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Exposome Factors Associated with Multimorbidity in Older Adults: An Exploratory Cross-Sectional Analysis in the Longitudinal Ageing Study Amsterdam

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Glossary

Term	Acronym	Definition
Built Environment	BE	The entirety of human-made structures, landscapes, and amenities within a community, encompassing buildings, roads, sidewalks, greenery such as parks, public transportation, and other infrastructural elements.
European Union	EU	Economic and political union between 27 European countries.
Geoscience and Health Cohort Consortium	GECCO	A Dutch infrastructure to support researchers to study the relation between environmental characteristics and health enriching 25+ renowned and on-going large-scale Dutch cohorts (1).
Longitudinal Ageing Study Amsterdam	LASA	Initiated by the Ministry of Health, Welfare and Sport in 1991, LASA is a scientific study that focuses on predictors of ageing such as physical, emotional, cognitive, and social functioning in late life, the connections between these components, how they change with the course of time, and the consequence of these changes (2).
Multimorbidity	-	The co-occurrence of two or more NCDs in an individual (3,4).
Non-communicable Diseases	NCDs	Also known as chronic diseases, tend to be of long duration and are the result of a combination of genetic, physiological, environmental, and behavioural factors (5).
Older Adult	-	An older adult in this study is defined as a person who is 65 years of age or older.
Physical Activity	-	Any bodily movement produced by skeletal muscles that requires energy expenditure, including during leisure time, for transport to get to and from places (6).
Physico-Chemical Environment	PC	The physical and chemical elements present in the environment such as temperature, and presence of air and noise pollutants.
Sensitivity Analysis	SA	The exploration of robustness and consistency of study findings. In this study, this included altering the buffer area for exposure measurement, stratification by sex and age groups, analyses using non-imputed data, and a Bonferroni correction.
Sociodemographic Environment	SocDemo	Social and demographic characteristics at a neighbourhood level that encompasses factors such as age distribution, marital status, and neighbourhood income indicators.
Variance Inflation Factor	VIF	A measure to quantify the extent of multicollinearity among exposure variables in a statistical model.
World Health Organization	WHO	A United Nations agency that connects nations, partners, and people to promote health, keep the world safe and serve the vulnerable, so everyone, everywhere, can attain the highest level of health.

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Abstract

Exposome Factors Associated with Multimorbidity in Older Adults: An Exploratory Cross-Sectional Analysis in the Longitudinal Ageing Study Amsterdam

Background: Ageing populations and longer life expectancies strain healthcare systems due to the rising prevalence of noncommunicable diseases (NCDs) and multimorbidity. Understanding the influence of environmental factors on NCD prevalence is crucial.

Objectives: The study employs the exposome framework to investigate how built, physico-chemical, and contextual sociodemographic environmental domains associate with NCDs and multimorbidity in older adults. It aims to explore these relationships while considering individual sociodemographic variables such as age, sex, education, and income, and to identify associations across different demographic groups.

Methods: Data from 1,465 older adults from the Longitudinal Ageing Study Amsterdam cohort, wave 2008-2009, matched with environmental data from the Dutch Geoscience and Health Cohort Consortium, were analyzed. Unordered multivariate multinomial regression analyses were conducted for each environmental domain and in a comprehensive model, adjusted for sociodemographic variables. Subsequent comprehensive sensitivity analyses were performed.

Results: Descriptive statistics revealed an average age of 72.8 years, female predominance (55%) with an even distribution among education categories and the majority falling within the high household income group. Most respondents reported having two or more NCDs. Multivariate multinomial regression analyses showed an association of increased greenery density and lower odds of singular NCDs (OR: 0.51, 95% CI: 0.34 – 0.77), proximity to essential services like general practices trended with lower multimorbidity, reduced air pollutant exposure, and favorable conditions such as optimal temperatures and attractive destinations in reducing NCD prevalence, with individual sociodemographic factors playing a crucial role.

Conclusion: This study emphasizes the importance of employing the exposome framework to comprehensively explore the relationship between environmental exposures and NCD prevalence among older adults. The findings provide insights for future research in similar contexts and inform urban planning and public health interventions aimed at reducing NCD prevalence to promote healthy ageing.

Keywords: Environmental characteristics, Noncommunicable disease, Exposome framework

1 Background

1.1 The Dual Ageing Dilemma: Impact on Healthcare Systems

As individuals age, there is an increasing strain on healthcare systems, necessitating greater reliance on medical intervention and long-term care (7). The impact of ageing on healthcare systems is exacerbated by the phenomenon of “dual ageing”, a simultaneous increase in the proportion of older adults in a population and a longer life expectancy of individuals. In 2020, the global population aged 60 years and older stood at 1 billion. By 2050, it is projected to double to 2.1 billion people, resulting in the proportion of older adults worldwide rising to 22%, up from 12% in 2015 (8). Similarly, in the European Union (EU), the number of older adults is forecasted to continue increasing, reaching 129.8 million inhabitants by 2050 (9). Countries like the Netherlands are also experiencing a significant demographic shift with a notable rise in their ageing population (10).

1.2 Multimorbidity in Older Adults

As the older adult population grows, healthcare systems will also experience an increased strain due to the growing prevalence of non-communicable diseases (NCDs) and multimorbidity among older adults (11). Multimorbidity, defined as the co-occurrence of two or more NCDs, is linked to greater health services utilization, reduced quality of life, and higher mortality rates in comparison to no NCD (3,4,12). In the Netherlands, a study by van Oostrom et al. demonstrated that multimorbidity is common in the Dutch context, especially among women, in higher age groups (13). Even so, there is suspicion of underdiagnosis and underreporting, leading to an underestimation of the true prevalence of multimorbidity (13). This impending issue of dual ageing highlights a challenge for healthcare systems worldwide as they cope with the implications of an increasingly older adult population living longer lives.

1.3 Increase in Urban Migration

In addition to this demographic shift, we are experiencing a great migration to urban areas, with 55% of the world’s population living in cities as of 2018, projected to rise to 68% by 2050 (14). This, along with global population growth, could add an additional 2.5 billion people to urban areas by 2050 (15). Although many rapidly urbanizing cities worldwide have a youthful demographic, the population of older adults residing in these areas is steadily increasing (15). These shifts present unprecedented challenges, particularly regarding the environments older adults inhabit, and require proactive measures.

1.4 The Exposome Framework

There is growing recognition that solely relying on the healthcare system to address age-related health issues is both unsustainable and inadequate. Environmental factors emerge

as pivotal upstream drivers of health and well-being, impacting multimorbidity prevalence of older adults (16). Understanding these upstream determinants of healthy ageing is imperative to relieve the strain on the healthcare system and ensure the ongoing welfare of older adults. To explore these factors effectively, the exposome framework is essential to employ a holistic approach (17). The exposome framework utilizes a life-course approach aimed at comprehensively understanding real-life exposures of all types. These exposures range from individual-level factors such as age and psychosocial stress to broader population-level factors like climate, air quality, built environment, and social capital (17–20).

For this study, the exposome will be categorized into three domains: the built environment (BE) representing amenity composition and proximity to services; the physico-chemical (PC) environment, encompassing the intangible chemical, temperature and noise agents; and the sociodemographic (SocDemo) such as neighbourhood-level income and demographic composition (21), adjusted for individual SocDemo factors, age, sex, education level and monthly household net income. The exposome framework offers guidance into the exploration of the intricate relationship between the environment and healthy ageing (22).

1.5 International Efforts to Promote Age-Friendly Environments

As life expectancies and urbanization accelerate, there has been international motivation and organization to improve the health of older adults by creating age-friendly cities that aim to promote active and healthy ageing for them (23). The WHO Global Age-Friendly Cities guide established in 2007 was crucial in initiating this effort (23). The WHO defines an age-friendly environment as one that fosters “healthy, active ageing by building and maintaining intrinsic capacity throughout the life-course” (24). Alongside this initiative, the United Nation’s Decade of Healthy Ageing, established in 2017, prioritizes communities that foster the abilities of older people (24).

1.6 The Link Between the Built Environment and Health Outcomes

Understanding upstream determinants of health and well-being, particularly the relationship between the environment and the individual, is crucial. Creating health-promotive, age-friendly environments significantly impacts disease dynamics and overall health (25).

Variability exists in the definition of the BE across literature sources, however, it can be summarized to the entirety of human-made structures, landscapes, and amenities within a community, encompassing buildings, greenery such as parks, public transportation, and other infrastructural elements (26–31). The BE plays a vital role in shaping the physical context where people live, work, and engage in activities (29).

The BE can influence individual feelings and behaviours, including physical activity levels and dietary choices (31–33). Research in public health and urban planning has focused on the link between the BE and NCDs through increased physical activity (31). The BE is a critical determinant of physical activity levels for older adults, whose mobility and health outcomes are strongly influenced by their surroundings, especially as they spend more time at homes and in their communities (25,34,35). A study found that 76.5% of older adults' physical activity occurred in their immediate neighbourhood (36). Despite this, most research on physical activity and the BE has focused on working-age adults, even though ageing significantly increases the importance of BE due to declines in functioning (34,37).

In addition to physical activity, the BE can also influence dietary behaviours through accessibility to healthy foods and the exposure to unhealthy food environments (31). A systematic review found that 80% of the studies reviewed identified at least one significant association between the community food environment and obesity (50). Adapting the food environment to provide proximal access to healthy options encourages individuals to adopt more healthful diets (39).

1.7 The Physico-Chemical Environment

The PC environment includes intangible agents that impact health outcomes primarily through harmful environmental stressors such as air quality, noise pollution, and extreme temperatures (31,32,40). The WHO identified several air pollutants, including environmental smoke, transport and industrial-related as being linked to numerous health issues such as cardiovascular disease, cancer, and increased mortality (32,41,42). Higher concentrations of particulate matter with a diameter of 2.5 micrometers ($PM_{2.5}$) are associated with increased multimorbidity, particularly in urban areas (40). Excessive and persistent noise, particularly in densely populated residential areas, can increase stress, disrupt sleep and lead to social withdrawal and poor mental wellbeing (43). Extreme temperatures from urban heat islands can increase mortality rates, especially among those with pre-existing health conditions (44). Further research is needed to understand how these environmental stressors affect multimorbidity in older adults, in combination with other exposome factors.

1.8 The Sociodemographic Environment

Key community features from the WHO Global Age-Friendly Cities guide – respect and inclusion, and social participation – are essential for creating a supportive environment for older adults (24). Several studies highlight the role of individual SocDemo factors in the relationship between the BE and health outcomes (45–47). Self-selection bias is a potential concern, as individuals with higher socioeconomic status tend to choose neighbourhoods with greater walkability and amenities like greenspace and parks, which correlate with higher

land values (47,48). Conversely, individuals with lower socioeconomic status may be forced to live in less affluent neighbourhoods due to external factors (49). Hence, the observed effects linking environmental factors and health outcomes may be influenced by underlying SocDemo factors. Previous studies have found associations between individual SocDemo factors and lifestyle behaviours that may increase obesity (50). However, there is insufficient evidence directly linking contextual SocDemo factors – such as neighbourhood-level age groups, immigration status, and income levels – to multimorbidity, despite a plausible connection (50). A comprehensive approach that examines various contextual SocDemo environmental factors alongside the BE and PC factors is necessary to fully understand the complexities of the association with multimorbidity.

1.9 Research Gaps

A scoping review highlighted limited evidence on environmental determinants in multimorbidity studies, with most focusing on biological or clinical factors (28). Previous research on the BE typically targets specific diseases or prioritizes physical activity outcomes, rather than multimorbidity (47,51). Employing the exposome framework in our study allows us to consider a wide range of exposures. While environmental health research often examines factors in isolation, the exposome framework emphasizes the need to explore combined effects of BE, PC, and contextual SocDemo factors.

Our study aims to address this research gap by utilizing readily available high-resolution data on 35 different environmental factors in the Netherlands (**Table 1**) (52). This comprehensive approach, which mirrors real-life exposures, enables a discovery-based analysis to identify specific environmental factors associated with the prevalence of NCDs and multimorbidity in older adults, offering a promising avenue for investigating these conditions and providing insights into the promotion of healthy ageing (53). We propose a cross-sectional study to investigate the nuanced association between the built, PC, and contextual SocDemo environment and the prevalence of NCDs and multimorbidity in older adults. The research aim is further broken down into the following objectives.

1.10 Objectives

1. Examine the relationship between built, PC, and contextual SocDemo environmental exposures and prevalence of NCDs and multimorbidity among older adults, while controlling for age, sex, educational attainment, and monthly household net income.
2. Investigate potential variations in the association between environmental exposures and health outcomes across different demographic groups through stratified analyses by sex and age groups.

1.11 Work Conditions and Contributions

This research was conducted within the esteemed Department of Epidemiology and Data Science at the Amsterdam University Medical Center (AUMC) in Amsterdam, The Netherlands, as a hybrid position. Renowned for its pioneering scientific research and dedication to educating the next generation of healthcare professionals, AUMC provided an ideal setting for this study. The project was carried out under the expert supervision of Dr. Jeroen Lakerveld and Dr. Bram Berntzen. Diana Juanita Mora played a central role in conducting a review of the literature, managing, and manipulating data, performing analyses, and writing the manuscript, all under the guidance and mentorship of both supervisors.

Dr. Jeroen Lakerveld, an associate professor at AUMC, brings a wealth of expertise to the project with a background in physiotherapy and public health research, with a Ph.D. focused on NCD prevention, now focusing on environmental determinants of lifestyle behaviors and NCD risk. Dr. Bram Berntzen, a post-doctoral fellow at AUMC, obtained his Ph.D. in Population Health from the Obesity Research Unit at the University of Helsinki. His current research explores the obesogenic environment and its intricate relationship with demographics and lifestyle behaviours.

