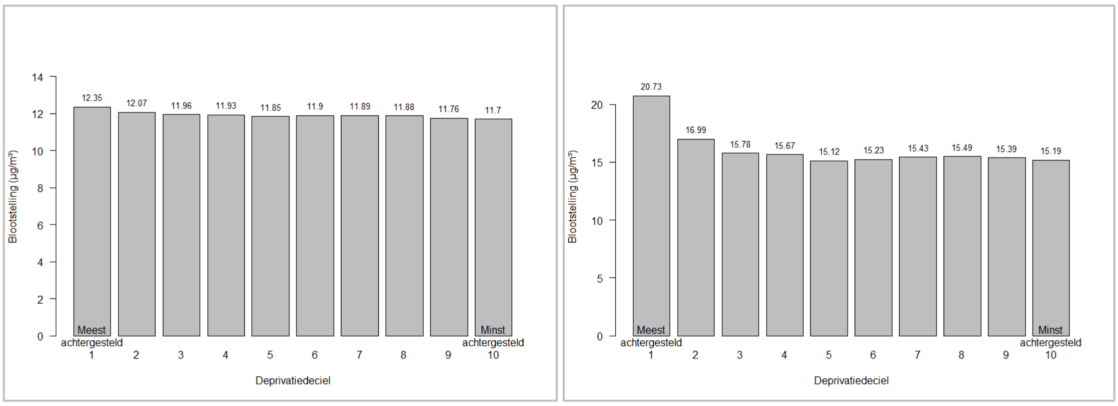

Fig. 18. Mean population exposure to $PM_{2.5}$ (left) and NO_2 (right) by deprivation decile in Flanders, 2019.

Table I. Inequality indicators of exposure to $PM_{2.5}$ and NO_2 in Flanders. The absolute and relative difference compare the most with the least deprived decile. The PAF compares the general population (average of all deciles) with the least deprived decile.

	$PM_{2.5}$	NO_2
Absolute difference in exposure	+0.65 µg/m³	+5.54 µg/m³
Relative difference in exposure	+5.6%	+36.5%
PAF for exposure	1.9%	5.7%

In 2019, a total of 62,314 people died in Flanders. $PM_{2.5}$ was responsible for 5,552 deaths (8.9% of all deaths), while NO_2 was linked to 2,135 deaths (3.4%). Figure 19 indicates that this health burden is disproportionately concentrated in more deprived deciles. The absolute mortality gap between the highest and lowest decile is largest for $PM_{2.5}$ (Table II). However, in relative terms, inequality is significantly greater for NO_2, with the largest differences in the most deprived deciles. This reflects the fact that NO_2 exposure varies more sharply and is more strongly associated with deprivation than $PM_{2.5}$ exposure. If the entire population were exposed to the pollution levels of decile 10, 23.8% of NO_2-related deaths and 17.3% of $PM_{2.5}$-related deaths could have been prevented.

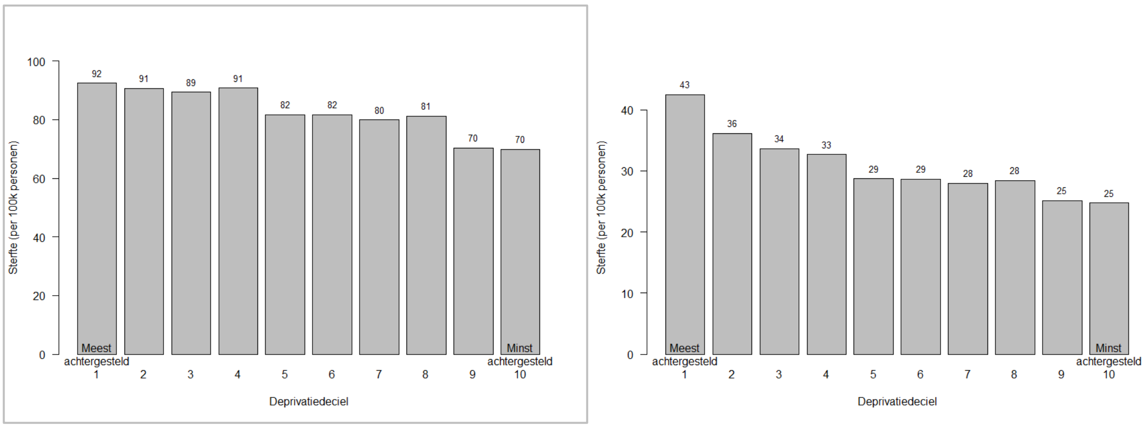

Fig. 19. Mortality attributable to $PM_{2.5}$ (left) and NO_2 (right) by deprivation decile in Flanders, 2019

Table II. Inequality indicators of mortality attributable to $PM_{2.5}$ and NO_2 in Flanders. The absolute and relative difference compare the most with the least deprived decile. The PAF compares the general population (average of all deciles) with the least deprived decile.

	$PM_{2.5}$	NO_2
Absolute difference in burden	23 deaths per 100k pers.	18 deaths per 100k pers.
Relative difference in burden	+32.3%	+71.8 %
Disease burden PAF	17.3%	23.8%

Impact assessment of local traffic interventions on disease burden: a case study on paediatric asthma incidence in two European cities

Vandeninden B, De Clercq E, Devleesschauwer B, Otavova M, Masquelier B, Fierens F, Faes C, Bouland C (2025) Impact assessment of local traffic interventions on disease burden: A case study on paediatric asthma incidence in two European cities. J Transp Health, 40: 101953. doi: 10.1016/j.jth.2024.101953

As part of the ELLIS project, we also estimated the reduction in NO_2 concentrations on annual car-free Sundays in two European cities, Brussels and Paris, which have extensive car-free zones (162 km^2 and 105 km^2). We then conducted health impact modelling of paediatric asthma incidence using a hypothesised expansion of annual car-free Sundays to car-free daily zones. Our study concluded that NO2 concentrations are considerably reduced on car-free Sundays versus regular Sundays in European cities where the annual car-free Sunday has an extensive geographical scope, such as Brussels (162km2) and Paris (105km2). We showed that local traffic interventions can reduce NO_2 exposure with 63-83% in the selected areas in Brussels and with 27-56% in the selected areas in Paris. As sensitivity analysis, different methods were used to assess the impact, namely (1) direct calculations, (2) direct calculations corrected for meteorological conditions, (3) random forest modelling and (4) boosted regression tree modelling, and results were shown to be robust across the different methods.

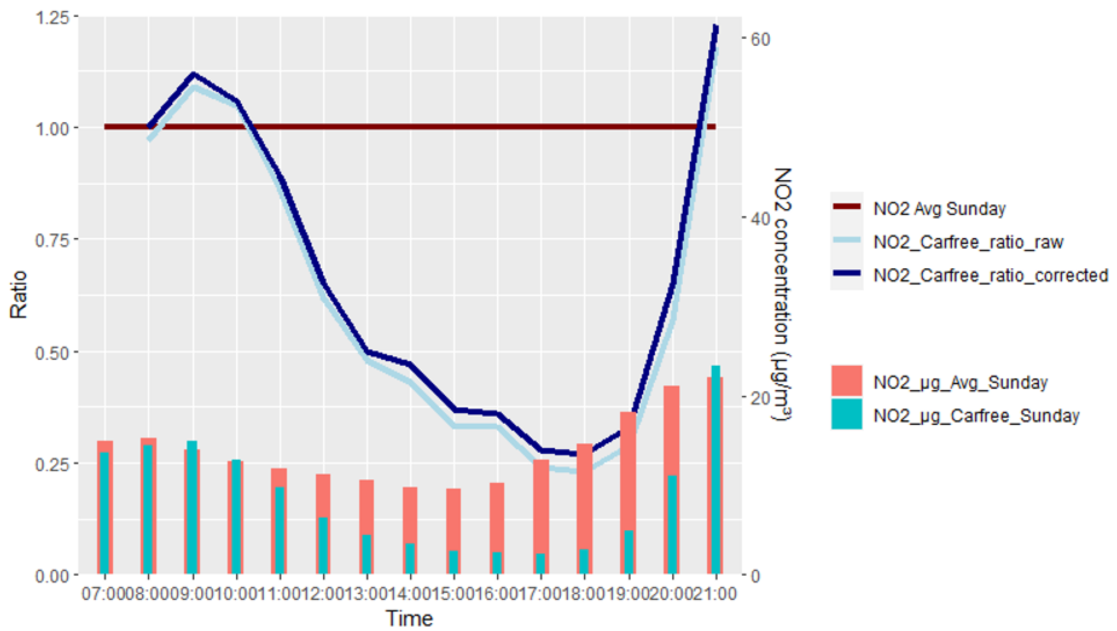

Fig. 20. Direct calculations for the ratio of NO_2 concentrations between regular Sundays and car-free Sundays hour-by-hour (2015-2022) using method (1) and method (2), for residential areas in Brussels