2 Methods

2.1 Study Design and Participants

We undertook a cross-sectional examination of the LASA cohort with the Dutch Geoscience and Health Cohort Consortium (GECCO) (52,54). LASA represents a cross-sequential cohort study spanning nearly three decades, comprising older adults aged 55-85 years, situated in three distinct geographical regions across the Netherlands, encompassing the environs of Zwolle, Oss and Amsterdam (55). This selection was deliberate, aiming for a comprehensive portrayal of the older Dutch population, inclusive of individuals from both urban and rural areas, as well as varying religious affiliations, including Protestant, Catholic, and secular communities (56). The research adhered to the principles of the Declaration of Helsinki and obtained approval from the medical ethics committee of the VU Medical Center (56,57).

The analysis for this study utilized data from LASA wave G, collected during 2008-2009, with respondents' residential addresses matched to GECCO environmental data, ensuring a precise approximation of their environmental exposures. Notably, wave G comprises respondents from both the original baseline cohort 1 and cohort 2, representing a "new" generation of older people. All participants provided informed consent prior to their involvement in the study.

The source population for the study comprised of 2,165 individuals, among whom 242 had deceased prior to approach, 70 refused participation, 28 were deemed ineligible, and 7 were not contacted, yielding in data from a total of 1,818 respondents, resulting in an 84% response rate, with attrition primarily attributable to mortality. Of these 1,818 respondents, 1,484 completed a self-administered lifestyle questionnaire, resulting in a final analytical sample size of 1,465 respondents correctly geo-matched to the GECCO database.

2.2 Data Collection

Respondents were visited at every measurement cycle at home by trained interviewers or interviewed via telephone when a face-to-face interview was not feasible (55). LASA data collection includes questionnaires and clinical tests across four domains: physical, cognitive, emotional, and social functioning, which involves a main interview, a self-administered questionnaire, and a subsequent medical interview including clinical measurements and blood samples (55).

2.3 Variables

2.3.1 *Exposure Measures*

Leveraging available data and insights from previous studies, we explored 35 exposome factors from GECCO, encompassing the built (14 factors), the PC (12 factors), and the SocDemo environment (9 factors), utilizing a variety of variables to represent these factors (**Table 1**)**.** Each exposure has a map resolution, with the residential address used as a centroid for the measurement of most exposures (**Table 1**). Other exposures were measured and linked to participants based on the administrative neighbourhood. Lastly, neighbourhood income exposures were defined by four-digit postal code areas, meaning an area of approximately 4,340 residents. Various BE factors had two Euclidean buffer measurements of 0.5 km and 1 km around the residential addresses of the participants. This study will include analysis of these factors with a 0.5 km buffer area, with the 1 km buffer area explored in the sensitivity analysis (SA). Further descriptions of the environmental exposures can be found in **Table 1**.

2.3.2 *Outcome Measures*

The outcome variable and socio-demographic variables utilized in this study were sourced from the LASA cohort. Multimorbidity was ascertained from participant self-reports of NCDs, categorized into three distinct groups: absence of NCD, presence of one NCD, and presence of two or more NCDs. Participants were queried regarding chronic illnesses or persistent symptoms lasting for a minimum of three months, along with conditions necessitating

medical intervention or continual monitoring by a healthcare professional. Included conditions were determined based on their prevalence in the Netherlands (**Table 2**).

2.3.3 *Covariates*

The following individual SocDemo factors were considered as potential confounders in this study: age, sex (female/male), educational attainment, and household income status (58). Age was maintained as a continuous variable for the primary analysis, while for the SA, age was categorized into two groups: individuals aged 60 to 71 years and those aged 72 to 100 years, using the median age as the upper limit of the first group. Based on the Dutch education system and transition to the labour market, three levels of education were defined: low (elementary education or less), middle (general intermediate, and lower vocational education), and high (university, college, higher vocational, general secondary, and intermediate vocational education).

Respondents reported their household income by selecting from 24 income range categories. For those with a partner, combined household income was provided. To ensure consistency, median incomes were calculated for each category. The highest income category ("5,446 € or more") was standardized using a similar spread observed in lower categories. Upper bounds were determined accordingly, facilitating accurate median calculation. To adjust for partner incomes, a standardization factor of 0.7 was applied based on Dutch state pension ratios. Household incomes were then categorized as low (<1,135 €), middle (1,135 €–1,816 €), and high (>1,816 €), with the middle category representing the Dutch net modal household income of 2007. Further details on individual SocDemo factors, can be found in **Table 2**.

Table 1. Description of Exposure data and Sources

Environmental Exposures	Description	Resolution
Built Environment		
Neighbourhood food environment index (2 variables)	The Food Environment Healthiness Index assesses food retailer healthfulness. Food retail outlets were assigned values of -5 (very unhealthy) to +5 (very healthy), followed by a Z-score calculation, for 0.5 km and 1 km buffer areas (1).	25x25m
Green space (2 variables)	Green space density obtained by aggregating Z-scores of land use data of trees, shrubs, and low vegetation, for 0.5 km and 1 km buffer areas (1).	25x25m
Land use mix (2 variables)	Land Use Mix Entropy Index was calculated as the sum of Z-scores of different land use classes: residential, commercial, social-cultural services,	25x25m

	offices and public services, green space and recreation, for 0.5 km and 1 km buffer areas (59).	
Accessibility of public transport (2 variables)	Density of public transport stops assessed as the sum of the Z-scores of the public transport network in the Netherlands (bus, ferry, metro, taxi, tram), for 0.5 km and 1 km buffer areas (1).	25x25m
Accessibility of sport facilities (2 variables)	Density of sport accommodations calculated as the sum of Z-scores for sports requiring significant physical effort, for 0.5 km and 1 km buffer areas (1).	25x25m
Neighbourhood walkability index (2 variables)	Dutch Walkability Index integrated seven components: population density, retail and service destination density, land-use mix, street connectivity, green space, sidewalk presence, and public transport density, subsequently summed and normalized to a score 0-100, higher values indicating higher walkability, for 0.5 km and 1 km areas (60).	25x25m
Parking pressure	Ratio of registered cars and parking places.	100x100m
Paid parking	Percentage of paid parking places in 1 km buffer.	100x100m
Urbanisation degree	Urbanisation level based on residential density: 1 = Very highly urban ≥ 2,500 addresses; 2 = Highly urban 1 500–2 500 addresses; 3 = Moderately urban 1,000–1,500 addresses; 4 = Less urban 500–1,000 addresses; 5 = Non-urban < 500 addresses, subsequently categorized into High Urban, Moderate Urban, and Non-urban (59).	Administrative neighbourhood
Driving destination accessibility index	Ease of reaching different types of destinations by car, based on a weighing system for areas that are more suitable for active transportation or walking. Index values were normalised to a scale of 0 (low drivability) to 100 (high drivability).	100x100m
Distance to long-distance public transport train station	Distance (km) to the closest train station.	100x100m
Distance to motorway exit	Distance (km) to the closest motorway exit.	100x100m
Accessibility of jobs	Road travel time (in hours) to access 100,000 jobs.	100x100m
Accessibility of neighbourhood facilities (8 variables)	Distance (km) to the nearest medical, recreational, or educational facilities in the neighbourhood (59).	Administrative neighbourhood
Physico-chemical Environment		
Air pollutants ($\mu g/m^3$)	Annual average concentrations of air pollutants modelled by Land-Use-Regression models (data source ESCAPE) (61,62) and a combination	

	of dispersion model calculations and measurements (data source RIVM) (1).	
Ammonia (NH_3)	Dispersion model and measurements.	1x1km
Benzene (C_6H_6)	Dispersion model and measurements.	
Ozone (O_3)	Dispersion model and measurements.	
Soot (EC)	Dispersion model and measurements.	
Sulphur dioxide (SO_2)	Dispersion model and measurements.	
NO_2	Land-Use-Regression model.	Point density
NO_x	Land-Use-Regression model.	
PM coarse	Land-Use-Regression model.	
PM10	Land-Use-Regression model.	
PM2.5	Land-Use-Regression model.	
Summer temperature (4 variables)	Monthly temperature (C^o) data (June-September) were interpolated based on 10 automatic monitoring stations (1,63,64).	25x25m
Traffic noise	Daily levels of noise (road, rail and air) were modelled and expressed as Lden (Level day-evening-night) in decibels (dB(A)) (65).	25x25m
Sociodemographic Environment		
Age groups (4 variables)	Shares of residents aged 0-14, 15-24, 25-44, 45-65 and 65+ years (%).	Administrative neighbourhood
Marital status (4 variables)	Shares of single, married, divorced, widowed residents in neighbourhood (%).	Administrative neighbourhood
Liveability score	Neighbourhoods categorised into liveability classes: 1 = Very insufficient to 9 = Excellent, and recategorized to ≤5 as Poor, and >6 as Good (78).	100x100m
Immigration status (2 variables)	Shares of immigrants from western and non-western countries (%) (67).	Administrative neighbourhood
Migration mobility	Relative migration mobility per 1000 inhabitants.	Administrative neighbourhood
Employment status	Share of employed residents in neighbourhood (%).	Administrative neighbourhood
Household sizes (3 variables)	Shares of one-person households, households with children (%).	Administrative neighbourhood
Home values	Average home values (x1000 €).	Administrative neighbourhood
Neighbourhood income (7 variables)	Percentages of residents with high (above 80th percentile) or low (below 40th percentile) compared to the national income distribution and incomes per inhabitant (x1000 €). Total ownership of passenger cars and motorcycles and passenger car ownership per household. Presence of households hovering	Four-digit postal code neighbourhoods

	around or below the social minimum income threshold, and home values (x1000 €).	

[a]*More comprehensive details on the meta-data are available via: http://www.gecco.nl/exposure-data-1. Ohanyan et al. (in press). Exposome-Wide-Association-Study of body mass index (BMI) using a novel meta-analytical approach for random forest models.*

Table 2. Description of Outcome and Covariate Variables

Outcome	**Description**
Multimorbidity	Self-report of the following, chosen based on prevalence in the Netherlands: 1) chronic non-specific lung disease (CNSLD), obstructive lung disease (OLD), asthma, chronic obstructive pulmonary disease (COPD), 2) cardiovascular diseases (CA), 3) peripheral arterial disease (PAD), 4) cerebrovascular accident (CVA) or stroke, 5) diabetes mellitus (DM) 6) osteoarthritis (OA) and rheumatoid arthritis (RA), and 7) cancer, with the option to provide two others defined as a disease of which symptoms and/or treatment had been present for at least three months, categorized into no NCDs, one NCD, and two or more NCDs (multimorbidity).
Sociodemographic Variables	**Description**
Age	Age at time of interview (continuous) Age at time of interview (categorical) 60-71 and 72-100 years
Sex	Male/Female
Educational attainment	Respondents' own educational attainment categorized as Low: elementary not completed and elementary education, Middle: lower vocational, general intermediate, and intermediate vocation education, and High: general secondary, higher vocational, college, and university education.
Household Net Income	Monthly household net income categorized into 24 categories, with 5,445 € or more as the highest category. These categories were divided into three main groups: <1,135 €, 1,135-1,816 €, >1,816 €.

[b]*More comprehensive details on the meta-data are available via https://lasa-vu.nl/en/topic-table/.*

2.4 Statistical Analysis

2.4.1 *Missingness*

Data analysis was conducted using R version 4.2.1 with RStudio (68). Missing data patterns were assessed for completeness and randomness before imputation. Most variables had less than 6% missing data, except income level (10.9%), liveability score (22.5%), and neighbourhood food environment index (16.9%). Multivariate imputation by chained equations (MICE) was used to address missingness, retaining individual SocDemo factors like age, sex, and education during imputation, as imputation is performed as a function of the other variables in the dataset. Predictive mean matching was used for continuous variables, while logistic regression or polytomous logistic regression was used for categorical variables, ensuring appropriate imputation strategies.

2.4.2 *Descriptive Analysis*

We used descriptive analysis on the non-imputed data to create a baseline table of the individual SocDemo factors of wave G participants: sex, age, educational attainment, income level, and NCD prevalence. Continuous variables were presented as mean and standard deviation (SD) or median and interquartile range (IQR) – dependent on the distribution of the variable (69), whereas categorical variables were presented as counts and relative frequencies.

2.4.3 *Bivariate Analysis and Multinomial Regression*

The study employed Pearson's Chi-squared test and Kruskal-Wallis rank sum test to compare NCD categories against participant baseline characteristics.

Subsequently, unordered multinomial regression, adjusted for individual SocDemo variables, investigated individual relationships with each exposure (Model A). Further analysis involved separate multivariate unordered multinomial regression for each environmental domain and NCD prevalence, adjusting for individual SocDemo variables (Model B), prior to incorporating all variables into a comprehensive model (Model C). Model outcomes were presented as odds ratios (ORs) and 95% confidence intervals (CIs), comparing presence of singular NCDs and two or more NCDs (multimorbidity) versus no NCD. Given the discovery nature of the analysis, findings should be interpreted tentatively, focusing on effect estimate size, trends, and directionality rather than P values. Multilevel modeling was not pursued due to derived neighbourhoods outnumbering the respondents, as neighbourhoods were based on individual addresses.