In a next step, we assessed the impact of air pollution on paediatric asthma. An exposure simulation similar to car-free days was used to conduct a Health Impact Assessment quantifying the mitigation potential of local traffic interventions on paediatric asthma incidence. We used existing evidence on exposure-response functions (ERFs) to quantify the asthma disease burden attributable to NO_2 exposure. We conclude that this could result in a reduction of paediatric asthma incidence ranging between 14% in residential areas of Brussels [95% Confidence Interval: 8-18%] to 29% [95% Confidence Interval: 19-34%] in heavily trafficked areas in Brussels, with reductions varying from 14% [95% Confidence Interval: 8-18%] to 17% [95% Confidence Interval: 10-22%] in Paris. This study underscored the importance of implementing policy interventions to reduce traffic levels and emissions in urban areas, which can decrease the disease burden beyond air pollution, by for instance promoting physical activity, reducing noise, and increasing green space availability.

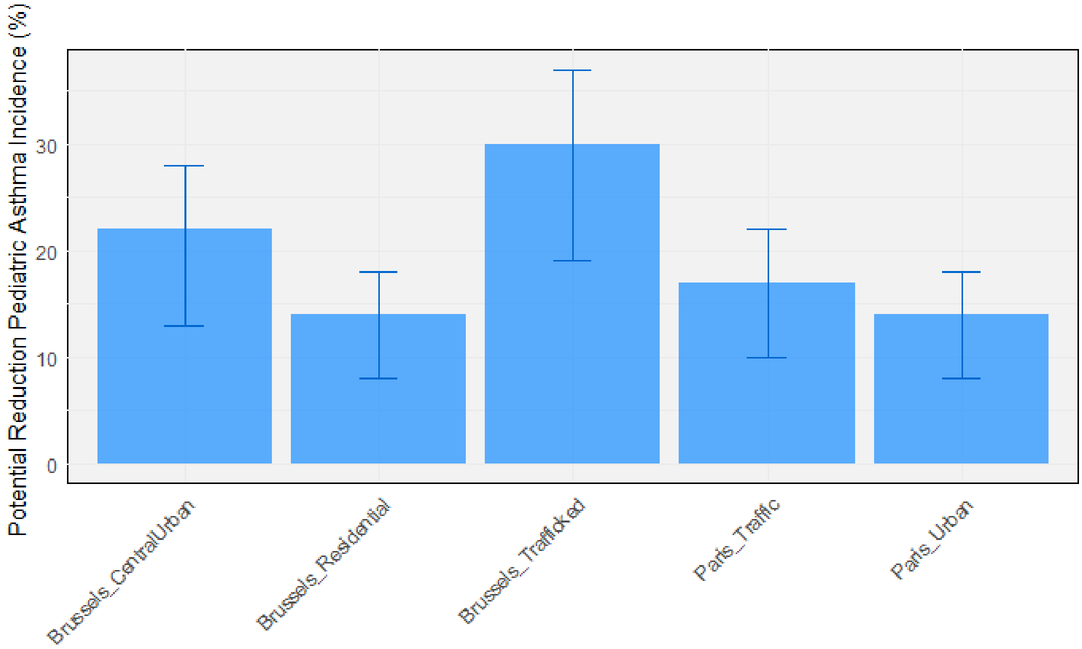

Fig. 21. Percentage of paediatric asthma incidence that could be avoided by local interventions in traffic volume in different areas of Brussels and Paris.

PART III. RECOMMENDATIONS

Belgian Indices of Multiple Deprivation

- **Continue updating and promoting the BIMD:** Regular updates and widespread dissemination of the BIMD by Sciensano will ensure that the index remains relevant and accurately reflects current deprivation patterns, thereby enhancing its utility for public health research and policy development.
- **Integrate the BIMD into decision-making processes:** Policy makers, governmental departments, regional bodies, local authorities, and academics are encouraged to use the indices to help target policies and funding to ultimately reduce inequalities across multiple domains.

Health inequalities

- **Implement targeted public health interventions:** Focus on the most deprived areas with tailored programs addressing lifestyle-related risk factors, such as smoking, alcohol consumption, and physical inactivity, to mitigate their impact on premature mortality.
- **Enhance access to healthcare services:** Ensure that populations in deprived areas have improved access to preventive and curative healthcare services, facilitating early detection and management of chronic diseases.
- **Address socioeconomic determinants of health:** Implement policies aimed at reducing poverty, improving education, and creating employment opportunities, thereby tackling the root causes of health inequalities.
- **Monitor and evaluate health inequalities:** Establish robust surveillance systems to regularly assess health disparities, allowing for timely interventions and policy adjustments.

Environmental health inequalities

- **Implement stricter air quality regulations:** Strengthen policies to reduce emissions from all sources including traffic and industrial sources, aiming to lower concentrations of pollutants such as NO_2 and $PM_{2.5}$.
- **Enhance urban planning to reduce exposure:** Design urban areas to minimize residential proximity to major roads and industrial zones, thereby reducing exposure to harmful environmental stressors.
- **Expand and maintain green spaces:** Increase the availability of green spaces in urban settings to mitigate the adverse health effects associated with environmental stressors and promote overall well-being.
- **Prioritize pollution reduction in deprived areas:** Focus air quality improvement measures in low-income and high-deprivation zones, and expand green infrastructure (e.g., urban forests, low-emission zones) to mitigate pollution exposure.
- **Enhance cross-sector collaboration for holistic solutions:** Strengthen cooperation between policymakers across sectors such as transportation, urban planning, public health, and environmental agencies to create integrated strategies for pollution mitigation. Ensure policies account for both environmental and social determinants of health.
- **Scale up real-world experiments and evidence-based policies:** Invest in pilot projects and real-world intervention studies to assess the effectiveness of pollution mitigation measures and retrieve empirical evidence.
- **Enhance monitoring & transparency:** Improve air quality monitoring at a fine spatial scale, ensuring data accessibility for policymakers and the public, and integrate air pollution and health impact data into public health reporting systems.

5. DISSEMINATION AND VALORISATION

5.1. STAKEHOLDER ENGAGEMENT

Follow-up committee meetings

The ELLIS follow-up committee was composed of representatives of the concerned federal and regional authorities and administrations, and experts in the field of environmental health inequalities. Throughout the project, five meetings with the follow-up committee were organised.

The kick-off meeting with the follow-up committee was organised on 28 October 2020. Eleven members of the follow-up committee attended the meeting, and discussed the project objectives and methods, and identified opportunities for synergies with ongoing projects. Subsequent meetings were organised on 26 October 2021, 24 October 2022, and 12 December 2023, and allowed discussing the progress of the project and identifying further opportunities for synergies with ongoing projects.

The final meeting with the follow-up committee was organised on 31 February 2025, and was set up as an open **study day** to mark the end of the ELLIS project. This final event allowed sharing the insights generated throughout the ELLIS project, and making the link towards future projects and policy needs.

https://www.sciensano.be/en/events/ellis-study-day-monitoring-and-mitigating-environmental-health-inequalities

- Welcome — Brecht Devleesschauwer, Sciensano

- Context setting — Matthias Braubach, WHO
- Belgian Indices of Multiple Deprivation (BIMD) — Laura Van den Borre, Sciensano
- BIMD & Health Impact — Martina Otavova, UCLouvain
- Air pollution & its health impact — Ingrid Pelgrims, Sciensano
- Health Impact of Transport & Urban planning — Bram Vandeninden, ULB & UHasselt
- The federal climate adaptation perspective on the ELLIS project — Samuel Lietaer, FPS Public Health
- The post-ELLIS era: the way forward — Eva De Clercq, Sciensano

As an outcome of the ELLIS study day, subsequent interactions with the NEHAP have been planned, to ensure a continuation of the ELLIS monitoring framework for environmental health inequalities.