2.4.4 *Model Assumptions*

2.4.4.1 Multicollinearity

Multicollinearity was tackled by assessing correlations graphically and statistically. Highly correlated variables (with correlation coefficients above 0.80) were identified and one variable from each pair was retained, prioritizing those with less missing data (70). Variance Inflation Factor (VIF) values were then used to further address multicollinearity, removing variables with VIF values above 10 until all were below this threshold (71).

2.4.4.2 Linearity

To ensure the validity of the multinomial regression analysis, adherence to the assumption of linearity was crucial. This assumption requires a linear relationship between continuous independent variables and the log odds of the dependent variable. To verify this, scatterplots were created, depicting the log odds of binomial outcomes against each continuous exposure. These plots consistently confirmed the presence of a linear association.

2.4.4.3 Influential Points

Outlier values within the dataset were assessed using Cook's distance values as a diagnostic tool. Graphical examination of Cook's distance values revealed no observations exceeding the commonly used threshold of 0.5. Additionally, an alternative threshold of 0.002 was applied based on sample size. Despite identifying influential observations according to this criterion, models adapted without removing these values showed discernible differences in final odds ratios. While ROC curves were plotted and AUC values calculated to assess discrimination ability, the exploratory nature of the analysis led to the decision to retain all values, adhering to the threshold of 0.5 without removal.

2.4.4.4 Independence

The assumption of independence of observations is typically maintained unless the dataset displays hierarchical, time-series, matched pairs, or clustered structures, none of which are evident in our data. Each respondent contributes at most one input per variable, thereby ensuring that observations within the model are not dependent on each other.

2.4.4.5 Model Fitness

Model fitness was evaluated using the likelihood ratio chi-square test, which showed that the full models provided a better fit than the null model across all four analyses. McFadden’s pseudo-R-squared was also used to gauge model fitness.

2.5 Sensitivity Analyses

Sensitivity analyses were conducted to ensure the robustness of findings. These included exploring environmental exposure variables within a 1 km buffer around participant addresses, multivariate logistic regression for individuals with and without NCDs within 0.5 km buffer areas across various environmental domains, comprehensive stratified analysis by sex and age groups (60-71 and 72-100 years of age) within 0.5 km buffer areas and applying the same analytic approach to the entire dataset before imputation. To account for multiple testing, the Bonferroni correction method was employed by dividing the conventional significance level of 0.05 by 35 independent hypothesis tests at the comprehensive model level to derive the Bonferroni-adjusted significance level.

3 Results

3.1 Descriptive statistics

Among the 1,465 respondents, a slight majority were females (55%), with an average age of 72.8 years (**Table 3**). Educational attainment was nearly evenly distributed among levels, with the majority having achieved middle (37%) and high (39%) education levels. However, there was a slightly less uniform distribution observed for household net income levels, with

the majority falling within the high category of more than 1,816 € per month. Regarding NCDs, the analysis revealed that a large share of respondents reported having two or more NCDs (41%), followed by one NCD (37%) and no NCD (23%). The descriptive analysis of environmental exposures can be found in the Supplementary information (**Table S2**).

Both the Chi-squared test and Kruskal-Wallis test revealed significant associations between SocDemo factors (sex, age, educational attainment, and monthly household net income levels) with NCDs (**Table S1**). Further, the proportion of men was highest in the no NCD category with the average age (75.2) being the highest among the two or more NCD category.

Table 3. Baseline Characteristics of Study Participants

Baseline Characteristics	
Characteristic	**Overall N = 1,465 (100%)[1]**
Sex (Female)	802 (55%)
Age	72.8 (8.4)
Educational Attainment	
Low Education	361 (25%)
Middle Education	536 (37%)
High Education	568 (39%)
Monthly Household Net Income	
Low < 1,135 €	303 (23%)
Middle 1,135 € to 1,816 €	482 (37%)
High > 1,816 €	521 (40%)
Noncommunicable Disease Prevalence	
No NCD	333 (23%)
One NCD	536 (37%)
Two or more NCDs (Multimorbidity)	596 (41%)

[1] Mean (standard deviation); n (%)

3.2 Association with Noncommunicable Diseases

The adjusted multivariate multinomial regression analysis explored the relationships between having singular NCDs or multimorbidity versus no NCD, concerning various environmental factors. This analysis was conducted for each exposure (Model A), per environmental domain (Model B) (**Figure 1**, **Figure 2**, **Figure 3**, **Figure 4**, **Figure 5**, **Figure 6**), and in a comprehensive environmental model (Model C), incorporating 35 variables (**Figure 7**, **Figure 8**). Adjustments were made for individual SocDemo factors including sex, age, educational attainment, and monthly household income level. Consistent associations were observed among each domain model and the comprehensive model, albeit with some contrasting trends.

3.2.1 Built Environment Domain

The BE model examined 13 variables concerning the presence of singular NCDs (**Figure 1**) and multimorbidity (**Figure 2**) compared to no NCD. While many BE variables showed no association, certain trends were noticeable. In Model B, an increase in distance to general practice (OR: 1.12, 95% CI: 0.86 – 1.45) trended with greater odds of multimorbidity (**Table S3**). This was also observed in Model C (OR: 1.29, 95% CI: 0.96 -1.73), with a slight trend for singular NCDs (OR: 1.07, 95% CI: 0.80 – 1.43) (**Table S6**), particularly among males (**Table S13**), and among those aged 72-100 for multimorbidity (**Table S14**). There was an increasing trend in odds for singular NCDs (OR: 1.12, 95% CI: 0.94 – 1.33) and multimorbidity (OR: 1.11, 95% CI: 0.92 – 1.34) with an increase in distance to daycare centres (**Table S3**). The trend was maintained in Model C and in the logistic regression SA (**Table S6**, **Table S9**, **Table S12**).

Longer distances to long-distance public transport stations trended towards a reduced odds of singular NCDs (OR: 0.96, 95% CI: 0.93 – 1.00) and multimorbidity (OR: 0.96, 95% CI: 0.93 – 1.00) in Model B, and maintained in Model C (**Table S3**, **Table S6**). Similarly, an increased distance to libraries trended towards decreasing the odds of singular NCDs (OR: 0.94, 95% CI: 0.80 – 1.11) and multimorbidity (OR: 0.90, 95% CI: 075 – 1.08) (**Table S3**). This trend was maintained in Model C (**Table S6**). These trends remained present in the logistic regression SA (**Table S9**, **Table S12**).

Notably, in Model B, a higher density of green space at a 0.5km buffer was associated with a decreased odds in both singular NCDs (OR: 0.54, 95% CI: 0.37 – 0.79) and multimorbidity (OR: 0.78, 95% CI: 0.55 – 1.13) (**Table S3**). This association remained in the logistic regression SA for Model B (**Table S9**). Similarly, the association remained present in Model C for a singular NCD (OR: 0.51, 95% CI: 0.34 – 0.77), as well as with multimorbidity (OR: 0.72, 95% CI: 0.48 – 1.05) (**Table S6**), and Model C logistic regression (**Table S12**). This finding is consistent across sexes and stronger for those aged 72-100 (**Table S13**, **Table S14**). This association was also significant when adjusting for multiple testing using Bonferroni's correction. However, this association was no longer present at a 1 km buffer (**Table S7**, **Table S8**).

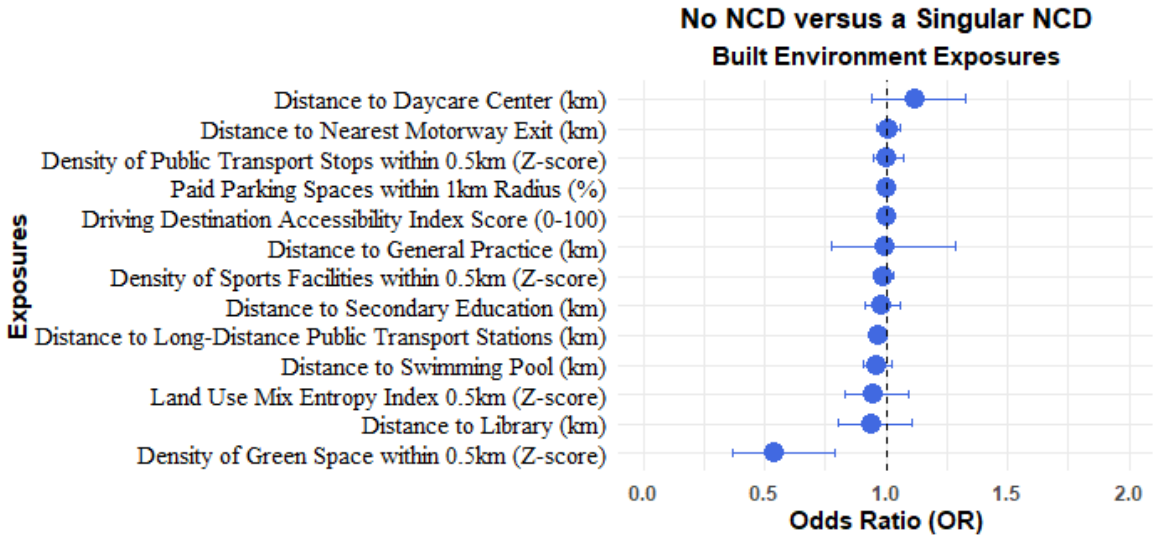

Figure 1. Forest Plot of the Multivariate Multinomial Regression of BE Exposures No NCD vs Singular NCDs

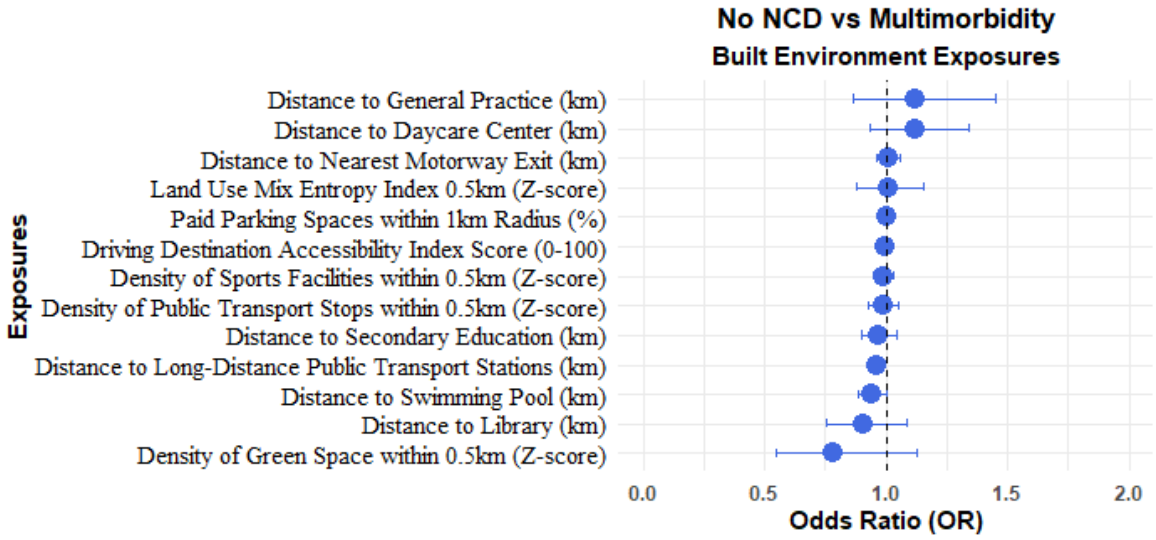

Figure 2. Forest Plot of the Multivariate Multinomial Regression of BE Exposures No NCD vs Multimorbidity

3.2.2 Physico-Chemical Environment Domain

In the PC environment Model B, six variables were explored (**Figure 3**, **Figure 4**). There was a slight increasing trend in odds of both singular NCDs (OR: 1.02, 95% CI: 0.84 – 1.24) and multimorbidity (OR: 1.05, 95% CI: 0.86 – 1.27) with higher monthly temperature (**Table S4**). This trend persisted in the logistic regression SA for Model B (**Table S10**). However, in Model C, higher temperature trended towards a decreased odds of both singular NCDs (OR: 0.83, 95% CI: 0.60 – 1.14) and multimorbidity (OR: 0.76, 95% CI: 0.55 – 1.06) (**Table S6**). Similarly, this was present in Model C of the logistic regression SA (**Table S12**). This trend was observed particularly in males (**Table S13**).

Higher levels of NH_3 were associated with lower odds of multimorbidity (OR: 0.96, 95% CI: 0.91 – 1.00) and a similar trend is observed for singular NCDs as seen in Model B (**Table**

S4). This trend was seen in the logistic regression SA (**Table S10**). Model C has effect estimates closer to the null (**Table S6**), which is similar among Model C in the SA (**Table S12**). As seen in Model B, an increase in $PM_{2.5}$ suggested a decreased odds of singular NCDs (OR: 0.88, 95% CI: 0.68 – 1.13) and multimorbidity (OR: 0.95, 95% CI: 0.72 – 1.21) (**Table S4**). This trend is consistent in the SA, Model B (**Table S10**). However, in Model C, higher PM2.5 trended to increase the odds of both singular NCDs (OR: 1.10, 95% CI: 0.80 – 1.51) and multimorbidity (OR: 1.12, 95% CI: 0.81 – 1.56) (**Table S6**), similarly so in the SA Model C (**Table S12**). The trending association is more apparent for the outcome of multimorbidity among males (**Table S13**).