In follow-up of the study day, the ELLIS project was presented at the NEHAP study day on March 13th 2025 in Brussels. Feedback on the presentation came mainly from the FPS Health, Food Chain Safety and Environment, and from the Flemish Department of Care, underlining that it remains important to generate the Belgian Index of Multiple Deprivation (BIMD) both including and excluding the health domain. The main reason for this is that health, and specifically disposable income and employment can be directly affected by the occurrence of chronic diseases. Other recommendations from the public included a call for FPS to increase the accessibility to small-scale data. Since the 2021 census is based on administrative databases, socio-economic data could be made available at the level of statistical sector on a yearly basis. FPS Health also suggested exploring the possibility to facilitate access to high-resolution data on heat, which is now often costly to acquire for research purposes.

As such, the tools developed during the ELLIS project could support the work of the federal risk assessment group (RAG) by including chronic disease status and resilience of the population to climate change-related events.

Blog posts

To foster interaction with the follow-up committee, we initiated a series of policy briefs, under the form of blog posts: https://www.brain-ellis.be/blog.

1. Otavova M. Towards the development of the Belgian Index of Multiple Deprivation. https://www.brain-ellis.be/blog/10-towards-the-development-of-a-belgian-index-of-multiple-deprivation
2. Vandeninden B. The opportunity for mitigation co-benefits and the importance of 'ONE HEALTH'. https://www.brain-ellis.be/blog/12-how-are-mobility-obesity-poverty-myocardial-infarctions-droughts-and-sea-level-rise-interconnected-the-opportunity-for-mitigation-co-benefits-and-the-importance-of-one-health
3. Vandeninden B. The importance and availability of data on environmental stressors in Belgium. https://www.brain-ellis.be/blog/13-the-importance-and-availability-of-data-on-environmental-stressors-in-belgium
4. Otavova M. Inequalities in mortality associated with housing conditions in Belgium between 1991 and 2019. https://www.brain-ellis.be/blog/16-inequalities-in-mortality-associated-with-housing-conditions-in-belgium-between-1991-and-2019
5. Vandeninden B. Increased car use and decreased public transport use post-COVID could structurally elevate hospitalisations and death. https://www.brain-ellis.be/blog/17-increased-

car-use-and-decreased-public-transport-use-post-covid-could-structurally-elevate-hospitalisations-and-death

5.2. DISSEMINATION

Belgian Indices of Multiple Deprivation (BIMD)

A series of dissemination activities have been set up to promote the use and impact of the Belgian Indices of Multiple Deprivation:

- Online tool: https://bimd.sciensano.be/tool
- GitHub repository: https://github.com/bimd-project/bimd
- R package: https://github.com/sciensanogit/bimd-pkg
- Webinar: https://youtu.be/BVN7FPMkPlU
- Healthy Belgium Factsheet: https://www.healthybelgium.be/en/health-status/factsheets/belgian-index-of-multiple-deprivation-and-cause-specific-premature-mortality

Oral presentations

1. Otavova M, Vandeninden B. Sciensano EpiTuesday Seminars, 09/03/2021, Brussels, Belgium (videoconference). ELLIS: Monitoring and mitigating environmental health inequalities in Belgium.
2. Vandeninden, B. Sciensano EpiTuesday Seminars, 24/08/2021, Brussels, Belgium. Mortality from environmental stress attributable to motorised road transport (in the framework of the ELLIS project)
3. Vandeninden, B., De Clercq, E., Faes, C. and Bouland, C. June 2021. Mobility, Health and Place Conference Oral presentation (Vandeninden B). Mortality attributable to exposure to environmental stress from motorised road traffic – explorative study
4. Otavova M, Faes C, Devleesschauwer B & Masquelier B. Inequalities in mortality associated with housing conditions in Belgium between 1991-2020. ENRGHI Conference. 30 June – 2 July 2021. Virtual event. Oral session.
5. Otavova M, Faes C, Devleesschauwer B & Masquelier B. Inequalities in mortality associated with housing conditions in Belgium between 1991-2020. BSPS Conference. 13 September - 15 September 2021. Virtual event. Oral session.
6. Devleesschauwer B. Presentation of the ELLIS Project. 2021 IANPHI Annual Meeting. https://ianphi.org/tools-resources/2021-annual-meeting.html
7. Vandeninden, B. , Faes, C., Bouland, C., De Clercq. EM. June 2022 International Medical Geography Symposium Cluster patterns of environmental stress are associated with health outcomes and socio-economic characteristics: identifying and mitigating hotspots of environmental injustice (scheduled)
8. Otavova M, Faes C, Devleesschauwer B & Masquelier B. 'Premature mortality attributable to socioeconomic inequality in Belgium between 1991 and 2020'. European Population Conference 2022, Groningen, the Netherlands, Oral session.
9. Otavova M, Faes C, Devleesschauwer B & Masquelier B. 'Premature mortality attributable to socioeconomic inequality in Belgium between 1991 and 2020'. 31st International Biometric Conference, Riga, Latvia, Oral session.
10. Otavova M, Faes C, Masquelier B & Devleesschauwer B. ''Measuring small-area level deprivation in Belgium: the Belgian Index of Multiple Deprivation' , British Society for Population Studies Conference, Winchester, United Kingdom. Oral session.