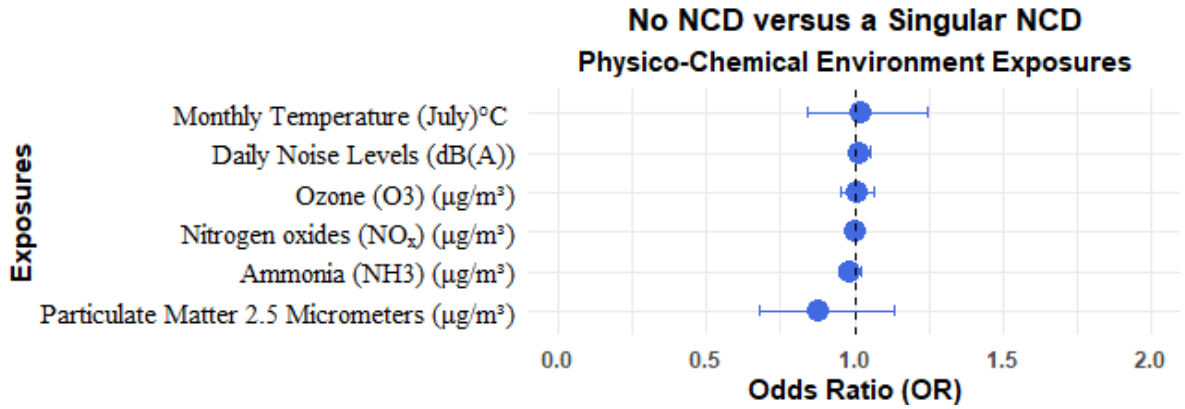

Figure 3. Forest Plot of the Multivariate Multinomial Regression of PC Environmental Exposures No NCD vs Singular NCDs

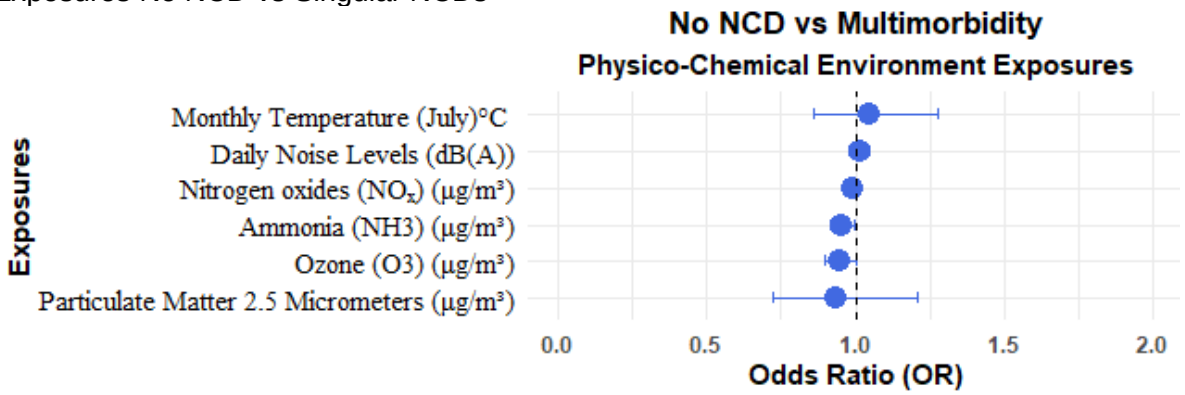

Figure 4. Forest Plot of the Multivariate Multinomial Regression of PC Environmental Exposures No NCD vs Multimorbidity

3.2.3 Sociodemographic Environment Domain

The contextual SocDemo analysis explored 16 variables, with many effect estimates around the null (**Figure 5**, **Figure 6**). There was a decreasing trend in the odds of both singular NCDs (OR: 0.95, 95% CI: 0.92 – 0.99) and multimorbidity (OR: 0.97, 95% CI: 0.93 – 1.01) with an increase in individuals with incomes below or equal to the 40th percentile of the national distribution in Model B (**Table S5**). Conversely, there was a decrease in odds of singular NCDs (OR: 0.96, 95% CI: 0.92 – 1.00) with an increase in individuals with incomes greater or equal to the 80th percentile (**Table S5**). All trends were consistent in Model C

(**Table S6**). Stratification revealed similarities across sex and age for both (**Table S13**, **Table S14**).

Neighbourhoods with a “good” liveability score exhibited a trend towards decreased odds of both singular NCDs (OR: 0.97, 95% CI: 0.61 – 1.53) and multimorbidity (OR: 0.88, 95% CI: 0.56 – 1.38) (**Table S5**). This trend persisted in Model C (**Table S6**) and in Model C SA (**Table S12**). Stratified analysis demonstrated an opposing trend, where a “good” liveability score trended with an increased odds in singular NCDs (OR: 1.28, 95% CI: 0.63 – 2.61) among females (**Table S13**). Moreover, higher household passenger car ownership demonstrated a reduced odds of both singular NCDs (OR: 0.21, 95% CI: 0.09 – 0.52) and multimorbidity (OR: 0.38, 95% CI: 0.16 – 0.93) (**Table S5**). This association was also evident in Model C for singular NCDs (OR: 0.17, 95% CI: 0.05 – 0.54) and multimorbidity (OR: 0.32, 95% CI: 0.10 – 1.01), respectively (**Table S6**), as in the SA Model C (**Table S12**). Stratified analysis showed this association primarily among males (**Table S13**). This association was also significant with Bonferroni’s correction.

Findings from the complete case secondary analysis remained consistent with the primary analysis findings, yielding similar results (**Table S15**, **Table S16, Table S17**, **Table S18**).

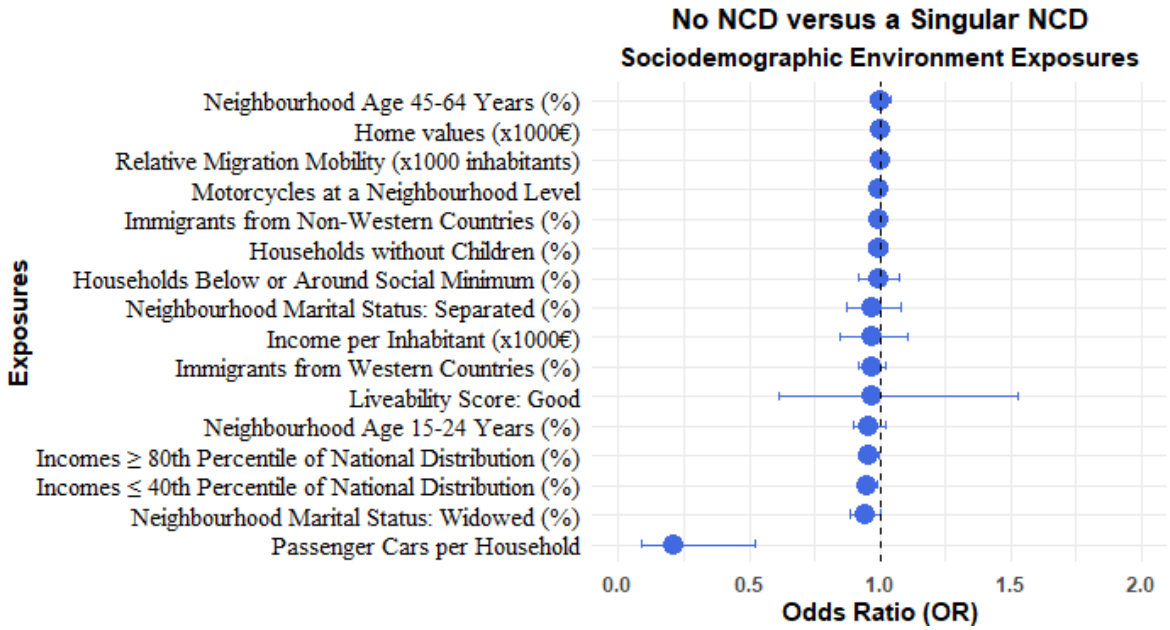

Figure 5. Forest Plot of the Multivariate Multinomial Regression of SocDemo Environmental Exposures No NCD vs Singular NCDs

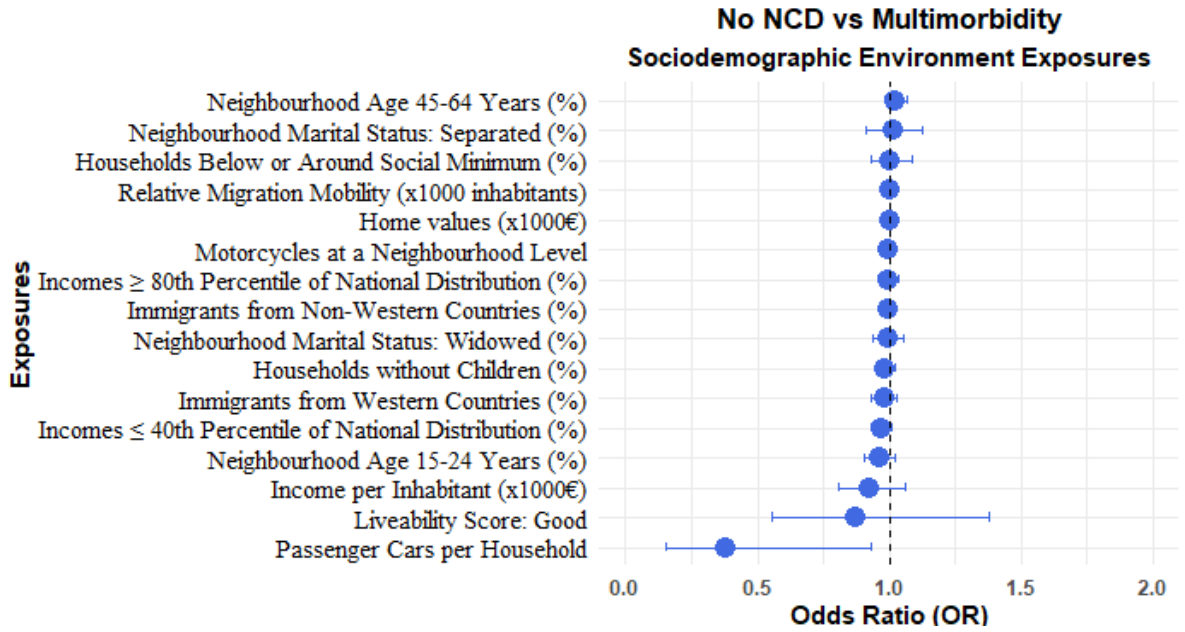

Figure 6. Forest Plot of the Multivariate Multinomial Regression of SocDemo Environmental Exposures No NCD vs Multimorbidity

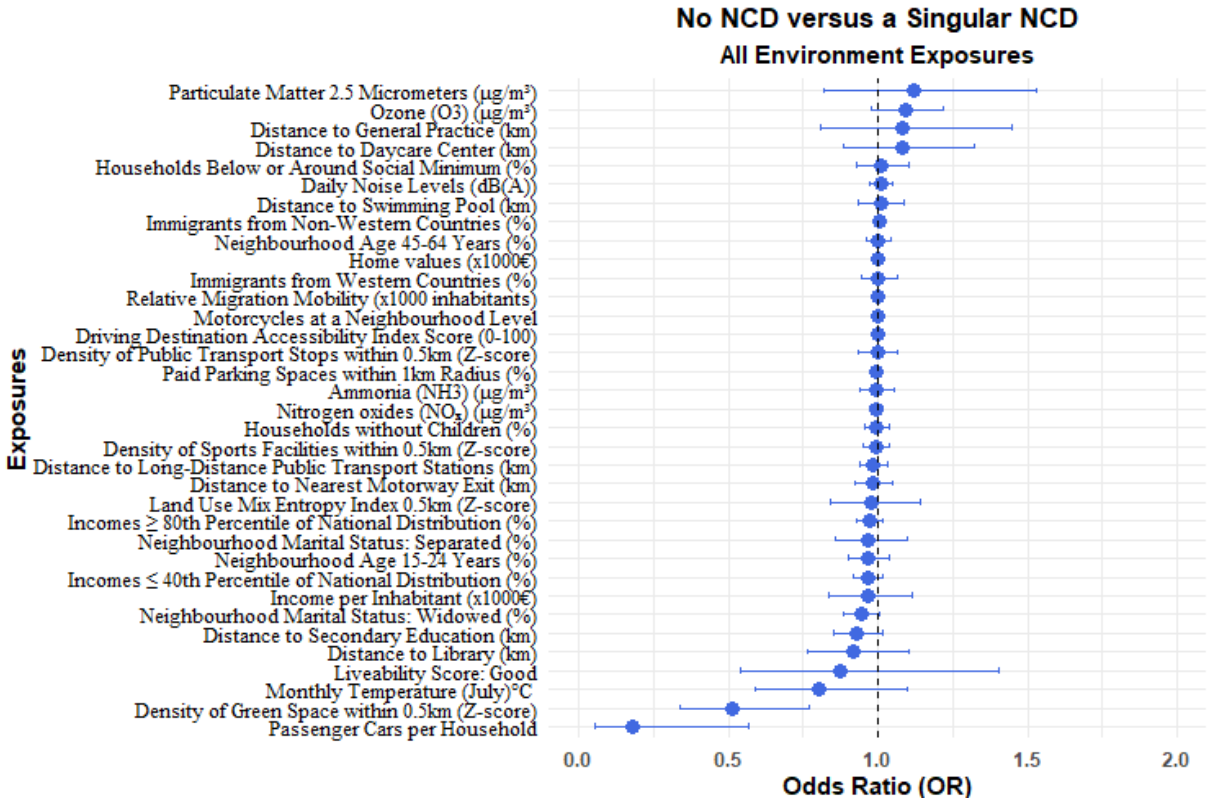

Figure 7. Forest Plot of the Multivariate Multinomial Regression of All Environmental Exposures No NCD vs Singular NCDs

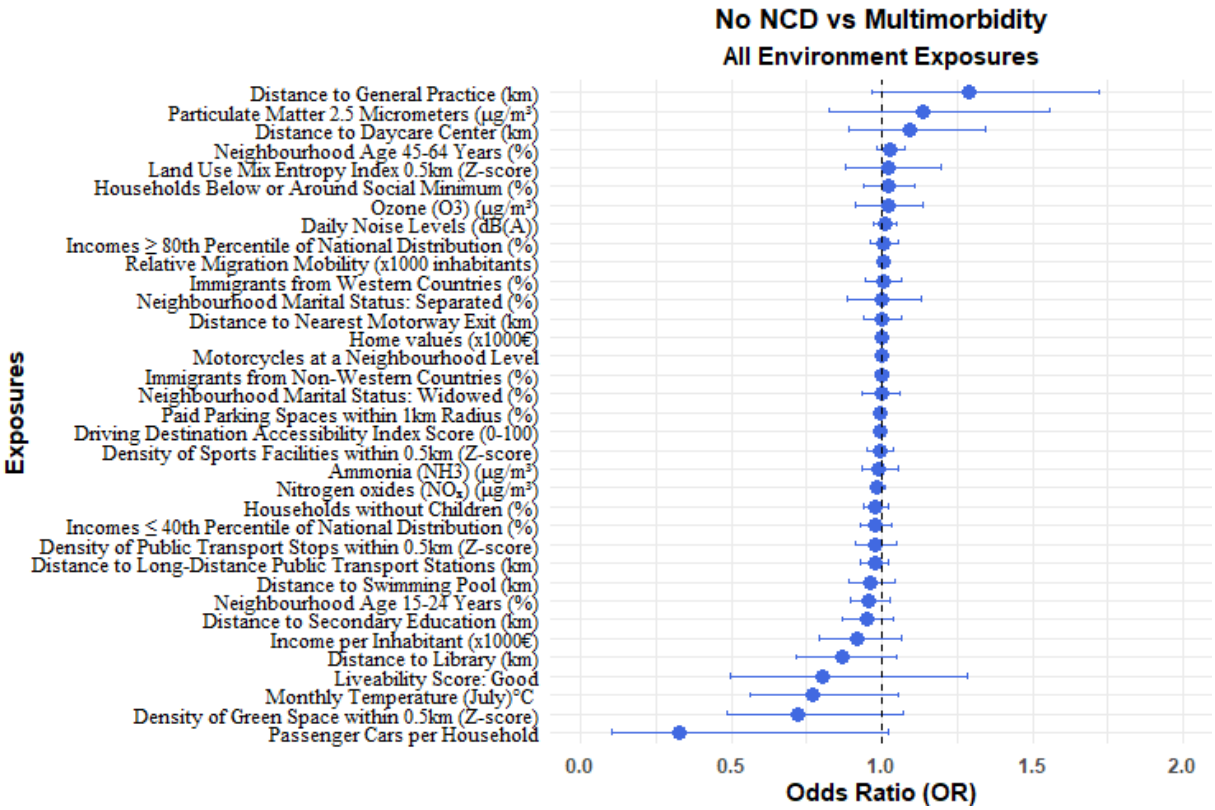

Figure 8. Forest Plot of the Multivariate Multinomial Regression of All Environmental Exposures No NCD vs Multimorbidity

4 Discussion

4.1 Principal Findings

Our study examined environmental exposures within environmental domains and in a comprehensive model, while controlling for individual SocDemo factors to identify trends in association with the prevalence NCDs. The presented analysis yields findings that could generate compelling hypotheses for future research on environmental exposures and NCD prevalence.

4.1.1 *Built Environment Domain*

A primary finding of our analysis was that a higher density of greenery (trees, shrubs, and low vegetation) within a 0.5 km radius of participants' homes was associated with a reduced odds of singular NCDs among older adults, and trending in the same direction for multimorbidity, regardless of sex. This stronger association with a decreased odds in singular NCDs could indicate an increase in greenery density primarily as a prevention measure for NCDs overall, with less protective effects for those already with an NCD to develop a subsequent illness. This association was found to be stronger for those aged 72-100, demonstrating that older aged adults could benefit more from these preventive measures. This effect was also more pronounced at 500 m compared to a 1 km radius, suggesting that older adults, particularly those who are retired or have limited mobility,

commonly among those aged 72-100, would benefit more from greenery in their immediate surroundings (34,35). The presence of greenery in the neighbourhood can encourage physical activity, provide opportunities for social interaction, and mitigate the negative impacts of urban environmental hazards such as air and noise pollution, and heat exposure, ultimately reducing the risk of developing NCDs and multimorbidity (72–75).The association was robust, supported by Bonferroni's correction.

The proximity to various services and facilities also had trending influence with NCD prevalence. Family-friendly cities, advocated by the European Network of Family-Friendly Municipalities, prioritize accessible, high-quality educational, social, and health services near residential areas (76). Increased distance to general practices can create barriers to healthcare access for older adults, potentially leading to health deterioration and onset of NCDs and multimorbidity due to lack of timely support. This trend of increased odds was stronger with the outcome multimorbidity compared to singular NCDs which demonstrates the important role healthcare access may have on preventing the development of subsequent NCDs, especially for older adults aged 72-100 that are at risk of being frailer than their younger counterparts aged 60-71 (77). This association was stronger for males, which could be in relation to the type of NCDs more commonly found amongst men (cancer and COPD) and the care and follow-up required (78). This finding underscores the critical role of healthcare access in managing NCD prevalence among older adults, alongside environmental exposures.

Greater distances to community services like daycare centers trended with higher odds of NCDs and multimorbidity, possibly indicating less family-friendly neighbourhoods lacking essential services for older adults. Conversely, increased distance to libraries, which might encourage walking or cycling, trended with decreased odds of NCDs and multimorbidity. A study from Finland indicated neighbourhood destinations that are appealing to older adults can support physical activity, and therefore decrease the likelihood of NCDs through this physical activity pathway (79).

Furthermore, increased distance to long-distance public transport stations trended to a reduced likelihood of both single NCDs and multimorbidity. This suggests that reliance on long-distance public transportation may not be imperative for older adults. Research conducted in the Netherlands revealed that less than 10% of older adults use public transport (80). In addition, this trend could indicate rural or semi-urban living resulting in residing further from transportation stations, which instead may be offering an increase in density of greenery and less exposure to urban pollutants.

4.1.2 *Physico-Chemical Environment Domain*

PC exposures like higher ammonia levels trended with lower odds of multimorbidity and single NCDs. These emissions have been found to be attributed primarily to agricultural sources (81). Thus, this may reflect the generally better health and cleaner environments experienced by rural residents as previously indicated by Statistics Netherlands (CBS) regarding differences among city and countryside dwellers (82). As for PM2.5, an increase of these particles from fossil fuel combustion, gasoline in cars, and coal used in power plants, trended with higher odds of singular NCDs and multimorbidity once explored in the comprehensive model, consistent with previous studies (83–85). The comprehensive model likely controls for other variables that were confounding the trend in the individual PC domain Model B. The stronger association among males may indicate different level of environmental exposures related to time spent outdoors, regarding gender differences in feelings of safety (86).

As for temperature impact on NCD prevalence, the maximum July temperature of 24.7°C in this analysis does not reach the threshold for extreme heat, as the Dutch National Heat Wave Plan activates at 27°C or higher for four consecutive days (87). Conversely, research indicates that warmer temperatures can benefit older adults by encouraging outdoor physical activity such as walking, which reduces NCD risk (88,89). The stronger trending association with multimorbidity in comparison to a singular NCD could indicate that warmer temperatures encourage physical activity and could prevent subsequent NCDs by supporting older adults to stay active despite currently living with an NCD. This trend was found primarily among males, which could be due to men partaking in physical activity outdoors more commonly than women (90). Given extreme hot and cold temperatures were not part of this study, temperature warrants further investigation due to its known negative health impacts (91).

4.1.3 *Sociodemographic Environment Domain*

As for contextual SocDemo variables, an increase in individuals with incomes below or equal to the 40th percentile trended with decreased odds of both single NCDs and multimorbidity, possibly due to government programs aimed at improving livability in deprived areas (92,93). Likewise, an increase in higher-income residents at a neighbourhood level trended with a decrease in single NCD odds among older adults. Previous research has shown that those with higher socioeconomic status can choose neighbourhoods with favorable characteristics like proximity to services and green spaces, protective against an increased odds of NCD prevalence (94). Similarly, neighbourhoods with a “good” liveability score trended towards a decreased odds of NCD prevalence. However, upon stratification, females demonstrated an increased odds of NCD prevalence with a “good” score. This score, based on several indicators including population composition, social cohesion, public space, safety, resources,

and housing, can potentially not be an accurate assessment of liveability for women (66). Nonetheless, this finding should be further explored in future research, considering gender differences.

Unexpectedly, an increase in passenger cars per household at the neighbourhood level decreased the odds of single NCDs and multimorbidity, particularly among older males. This is likely an indication of living in a more affluent neighbourhood rather than older adults driving or using cars themselves. Car ownership serves as a proxy for higher socioeconomic status as the Netherlands is the third most expensive country in Europe to own a car, considering costs like fuel, tax, insurance, and maintenance (95). This association also functions as a proxy for rural living, which offers health-promotive benefits like safety and cleanliness compared to urban areas (82).

The study's findings highlight the multifaceted influence of environmental and underlying individual SocDemo factors on the prevalence of NCDs among older adults. Key findings highlight the critical role of density of greenery in urban design, proximity to essential services like general practices in relation to multimorbidity, the benefits of countryside versus urban dwelling by mitigating exposure to urban pollutants, and conditions that encourage physical activity such as ideal temperatures and attractive destinations. Although many of the findings yielded non-significant results with small effect estimates, their relevance remains important given the broad reach of environmental exposures, which can impact entire populations. Thus, even minor effects assume importance at a population level. Considering these findings is crucial in advancing our comprehension of NCD prevalence and multimorbidity determinants, ultimately contributing to initiatives aimed at promoting healthy ageing on a broader scale.

4.2 Study Limitations, Strengths, and Future Research

4.2.1 *Methodological Limitations*

The methodological approach adopted in this analysis endeavors to explore real-life exposures and situations by comprehensively exploring all exposures within a per domain and unified model, aligning with the exposome framework. However, this approach is not without its usual challenges. The inclusion of many exposures within the comprehensive model poses challenges related to statistical power. Addressing these issues necessitates a larger sample size to mitigate power concerns.

In addition, certain exposures had to be excluded from the models, such as food environment index, neighbourhood walkability index, and urbanization degree, due to high multicollinearity with other indexes and SocDemo variables, potentially resulting in missed opportunities to uncover relevant findings. Consequently, our methodological approach limits

the exploration of all initially planned exposures. Nonetheless, it facilitates the interpretation of multiple exposures at once—a crucial aspect for real-life scenarios where interventions, such as urban planning, encompass multiple factors simultaneously.

The cross-sectional nature of the study inherently restricts the ability to infer causal relationships as data is captured at a single point in time to where the participant was currently residing at the time of data collection. It is unclear whether the environmental exposures connected to their residential address can directly attribute to their NCD outcomes. Longitudinal studies that utilize this comprehensive model methodology could better understand the dynamic interactions of environmental exposures and NCD development in older adults. Further research would also benefit from disentangling associations between rural-urban dwellings, as it is possible that relevant effect modification exists.

4.2.2 *Differing Methodological Approaches*

Contrasting with our approach, machine learning offers advantages in addressing potential nonlinear associations and handling numerous predictors and multicollinearity. However, its interpretability is compromised by its black-box nature, which obscures the direct understanding of how exposures relate to outcomes. Another alternative, index creation, provides benefits such as reducing the number of predictors, yielding more interpretable models, and mitigating multicollinearity. Nevertheless, the holistic view of indexes may obscure the specific effects of individual exposures, resulting in oversimplification. Additionally, if weights are applied to exposures, this may introduce variability in results, as these weights can be perceived as arbitrary and subjective (96).

4.2.3 *Multimorbidity and its Challenges*

This analysis considered the likelihood of a singular NCD and multimorbidity versus no NCD prevalence among older adults. Multimorbidity, ascertained from self-reporting, is susceptible to reporting bias due to the potential for both over-reporting and under-reporting of NCD prevalence. However, providing participants with a strict definition of what constitutes a NCD likely minimized this bias. Despite these precautions, future studies would benefit from incorporating objective measures to validate self-reported NCDs.

It is important to acknowledge that an already present NCD can influence an individual’s behaviours and, subsequently, their environment exposures. Individuals with multimorbidity, depending on the severity of their conditions, may interact with their environments less actively than those without NCDs. The observation that there is a stronger trend between an increased distance to general practice and multimorbidity, compared to singular NCDs, highlights the critical role healthcare access might play over other environmental exposures.

In contrast, an increase in greenery was found more relevant in reducing the likelihood of singular NCDs. Further, individuals with multimorbidity may be more genetically predisposed to NCDs, possibly making environmental exposures less relevant in their disease outcomes or potentially more sensitivity to milder environmental exposures compared to individuals with singular NCDs (97).

Moreover, future research that categorizes multimorbidity based on groupings of specific types of NCD pairings would further enhance our understanding of the relationship between environmental exposures and the distinct pathophysiology of NCDs. For instance, respiratory NCDs might be more strongly associated with exposure to air pollutants (98), whereas cardiovascular diseases may be influenced greater by the presence of green spaces (99).