11. Vandeninden B, Bouland C, Faes C, De Clercq EM "Cluster patterns of environmental stress are associated with health outcomes and socio-economic characteristics: identifying hotspots of environmental injustice, Medical Geography Symposium June 2022 Edinburgh
12. Vandeninden B, Faes C, Devleesschauwer B & Bouland C >25% of Pediatric asthma incidence in central-urban and trafficked areas in Belgium's capital city Brussels saved if local traffic was permanently reduced to the traffic-levels of car-free Sunday, short Pitch Presentation, Urban Transitions Conference November 2022 Barcelona, Spain
13. Schlüter BS, Otavova M, Masquelier B & Devleesschauwer B. ''Quantifying spatial inequalities in cause-specific mortality', British Society for Population Studies Conference, Winchester, United Kingdom. Oral session
14. Vandeninden B, Faes C, Devleesschauwer B & Bouland C >25% of Pediatric asthma incidence in central-urban and trafficked areas in Belgium's capital city Brussels saved if local traffic was permanently reduced to the traffic-levels of car-free Sunday, Oral Presentation, European Public Health Conference, November 2023, Dublin, Ireland
15. Otavova M, Faes C, Masquelier B & Devleesschauwer B. Trends in socioeconomic inequalities in cause-specific premature mortality in Belgium (1998-2019), Oral session, Belgian Demography Day, April 2023, Louvain-la-Neuve, Belgium
16. Otavova M, Faes C, Masquelier B, Devleesschauwer B & Schlüter BS. Spatial variation in inequality distribution of all-cause and cause-specific premature mortality in Belgium since 2000, Oral session, Population Association of America, April 2024, Ohio, Columbus, United States.
17. Otavova M, Faes C, Masquelier B, Devleesschauwer B & Schlüter BS. Spatial variation in inequality distribution of all-cause and cause-specific premature mortality in Belgium since 2000, Oral session, Geomed, September 2024, Hasselt, Belgium.
18. Vandeninden B, De Clercq EM, Faes F, Bouland C, Spatial Insights into potential Health Benefits from Urban Traffic Reduction: Case-study on Car-Free Initiatives in European Capitals and paediatric asthma, oral presentation, GEOMED 2024, Hasselt September 9-11th 2024
19. Vandeninden B, De Clercq EM, Faes F, Bouland C, Spatial insights into potential health benefits from urban traffic reduction: case study on car-free initiatives in European capitals and paediatric asthma, oral presentation, Urban transitions 2024 Barcelona 5-7 November 2024
20. Otavova M, Masquelier B & Ouellette N. Uncovering socioeconomic disparities in modal age at death in Belgium since 2000, Oral session, International Biometric Conference, December 2024, Atlanta, United States.
21. De Clercq EM. The ELLIS project: Monitoring and Mitigation of Environmental Health Inequalities. Oral Presentation, NEHAP Study Day 28th October 2021, Brussels, Belgium.
22. De Clercq EM. Monitoring and mitigating environmental health inequalities related to air quality in Belgium. Oral presentation, 27th meeting of the Joint Convention/WHO Task Force on the Health Aspects of Long range Transboundary Air Pollution, 22-23 May 2024, Bonn, Germany.
23. De Clercq EM. The ELLIS project: Monitoring and Mitigation of Environmental Health Inequalities. Oral Presentation, NEHAP Study Day 13th March 2025, Brussels, Belgium.