While multimorbidity is generally defined as the co-occurrence of two or more NCDs, there is no universally accepted definition (100). This definition, solely based on the numerical count of NCDs, may oversimplify the complexity and varying burden of different NCD combinations and their individual pathophysiology. Thus, future studies should adopt a more nuanced approach to investigating multimorbidity. For example, researchers could explore multimorbidity based on whether NCDs affect the same organ or different organ systems (78). NCDs affecting different organs may require distinct healthcare professionals, diverse medications, which could result in adverse drug interactions and drug-to-disease interactions (78). A definition of multimorbidity that considers the relationships between NCDs and body systems, rather than just the count of conditions, would more accurately reflect the impact of multimorbidity on individual experiences and healthcare systems.

4.2.4 *Study Strengths*

The methodological approach of this study is a key strength, as it aimed to explore real-life comprehensively exposures and situations within the exposome framework. In contrast to previous research endeavours that often examine individual environmental factors in isolation, our approach adopted a broader perspective, capturing an array of exposures in alignment with the exposome framework. This holistic approach allowed for a more nuanced understanding of the complex interplay of multiple exposures. Furthermore, this study's emphasis on NCD prevalence and multimorbidity as the outcome is noteworthy. Previous studies have typically focused on a specific NCD, while our study extends its scope to the broader concept of multimorbidity. Moreover, our analysis contributes to the expansion of existing knowledge regarding NCDs, which has predominantly centered on biological or clinical determinants of disease. This broader conceptualization enhances our understanding

of the multifaceted nature of NCD prevalence and multimorbidity, highlighting environmental factors as relevant determinants.

Additionally, our study conducted sensitivity analyses to further explore environmental exposures, including examining a second buffer measurement of 1 km to identify if trends and associations are still relevant within a greater area. We applied Bonferroni correction for multiple testing to ensure that statistically significant associations were not merely the result of chance, resulting in false positives. Moreover, our exploration of sex and age stratification yielded interesting findings, providing valuable insights that could support the development of more targeted public health interventions. These analyses enhance the robustness of our findings and contribute to a more nuanced understanding of the relationships between environmental exposures and NCD prevalence and multimorbidity.

4.3 Implications for Practice

Given the discovery-based approach of this study, the findings of trends and associations between varying environmental factors and multimorbidity must be further explored in other settings utilizing other study designs to further support the evidence needed to create evidence-informed public health interventions. However, public health professionals and policy makers can consider the findings of potential health benefits of green spaces and reducing barriers such as distance to healthcare, alongside previous research on these determinants, to inform interventions such as urban design that supports healthy ageing. Moreover, SocDemo factors emerge as important underlying determinants of NCD prevalence, indicating the need for social services that address socioeconomic disparities to promote equitable health outcomes among older adults.

5 Conclusion

This study examined the associations between environmental exposures and the prevalence of singular NCDs and multimorbidity among older adults, accounting for individual SocDemo factors. The comprehensive methodological approach revealed associations while adjusting for various environmental factors, but faced challenges such as statistical power and multicollinearity, necessitating larger sample sizes in future research.

Key findings included the presence of increased greenery near older adults associated with a lower odds of NCD prevalence. Additionally, reducing barriers such as distance to healthcare access emerged as a crucial factor, particularly in mitigating the likelihood of multimorbidity. Further, findings underscored the differential outcomes between proxies of rural versus urban dwelling, indicating potential health benefits associated with rural environments. This is crucial to note given the projected migration to urban dwellings

globally. Lastly, SocDemo factors were identified as an important underlying factor influencing NCD prevalence. Moving forward, future studies would benefit from a more nuanced definition of multimorbidity that encompasses the interrelationships between NCDs and organ systems, thereby offering a more comprehensive understanding of their impact on individuals and healthcare systems. As well, it may help to identify environmental exposure associations with NCD prevalence considering the role of rural-urban dwelling.

Overall, this study highlights the importance of considering multiple environmental exposures and SocDemo proxies, aligning with the conceptual exposome framework. This approach advocates for more thorough research, serving as a foundational step for further investigation in countries with similar and divergent contexts. Such research aims to inform urban planning and public health interventions, ultimately striving to reduce NCD prevalence among older adults and promote a proactive approach to healthy ageing.

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Supplementary Information

Table S1. Bivariate Analysis of Baseline Characteristics and NCD Prevalence

Characteristic	No NCD N = 333 (23%)[1]	1 NCD N = 536 (37%)[1]	2 or more NCDs N = 596 (41%)[1]	P value[2]
Sex (Female)	145 (44%)	320 (60%)	337 (57%)	<0.001
Age	69.6 (7.3)	72.2 (8.3)	75.2 (8.3)	<0.001
Education Level				<0.001
Low Education	51 (15%)	129 (24%)	181 (30%)	
Middle Education	119 (36%)	187 (35%)	230 (39%)	
High Education	163 (49%)	220 (41%)	185 (31%)	
Household Net Income Level				<0.001
Low <1,135€	43 (15%)	103 (22%)	157 (29%)	
Middle 1,135€-1,816€	95 (33%)	184 (39%)	203 (38%)	
High >1,816€	154 (53%)	188 (40%)	179 (33%)	

[1] Mean (standard deviation); n (%)
[2] Pearson's Chi-squared test; Kruskal-Wallis rank sum test
NCD: Noncommunicable Disease

Table S2. Descriptive analysis of all Environmental Exposures at Baseline using Median and Interquartile Range

Exposure	**Overall** N = 1465 (100%)[1]
Food Environment Index 0.5 km (Z-score)	-0.13 (-0.19, -0.07)
Density of Green Space within 0.5 km (Z-score)	-0.15 (-0.34, 0.13)
Land Use Mix Entropy Index 0.5 km (Z-score)	2.68 (1.84, 3.51)
Density of Public Transport Stops within 0.5 km (Z-score)	2.43 (0.83, 4.43)
Density of Sports Facilities within 0.5 km (Z-score)	3.82 (1.27, 6.37)
Dutch Walkability Index 0.5 km Score (0-100)	38 (28, 49)
Food Environment Index 1 km (Z-score)	-0.07 (-0.10, -0.05)
Density of Green Space within 1 km (Z-score)	-0.11 (-0.35, 0.20)
Land Use Mix Entropy Index 1 km (Z-score)	2.23 (1.60, 2.74)
Density of Public Transport Stops within 1 km (Z-score)	2.45 (0.90, 4.42)
Density of Sports Facilities within 1 km (Z-score)	3.50 (1.91, 5.09)
Dutch Walkability Index 1km Score (0-100)	33 (23, 44)
Ratio of Registered Cars to Available Parking Spaces	0.5 (0.3, 0.7)
Paid Parking Spaces within 1km Radius (%)	0.1 (0.0, 23.9)
Urbanization Degree	

Non-urban	265 (18%)
Moderate Urban	541 (37%)
High Urban	658 (45%)
Driving Destination Accessibility Index Score (0-100)	33 (33, 36)
Distance to Long-Distance Public Transport Stations (km)	2.1 (1.1, 8.0)
Distance to Nearest Motorway Exit (km)	3.2 (1.6, 8.0)
Road Travel Time to 100,000 jobs (hours)	31.5 (20.5, 41.8)
Distance to General Practice (km)	0.7 (0.5, 1.0)
Distance to Library (km)	1.1 (0.7, 1.8)
Distance to Cinema (km)	5.5 (2.1, 10.9)
Distance to Primary Education (km)	0.5 (0.4, 0.7)
Distance to Secondary Education (km)	2.0 (1.1, 4.5)
Distance to Hospital (km)	6.4 (2.3, 11.1)
Distance to Swimming Pool (km)	1.9 (1.1, 4.0)
Distance to Daycare Center (km)	0.5 (0.4, 0.9)
Benzene (C_6H_6) (μg/m³)	0.6 (0.5, 0.7)
Soot (EC) (μg/m³)	1.0 (0.8, 1.2)
Particulate Matter 2.5 Micrometers (μg/m³)	16.1 (15.8, 17.1)

Particulate Matter Coarse (µg/m³)	8.0 (7.8, 8.5)
Particulate Matter 10 Micrometers (µg/m³)	28.0 (26.6, 30.2)
Sulfur dioxide (SO_2) (µg/m³)	1.0 (0.7, 1.4)
Ammonia (NH_3) (µg/m³)	7.8 (6.2, 10.0)
Nitrogen dioxide (NO_2) 2006 (µg/m³)	22.4 (19.8, 26.1)
Nitrogen oxides (NO_x) (µg/m³)	31.5 (27.0, 39.5)
Ozone (O_3) (µg/m³)	40.5 (38.4, 42.3)
Monthly Temperature (July)°C	23.0 (22.5, 23.5)
Monthly Temperature (June)°C	17.4 (16.9, 17.8)
Monthly Temperature (August)°C	17.3 (16.9, 17.7)
Monthly Temperature (September)°C	18.8 (18.4, 19.3)
Daily Noise Levels (dB(A))	54 (51, 58)
Neighbourhood Age 0-14 Years (%)	17.0 (14.0, 20.0)
Neighbourhood Age 15-24 Years (%)	11.0 (10.0, 13.0)
Neighbourhood Age 25-44 Years (%)	26.0 (22.8, 30.0)
Neighbourhood Age 45-64 Years (%)	27.0 (24.0, 31.0)
Neighbourhood Age 65 Years and Older (%)	15.0 (11.0, 20.0)
Neighbourhood Marital Status: Single (%)	44.0 (41.0, 49.0)

Neighbourhood Marital Status: Married (%)	45.0 (36.0, 49.0)
Neighbourhood Marital Status: Separated (%)	6.0 (4.0, 8.0)
Neighbourhood Marital Status: Widowed (%)	5.0 (3.0, 7.0)
Liveability Score	
Poor	226 (20%)
Good	909 (80%)
Immigrants from Western Countries (%)	7.0 (4.0, 9.0)
Immigrants from Non-Western Countries (%)	5.0 (2.0, 12.0)
Relative Migration Mobility (per 1000 inhabitants)	79 (62, 111)
Households Below or Around Social Minimum (%)	6.0 (4.0, 10.0)
Households with Children (%)	37.0 (28.0, 42.0)
Households without Children (%)	31.0 (25.0, 34.0)
Single-person Households (%)	29.0 (24.0, 46.0)
Home values (x1000€)	227 (191, 283)
Income per Inhabitant (x1000€)	12.1 (11.2, 13.3)
Incomes ≥ 80th Percentile of National Distribution (%)	19.0 (15.0, 27.0)
Incomes ≤ 40th Percentile of National Distribution (%)	39.0 (36.0, 43.0)
Motorcycles at a Neighbourhood Level	90 (50, 155)

Passenger Cars at a Neighbourhood Level	1,030 (550, 1,786)
Passenger Cars per Household	1.0 (0.7, 1.1)
[1] Median (Interquartile Range); n (%)	

Table S3. Adjusted Multivariate Multinomial Regression of BE Exposures and NCDs

	Model A[1]				Model B[2]			
	1 NCD		2 or more NCDs		1 NCD		2 or more NCDs	
Variable	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**
Density of Green Space within 0.5km (Z-score)	**0.54**	**0.39, 0.76**	0.86	0.64, 1.22	**0.54**	**0.37, 0.79**	0.78	0.55, 1.13
Land Use Mix Entropy Index 0.5km (Z-score)	0.96	0.86, 1.06	1.07	0.96, 1.19	0.95	0.83, 1.09	1.01	0.88, 1.16
Density of Public Transport Stops within 0.5km (Z-score)	1.03	0.98, 1.08	1.03	0.98, 1.08	1.01	0.94, 1.07	0.99	0.93, 1.05
Density of Sports Facilities within 0.5km (Z-score)	1.00	0.97, 1.04	1.01	0.97, 1.05	0.99	0.95, 1.03	0.99	0.95, 1.03
Paid Parking Spaces within 1km Radius (%)	1.00	0.98, 1.00	1.00	0.99, 1.79	1.00	1.00, 1.00	1.00	1.00, 1.01
Driving Destination Accessibility Index Score (0-100)	0.99	0.99, 1.01	0.99	0.98, 1.00	1.00	0.99, 1.01	0.99	0.98, 1.01
Distance to Long-Distance Public Transport Stations (km)	0.97	0.94, 1.00	0.96	0.93, 1.78	0.96	0.93, 1.00	**0.96**	**0.93, 1.00**
Distance to Nearest Motorway Exit (km)	0.99	0.96, 1.02	0.98	0.95, 1.01	1.01	0.96, 1.05	1.01	0.96, 1.06
Distance to General Practice (km)	0.93	0.80, 1.08	0.88	0.76, 1.03	1.00	0.77, 1.28	1.12	0.86, 1.45

Distance to Library (km)	0.93	0.83, 1.03	0.90	0.80, 1.01	0.94	0.80, 1.11	0.90	0.75, 1.08
Distance to Secondary Education (km)	0.99	0.97, 1.02	0.98	0.95, 1.00	0.98	0.91, 1.05	0.97	0.90, 1.04
Distance to Swimming Pool (km)	0.98	0.94, 1.02	0.95	0.91, 0.99	0.96	0.91, 1.02	0.94	0.89, 1.00
Distance to Daycare Center (km)	1.03	0.91, 1.16	0.95	0.83, 1.08	1.12	0.94, 1.33	1.11	0.92, 1.34

[1] Model A: Adjusted for age, sex, education, and income, Reference: No NCD
[2] Model B: Adjusted for age, sex, education, and income and all other BE exposures in the domain, Reference: No NCD
Bold represent those with a p-value less than 0.05
OR: Odds Ratio, CI: Confidence Interval
NCD: Noncommunicable Disease

Table S4. Adjusted Multivariate Multinomial Regression of PC Environment Exposures and NCDs

	Model A[1]				**Model B[2]**			
	1 NCD		**2 or more NCDs**		**1 NCD**		**2 or more NCDs**	
Variable	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**
Ammonia (NH_3) (μg/m³)	0.97	0.94, 1.00	0.96	0.93, 0.99	0.98	0.94, 1.02	**0.96**	**0.91, 1.00**
Ozone (O_3) (μg/m³)	1.01	0.96, 1.05	0.98	0.93, 1.02	1.01	0.95, 1.07	0.95	0.90, 1.01
Nitrogen oxides (NO_x) (μg/m³)	1.00	0.99, 1.01	1.00	0.99, 1.01	1.00	0.98, 1.02	0.99	0.97, 1.01
Particulate Matter 2.5 Micrometers (μg/m³)	0.89	0.76, 1.06	0.93	0.79, 1.11	0.88	0.68, 1.13	0.94	0.72, 1.21
Monthly Temperature (July)°C	0.95	0.77, 1.17	1.05	0.85, 1.30	1.02	0.84, 1.24	1.05	0.86, 1.27
Daily Noise Levels (dB(A))	1.01	0.98, 1.03	1.01	0.99, 1.03	1.02	0.98, 1.05	1.01	0.98, 1.05

[1] Model A: Adjusted for age, sex, education, and income, Reference: No NCD
[2] Model B: Adjusted for age, sex, education, and income and all other PC exposures in the domain, Reference: No NCD
Bold represent those with a p-value less than 0.05
OR: Odds Ratio, CI: Confidence Interval
NCD: Noncommunicable Disease

Table S5. Adjusted Multivariate Multinomial Regression of SocDemo Environment Exposures and NCDs

	Model A[1]				Model B[2]			
	1 NCD		2 or more NCDs		1 NCD		2 or more NCDs	
Variable	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**
Neighbourhood Age 15-24 Years (%)	1.01	0.96, 1.05	0.97	0.95, 1.04	0.96	0.90, 1.02	0.96	0.90, 1.02
Neighbourhood Age 45-64 Years (%)	0.98	0.96, 1.01	0.98	0.96, 1.01	1.00	0.96, 1.04	1.02	0.98, 1.07
Neighbourhood Marital Status: Separated (%)	0.99	0.97, 1.00	0.98	0.97, 0.99	0.97	0.87, 1.08	1.02	0.91, 1.13
Neighbourhood Marital Status: Widowed (%)	0.97	0.93, 1.01	0.80	0.97, 1.05	0.94	0.89, 1.00	0.99	0.94, 1.05
Liveability Score								
Poor	—	—	—	—	—	—	—	—
Good	0.82	0.56, 1.19	0.71	0.49, 1.03	0.97	0.61, 1.53	0.88	0.56, 1.38
Immigrants from Western Countries (%)	1.00	0.97, 1.03	1.02	0.99, 1.05	0.97	0.92, 1.02	0.98	0.93, 1.03
Immigrants from Non-Western Countries (%)	1.01	1.00, 1.02	1.01	1.00, 1.02	1.00	0.98, 1.02	0.99	0.97, 1.01
Relative Migration Mobility (x1000 inhabitants)	1.00	1.00, 1.01	1.00	1.00, 1.00	1.00	1.00, 1.00	1.00	1.00, 1.01
Households without Children (%)	0.98	0.96, 1.00	0.97	0.95, 0.99	0.99	0.96, 1.03	0.99	0.95, 1.02

Home values (x1000€)	1.00	1.00, 1.00	1.00	1.00, 1.00	1.00	1.00, 1.00	1.00	1.00, 1.00
Incomes ≥ 80th Percentile of National Distribution (%)	0.98	0.97, 1.00	0.99	0.97, 1.00	**0.96**	**0.92, 1.00**	1.00	0.96, 1.04
Incomes ≤ 40th Percentile of National Distribution (%)	1.00	0.97, 1.02	1.00	0.97, 1.02	**0.95**	**0.92, 0.99**	0.97	0.93, 1.01
Income per Inhabitant (x1000€)	0.95	0.89, 1.01	0.97	0.91, 1.03	0.97	0.85, 1.11	0.93	0.81, 1.06
Households Below or Around Social Minimum (%)	1.03	1.00, 1.06	1.05	1.01, 1.08	0.99	0.92, 1.07	1.01	0.93, 1.09
Motorcycles at a Neighbourhood Level	1.00	1.00, 1.00	1.00	1.00, 1.00	1.00	1.00, 1.00	1.00	1.00, 1.00
Passenger Cars per Household	**0.51**	**0.32, 0.82**	**0.40**	**0.25, 0.65**	**0.21**	**0.09, 0.52**	**0.38**	**0.16, 0.93**

[1] Model A: Adjusted for age, sex, education, and income, Reference: No NCD
[2] Model B: Adjusted for age, sex, education, and income and all other contextual SocDemo exposures in the domain, Reference: No NCD
Bold represent those with a p-value less than 0.05
OR: Odds Ratio, CI: Confidence Interval
NCD: Noncommunicable Disease

Table S6. Adjusted Multivariate Multinomial Regression of All Environment Exposures and NCDs

	Model C[1]			
	1 NCD		**2 or more NCDs**	
Variable	**OR**	**95% CI**	**OR**	**95% CI**
Density of Green Space within 0.5km (Z-score)	**0.51**	**0.34, 0.77**	0.72	0.48, 1.06
Land Use Mix Entropy Index 0.5km (Z-score)	0.97	0.83, 1.14	1.02	0.87, 1.19
Density of Public Transport Stops within 0.5km (Z-score)	0.99	0.95, 1.04	0.98	0.91, 1.05

Density of Sports Facilities within 0.5km (Z-score)	1.00	0.95, 1.04	0.99	0.95, 1.04
Paid Parking Spaces within 1km Radius (%)	1.00	0.99, 1.01	1.00	0.99, 1.01
Driving Destination Accessibility Index Score (0-100)	1.00	0.98, 1.02	0.99	0.98, 1.01
Distance to Long-Distance Public Transport Stations (km)	0.97	0.92, 1.03	0.97	0.92, 1.03
Distance to Nearest Motorway Exit (km)	0.96	0.89, 1.05	1.00	0.92, 1.08
Road Travel Time to 100,000 jobs (hours)	1.01	0.98, 1.04	1.01	0.98, 1.04
Distance to General Practice (km)	1.07	0.80, 1.43	1.29	0.96, 1.73
Distance to Library (km)	0.92	0.77, 1.10	0.86	0.71, 1.04
Distance to Secondary Education (km)	0.93	0.85, 1.01	0.95	0.86, 1.04
Distance to Hospital (km)	1.02	0.94, 1.09	1.00	0.92, 1.07
Distance to Swimming Pool (km)	1.01	0.93, 1.09	0.97	0.89, 1.05
Distance to Daycare Center (km)	1.07	0.87, 1.31	1.09	0.88, 1.34
Ammonia (NH_3) (μg/m³)	0.99	0.94, 1.05	0.99	0.93, 1.05
Ozone (O_3) (μg/m³)	1.07	0.95, 1.20	1.01	0.89, 1.14
Nitrogen oxides (NO_x) (μg/m³)	0.99	0.97, 1.02	0.98	0.96, 1.01
Particulate Matter 2.5 Micrometers (μg/m³)	1.10	0.80, 1.51	1.12	0.81, 1.56
Monthly Temperature (July)°C	0.83	0.60, 1.14	0.76	0.55, 1.06
Daily Noise Levels (dB(A))	1.01	0.98, 1.05	1.01	0.97, 1.05

Neighbourhood Age 15-24 Years (%)	0.97	0.91, 1.04	0.96	0.89, 1.03
Neighbourhood Age 45-65 Years (%)	1.00	0.96, 1.05	1.03	0.99, 1.07
Neighbourhood Marital Status: Separated (%)	0.97	0.86, 1.10	1.00	0.89, 1.14
Neighbourhood Marital Status: Widowed (%)	0.95	0.89, 1.01	1.00	0.94, 1.06
Liveability Score				
Poor	—	—	—	—
Good	0.87	0.54, 1.40	0.80	0.50, 1.29
Immigrants from Western Countries (%)	1.00	0.94, 1.07	1.00	0.94, 1.07
Immigrants from Non-Western Countries (%)	1.01	0.98, 1.03	1.00	0.98, 1.02
Relative Migration Mobility (x1000 inhabitants)	1.00	1.00, 1.01	1.00	1.00, 1.01
Households without Children (%)	0.99	0.95, 1.04	0.98	0.94, 1.02
Home values (x1000€)	1.00	1.00, 1.01	1.00	1.00, 1.00
Incomes ≥ 80th Percentile of National Distribution (%)	0.97	0.93, 1.02	1.01	0.96, 1.05
Incomes ≤ 40th Percentile of National Distribution (%)	0.96	0.91, 1.02	0.98	0.93, 1.03
Income per Inhabitant (x1000€)	0.96	0.83, 1.11	0.92	0.79, 1.06
Households Below or Around Social Minimum (%)	1.01	0.93, 1.10	1.02	0.94, 1.11
Motorcycles at a Neighbourhood Level	1.00	1.00, 1.00	1.00	1.00, 1.00
Passenger Cars per Household	**0.17**	**0.05, 0.54**	0.32	0.10, 1.01

[1] Model C: Adjusted for age, sex, education, and income and all domain exposures, Reference: No NCD
Bold represent those with a p-value less than 0.05
OR: Odds Ratio, CI: Confidence Interval
NCD: Noncommunicable Disease

Table S7. Adjusted Multivariate Multinomial Regression of BE Exposures in a 1 km Euclidean Buffer and NCDs

	Model A[1]				Model B[2]			
	1 NCD		2 or more NCDs		1 NCD		2 or more NCDs	
Variable[1]	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**
Density of Green Space within 1 km (Z-score)	0.78	0.55, 1.10	1.25	0.89, 1.74	0.77	0.51, 1.16	1.16	0.78, 1.73
Land Use Mix Entropy Index 1 km (Z-score)	1.02	0.88, 1.19	1.22	1.04, 1.43	0.97	0.78, 1.21	1.08	0.86, 1.35
Density of Public Transport Stops within 1 km (Z-score)	1.04	0.99, 1.10	1.06	1.00, 1.11	1.04	0.96, 1.13	1.02	0.94, 1.11
Density of Sports Facilities within 1 km (Z-score)	1.01	0.96, 1.07	1.05	0.99, 1.11	0.96	0.88, 1.05	0.98	0.90, 1.07
Paid Parking Spaces within 1 km Radius (%)	1.00	0.98, 1.00	1.00	0.99, 1.79	1.00	0.99, 1.00	1.00	0.99, 1.00
Driving Destination Accessibility Index Score (0-100)	0.99	0.99, 1.01	0.99	0.98, 1.00	1.00	0.99, 1.02	1.00	0.98, 1.01
Distance to Long-Distance Public Transport Stations (km)	0.97	0.94, 1.00	0.96	0.93, 1.78	**0.96**	**0.93, 1.00**	**0.96**	**0.93, 1.00**
Distance to Nearest Motorway Exit (km)	0.99	0.96, 1.02	0.98	0.95, 1.01	1.01	0.96, 1.05	1.01	0.96, 1.05
Distance to General Practice (km)	0.93	0.80, 1.08	0.88	0.76, 1.03	1.01	0.78, 1.30	1.12	0.87, 1.46
Distance to Library (km)	0.93	0.83, 1.03	0.90	0.80, 1.01	0.92	0.78, 1.09	0.90	0.75, 1.07

Distance to Secondary Education (km)	0.99	0.94, 1.04	0.93	0.89, 0.99	1.00	0.92, 1.08	1.00	0.92, 1.08
Distance to Swimming Pool (km)	0.98	0.94, 1.02	0.95	0.91, 0.99	0.97	0.91, 1.03	0.94	0.89, 1.00
Distance to Daycare Center (km)	1.03	0.91, 1.16	0.95	0.83, 1.08	1.10	0.93, 1.30	1.09	0.91, 1.30

[1] Model A: Adjusted for age, sex, education, and income, Reference: No NCD
[2] Model B: Adjusted for age, sex, education, and income and all other BE exposures in the domain, Reference: No NCD
Bold represent those with a p-value less than 0.05
OR: Odds Ratio, CI: Confidence Interval
NCD: Noncommunicable Disease

Table S8. Adjusted Multivariate Multinomial Regression of All Environment Exposures in a 1 km Euclidean Buffer and NCDs

	Model C[1]			
	1 NCD		**2 or more NCDs**	
Variable	**OR**	**95% CI**	**OR**	**95% CI**
Density of Green Space within 1 km (Z-score)	0.81	0.51, 1.28	1.16	0.74, 1.81
Land Use Mix Entropy Index 1 km (Z-score)	1.01	0.78, 1.29	1.10	0.85, 1.42
Density of Public Transport Stops within 1 km (Z-score)	1.05	0.95, 1.16	1.03	0.93, 1.14
Density of Sports Facilities within 1 km (Z-score)	0.99	0.89, 1.09	1.01	0.91, 1.12
Paid Parking Spaces within 1 km Radius (%)	1.00	0.99, 1.01	1.00	0.99, 1.01
Driving Destination Accessibility Index Score (0-100)	1.00	0.99, 1.02	1.00	0.98, 1.01
Distance to Long-Distance Public Transport Stations (km)	0.96	0.91, 1.02	0.97	0.91, 1.03
Distance to Nearest Motorway Exit (km)	0.96	0.89, 1.05	1.00	0.91, 1.08