Poster presentations

1. De Clercq EM, Vandeninden B, Otavova M, Faes F, Masquelier B, Eggerinckx T, Bouland C, Devleesschauwer B. Congrès de la Société Francophone de santé Environnement (SFSE), 16-20/11/2020, Lille, France (videoconference). Multi-expositions, conditions de vie et santé : de la

connaissance à l'action. Surveillance et réduction des inégalités en santé environnementale : le projet ELLIS

2. Otavova M, Faes C, Devleesschauwer B & Masquelier B. Inequalities in mortality associated with housing conditions in Belgium between 1991-2020. EUPHA conference, 10. November - 12. November 2021. Virtual event. Poster session.
3. Otavova M, Faes C, Devleesschauwer B & Masquelier B. Inequalities in mortality associated with housing conditions in Belgium between 1991-2020. IPC conference, 5. December – 10. December 2021. Virtual event. Poster session.
4. Vandeninden B, De Clercq EM, Faes C & Bouland C. Seasonal and spatial patterns of mortality associated with exposure to air pollution International Society for Environmental Epidemiology (ISEE) Conference, September 2022, Athens
5. Vandeninden B , Faes C, Devleesschauwer B & Bouland C >25% of Pediatric asthma incidence in central-urban and trafficked areas in Belgium's capital city Brussels saved if local traffic was permanently reduced to the traffic-levels of car-free Sunday, Poster presentation, Urban Transitions Conference November 2022 Barcelona, Spain
6. Otavova M, Faes C, Devleesschauwer B & Masquelier B. 'Premature mortality attributable to socioeconomic inequality in Belgium between 1991 and 2020'. Population Association of America Conference 2023. New Orleans, Louisiana.
7. Otavova M, Masquelier B & Ouellette N. Uncovering socioeconomic disparities in modal age at death in Belgium since 2000. Poster session. Population Association of America, April 2024, Columbus, Ohio.
8. Vandeninden B, De Clercq EM, Bouland C, Faes C, Cluster pattern analysis of environmental stressors and quantifying their impact on all-cause mortality in Belgium, poster GEOMED 2024, Hasselt September 9-11th 2024
9. Vandeninden B, Bouland C, De Clercq EM, Faes E, The Role of Mobility Metrics In Shaping Healthier Cities, example: Mobiscore, poster, Urban transitions 2024 Barcelona 5-7 November 2024
10. Otavova M, Masquelier B & Ouellette N. Uncovering socioeconomic disparities in modal age at death in Belgium since 2000. Poster session. Geomed, September 2024, Hasselt, Belgium.

Press releases and media coverage

https://www.sciensano.be/nl/pershoek/nieuw-meetinstrument-sciensano-en-uclouvain-toont-aan-wie-een-achtergestelde-buurt-woont-heeft

https://www.sciensano.be/fr/coin-presse/constat-dun-nouvel-instrument-de-mesure-de-sciensano-et-de-luclouvain-les-personnes-vivant-dans-un

https://www.rtbf.be/article/ou-les-inegalites-de-sante-sont-elles-les-plus-elevees-le-nouvel-outil-de-sciensano-et-luclouvain-les-devoile-dans-une-cartographie-11311215

https://trends.levif.be/a-la-une/social/les-personnes-vivant-dans-un-quartier-defavorise-ont-deux-fois-plus-de-risques-de-deceder-prematurement

https://www.lesoir.be/560818/article/2024-01-11/vivre-dans-la-pauvrete-cest-risquer-deux-fois-plus-de-deceder-avant-75-ans

5.3. LEGACY

The ELLIS project and its methodological framework have been the foundation for a series of new initiatives that draw inspiration from its approach:

1. **EBOD-FL, Mapping the environmental burden of disease in Flanders.** Using the comparative risk assessment paradigm, this project aims to determine the Flemish environmental burden of disease in way that ranks the different stressors according to impact. The results can aid the integration of a health perspective into environmental policy, and determine priorities for prevention.
2. **BEST-COST, Burden of disease based methods for estimating the socio-economic cost of environmental stressors.** BEST-COST is a 4-year EU-funded research project which brings together a consortium of 17 partners from Europe and the USA, and is led by Sciensano, the Belgian institute for health. The project sets out to improve methodologies for understanding the socioeconomic cost of environmental stressors, focusing on air and noise pollution. The project will trial new methodologies in five European countries to understand how they can be used at the national level as well as transferred to other countries and other stressors.
3. **BELAIR-POL, Assessing the benefits of air pollution reduction interventions on multi-morbidity and mortality in Belgium.** This project aims to valorise existing Sciensano data sources in an integrated framework to assess the contribution of air pollution to the societal impact of non-communicable diseases, multi-morbidity and mortality in Belgium. The results will allow policymakers to have a deeper insight on the potential health benefits of air pollution reduction policies in Belgium and facilitate the prioritisation of air quality strategies.

6. PUBLICATIONS

1. Otavova M, Faes C, Bouland C, De Clercq E, Vandeninden B, Eggerickx T, Sanderson J-P, Devleesschauwer B, Masquelier B (2022) Inequalities in mortality associated with housing conditions in Belgium between 1991 and 2020. BMC Public Health 22:2397. doi: 10.1186/s12889-022-14819-w
2. Putrik P, Otavova M, Faes C, Devleesschauwer B (2022) Variation in smoking attributable all-cause mortality across municipalities in Belgium, 2018: application of a Bayesian approach for small area estimations. BMC Public Health 22:1699. doi: 10.1186/s12889-022-14067-y
3. Demoury C, Aerts R, Vandeninden B, Van Schaeybroeck B, De Clercq EM (2022) Impact of short-term exposure to extreme temperatures on mortality: a multi-city study in Belgium. Int J Environ Res Public Health 19(7): 3763. 10.3390/ijerph19073763
4. Otavova M, Masquelier B, Faes C, Van Den Borre L, Vandeninden B, De Clercq E, Devleesschauwer B (2024) Trends in socioeconomic inequalities in cause-specific premature mortality in Belgium, 1998-2019. BMC Public Health 24:470. doi: 10.1186/s12889-024-17933-z
5. Otavova M, Masquelier B, Faes C, Van den Borre L, Bouland C, De Clercq E, Vandeninden B, De Bleser A, Devleesschauwer B (2023) Measuring small-area level deprivation in Belgium: the Belgian Index of Multiple Deprivation. Spat Spatiotemporal Epidemiol 45:100587. doi: 10.1016/j.sste.2023.100587
6. Vandeninden B, De Clercq E, Devleesschauwer B, Otavova M, Bouland C, Faes C (2024) Cluster pattern analysis of environmental stressors and quantifying their impact on all-cause mortality in Belgium. BMC Public Health 24:536. doi: 10.1186/s12889-024-18011-0

7. Vandeninden B, De Clercq E, Devleesschauwer B, Otavova M, Masquelier B, Fierens F, Faes C, Bouland C (2025) Impact assessment of local traffic interventions on disease burden: A case study on paediatric asthma incidence in two European cities. J Transp Health, 40: 101953. doi: 10.1016/j.jth.2024.101953
8. Vandeninden B, Bouland C, Devleesschauwer B, Vanpoucke C, Hooyberghs H, Otavova M, Faes C, De Clercq EM. Implications of spatial and seasonal air pollution patterns, socioeconomic disparities, and 15-minute communities for achieving WHO air quality guidelines. Sci Rep, under review.
9. Otavova M, Masquelier B, Faes C, Bouland C, De Clercq EM, Vandeninden B, Devleesschauwer B, Schluter BS. Spatial variation in cause-specific premature mortality and its association with socioeconomic deprivation in Belgium from 2000 to 2019. Arch Public Health. Under review
10. Vandeninden B, Devleesschauwer B, Otavova M, Faes C, Bouland C, De Clercq EM. Quantifying the urban and transport planning related disease burden in three Belgian cities. Journal of Public Health. Under review.
11. Otavova M, et al. Uncovering socioeconomic disparities in modal age at death and its dispersion in Belgium since 2000. In preparation.

7. ACKNOWLEDGEMENTS

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- IRCEL-CELINE
- Leefmilieu Brussels
- Omgeving Vlaanderen
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