Road Travel Time to 100,000 jobs (hours)	1.01	0.98, 1.04	1.01	0.98, 1.04
Distance to General Practice (km)	1.07	0.80, 1.43	1.27	0.95, 1.71
Distance to Library (km)	0.91	0.76, 1.09	0.86	0.72, 1.04
Distance to Secondary Education (km)	0.94	0.86, 1.04	0.98	0.89, 1.07
Distance to Hospital (km)	1.02	0.94, 1.06	1.00	0.93, 1.08
Distance to Swimming Pool (km)	1.01	0.93, 1.09	0.96	0.89, 1.04
Distance to Daycare Center (km)	1.07	0.87, 1.31	1.08	0.88, 1.34
Ammonia (NH_3) (μg/m³)	1.00	0.94, 1.06	1.00	0.93, 1.08
Ozone (O_3) (μg/m³)	1.08	0.96, 1.2	1.04	0.92, 1.17
Nitrogen oxides (NO_x) (μg/m³)	0.99	0.97, 1.02	0.98	0.96, 1.01
Particulate Matter 2.5 Micrometers (μg/m³)	1.14	0.82, 1.59	1.16	0.83, 1.61
Monthly Temperature (July)°C	0.84	0.60, 1.18	0.79	0.56, 1.11
Daily Noise Levels (dB(A))	1.02	0.98, 1.05	1.02	0.98, 1.05
Neighbourhood Age 15-24 Years (%)	0.95	0.89, 1.02	0.94	0.87, 1.01
Neighbourhood Age 45-65 Years (%)	1.00	0.96, 1.05	1.03	0.99, 1.08
Neighbourhood Marital Status: Separated (%)	0.95	0.84, 1.08	0.98	0.87, 1.11
Neighbourhood Marital Status: Widowed (%)	0.94	0.88, 1.00	0.99	0.93, 1.06
Liveability Score				

Poor	—	—	—	—
Good	0.89	0.55, 1.43	0.82	0.51, 1.32
Immigrants from Western Countries (%)	1.00	0.94, 1.07	1.00	0.94, 1.06
Immigrants from Non-Western Countries (%)	1.01	0.98, 1.03	1.00	0.97, 1.02
Relative Migration Mobility (x1000 inhabitants)	1.00	1.00, 1.01	1.00	1.00, 1.01
Households without Children (%)	0.98	0.94, 1.02	0.97	0.93, 1.01
Home values (x1000€)	1.00	1.00, 1.01	1.00	1.00, 1.00
Incomes ≥ 80th Percentile of National Distribution (%)	0.96	0.92, 1.01	1.00	0.96, 1.05
Incomes ≤ 40th Percentile of National Distribution (%)	0.96	0.91, 1.01	0.98	0.93, 1.03
Income per Inhabitant (x1000€)	0.96	0.84, 1.11	0.92	0.80, 1.06
Households Below or Around Social Minimum (%)	1.00	0.92, 1.09	1.02	0.94, 1.11
Motorcycles at a Neighbourhood Level	1.00	1.00, 1.00	1.00	1.00, 1.00
Passenger Cars per Household	**0.17**	**0.05, 0.57**	0.34	0.10, 1.11

[1] Model C: Adjusted for age, sex, education, and income and all domain exposures, Reference: No NCD
Bold represent those with a p-value less than 0.05
OR: Odds Ratio, CI: Confidence Interval
NCD: Noncommunicable Disease

Table S9. Adjusted Multivariate Logistic Regression of BE Exposures and NCDs

	No NCD vs Any NCD

	Model A[1]		Model B[2]	
Variable	**OR**	**95% CI**	**OR**	**95% CI**
Density of Green Space within 0.5km (Z-score)	**0.71**	**0.53, 0.94**	**0.64**	**0.45, 0.92**
Land Use Mix Entropy Index 0.5km (Z-score)	1.05	0.96, 1.15	1.00	0.86, 1.17
Density of Public Transport Stops within 0.5km (Z-score)	1.05	1.00, 1.10	1.00	0.94, 1.07
Density of Sports Facilities within 0.5km (Z-score)	1.02	0.98, 1.05	1.00	0.96, 1.04
Paid Parking Spaces within 1km Radius (%)	1.00	1.00, 1.00	1.00	1.00, 1.01
Driving Destination Accessibility Index Score (0-100)	0.99	0.99, 1.00	1.00	0.98, 1.01
Distance to Long-Distance Public Transport Stations (km)	1.00	1.00, 1.00	**0.94**	**0.90, 0.98**
Distance to Nearest Motorway Exit (km)	1.00	1.00, 1.00	0.97	0.90, 1.04
Road Travel Time to 100,000 jobs (hours)	1.00	1.00, 1.00	1.01	0.99, 1.04
Distance to General Practice (km)	0.89	0.79, 1.02	1.03	0.81, 1.32
Distance to Library (km)	0.89	0.80, 0.98	0.91	0.75, 1.04
Distance to Secondary Education (km)	0.97	0.93, 1.01	0.96	0.90, 1.03
Distance to Hospital (km)	0.99	0.97, 1.01	1.01	0.96, 1.07
Distance to Swimming Pool (km)	0.97	0.94, 1.01	0.95	0.90, 1.01
Distance to Daycare Center (km)	0.98	0.89, 1.10	1.12	0.95, 1.34

[1] Model A: Adjusted for age, sex, education, and income, Reference: No NCD
[2] Model B: Adjusted for age, sex, education, and income and all other BE exposures in the domain, Reference: No NCD

Bold represent those with a p-value less than 0.05
OR: Odds Ratio, CI: Confidence Interval
NCD: Noncommunicable Disease

Table S10. Adjusted Multivariate Logistic Regression of PC Environment Exposures and NCDs

	No NCD vs Any NCD			
	Model A[1]		Model B[2]	
Variable	**OR**	**95% CI**	**OR**	**95% CI**
Ammonia (NH_3) (μg/m³)	0.96	0.94, 0.99	0.97	0.94, 1.01
Nitrogen oxides (NO_x) (μg/m³)	1.00	0.99, 1.01	1.00	0.98, 1.02
Particulate Matter 2.5 Micrometers (μg/m³)	0.92	0.79, 1.06	0.90	0.72, 1.44
Monthly Temperature (July)°C	0.98	0.81, 1.18	1.04	0.75, 1.44
Daily Noise Levels (dB(A))	1.01	0.99, 1.03	1.01	0.98, 1.04

[1] Model A: Adjusted for age, sex, education, and income, Reference: No NCD
[2] Model B: Adjusted for age, sex, education, and income and all other PC exposures in the domain, Reference: No NCD
Bold represent those with a p-value less than 0.05
OR: Odds Ratio, CI: Confidence Interval
NCD: Noncommunicable Disease

Table S11. Adjusted Multivariate Logistic Regression of SocDemo Environment Exposures and NCDs

	No NCD vs Any NCD			
	Model A[1]		Model B[2]	
Variable	**OR**	**95% CI**	**OR**	**95% CI**

Neighbourhood Age 15-24 Years (%)	0.99	0.96, 1.03	0.99	0.94, 1.05
Neighbourhood Age 45-64 Years (%)	0.97	0.95, 0.99	1.00	0.97, 1.03
Neighbourhood Marital Status: Separated (%)	1.06	1.02, 1.11	1.01	0.93, 1.09
Neighbourhood Marital Status: Widowed (%)	1.03	0.99, 1.07	1.00	0.95, 1.06
Liveability Score				
Poor	—	—	—	—
Good	0.71	0.51, 0.99	1.23	0.87, 1.74
Immigrants from Western Countries (%)	1.00	1,00, 1.02	1.02	0.98, 1.06
Immigrants from Non-Western Countries (%)	1.01	1.00, 1.02	0.99	0.98, 1.01
Relative Migration Mobility (x1000 inhabitants)	1.00	1.00, 1.01	1.00	1.00, 1.00
Households without Children (%)	0.98	0.96, 1.00	0.99	0.96, 1.02
Home values (x1000€)	1.00	1.00, 1.00	1.00	1.00, 1.00
Incomes ≥ 80th Percentile of National Distribution (%)	0.98	0.96, 0.99	0.99	0.96, 1.02
Incomes ≤ 40th Percentile of National Distribution (%)	1.01	0.99, 1.03	1.02	0.98, 1.05
Income per Inhabitant (x1000€)	0.95	0.90, 1.00	1.02	0.91, 1.15
Households Below or Around Social Minimum (%)	1.04	1.02, 1.08	0.97	0.92, 1.03
Motorcycles at a Neighbourhood Level	1.00	1.00, 1.00	1.00	1.00, 1.00
Passenger Cars per Household	**0.42**	**0.27, 0.63**	0.75	0.35, 1.60

[1] Model A: Adjusted for age, sex, education, and income, Reference: No NCD
[2] Model B: Adjusted for age, sex, education, and income and all other contextual SocDemo exposures in the domain, Reference: No NCD
Bold represent those with a p-value less than 0.05
OR: Odds Ratio, CI: Confidence Interval
NCD: Noncommunicable Disease

Table S12. Adjusted Multivariate Logistic Regression of All Environment Exposures and NCDs

	No NCD vs Any NCD	
	Model C[1]	
Variable	**OR**	**95% CI**
Density of Green Space within 0.5km (Z-score)	**0.61**	**0.43, 0.87**
Land Use Mix Entropy Index 0.5km (Z-score)	1.00	0.87, 1.15
Density of Public Transport Stops within 0.5km (Z-score)	1.00	0.94, 1.06
Density of Sports Facilities within 0.5km (Z-score)	0.99	0.95, 1.03
Paid Parking Spaces within 1km Radius (%)	1.00	0.99, 1.01
Driving Destination Accessibility Index Score (0-100)	1.00	0.98, 1.01
Distance to Long-Distance Public Transport Stations (km)	0.97	0.92, 1.02
Distance to Nearest Motorway Exit (km)	0.98	0.91, 1.05
Road Travel Time to 100,000 jobs (hours)	1.01	0.98, 1.04
Distance to General Practice (km)	1.17	0.91, 1.53
Distance to Library (km)	0.88	0.73, 1.02

Distance to Secondary Education (km)	0.94	0.87, 1.02
Distance to Hospital (km)	1.01	0.95, 1.08
Distance to Swimming Pool (km)	0.98	0.92, 1.06
Distance to Daycare Center (km)	1.08	0.90, 1.32
Ammonia (NH_3) (μg/m³)	0.99	0.94, 1.04
Nitrogen oxides (NO_x) (μg/m³)	1.00	0.97, 1.02
Particulate Matter 2.5 Micrometers (μg/m³)	1.12	0.84, 1.52
Monthly Temperature (July)°C	0.75	0.47, 1.19
Daily Noise Levels (dB(A))	1.01	0.98, 1.04
Neighbourhood Age 15-25 Years (%)	0.96	0.90, 1.03
Neighbourhood Age 45-65 Years (%)	1.01	0.98, 1.05
Neighbourhood Marital Status: Separated (%)	0.98	0.88, 1.10
Neighbourhood Marital Status: Widowed (%)	0.97	0.91, 1.03
Liveability Score		
Poor	—	—
Good	0.81	0.52, 1.25
Immigrants from Western Countries (%)	1.01	0.95, 1.07
Immigrants from Non-Western Countries (%)	1.00	0.98, 1.02

Relative Migration Mobility (x1000 inhabitants)	1.00	1.00, 1.01
Households without Children (%)	0.98	0.95, 1.02
Home values (x1000€)	1.00	1.00, 1.00
Incomes ≥ 80th Percentile of National Distribution (%)	0.99	0.95, 1.03
Incomes ≤ 40th Percentile of National Distribution (%)	0.97	0.93, 1.02
Income per Inhabitant (x1000€)	0.94	0.82, 1.07
Households Below or Around Social Minimum (%)	1.02	0.94, 1.10
Motorcycles at a Neighbourhood Level	1.00	1.00, 1.00
Passenger Cars per Household	**0.21**	**0.07, 0.59**

[1] Model C: Adjusted for age, sex, education, and income and all domain exposures, Reference: No NCD
Bold represent those with a p-value less than 0.05
OR: Odds Ratio, CI: Confidence Interval
NCD: Noncommunicable Disease

Table S13. Sex Stratification: Adjusted Multivariate Multinomial Regression of All Environment Exposures and NCDs

	Model C[1]							
	Females		**Males**		**Females**		**Males**	
	1 NCD				**2 or more NCDs**			
Variable	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**
Density of Green Space within 0.5km (Z-score)	**0.40**	**0.22, 0.74**	**0.40**	**0.20, 0.79**	0.57	0.32, 1.01	0.70	0.37, 1.33

Land Use Mix Entropy Index 0.5km (Z-score)	1.08	0.99, 1.61	0.81	0.64, 1.03	1.10	0.98, 1.66	0.83	0.66, 1.05
Density of Public Transport Stops within 0.5km (Z-score)	1.06	0.95, 1.18	0.93	0.83, 1.04	1.03	0.92, 1.16	0.95	0.85, 1.06
Density of Sports Facilities within 0.5km (Z-score)	0.99	0.92, 1.05	0.98	0.92, 1.05	0.97	0.90, 1.04	1.01	0.95, 1.08
Paid Parking Spaces within 1km Radius (%)	1.01	0.99, 1.02	0.99	0.98, 1.01	1.00	0.99, 1.02	1.00	0.99, 1.01
Driving Destination Accessibility Index Score (0-100)	1.03	1.00, 1.06	0.98	0.96, 1.00	1.01	0.99, 1.04	0.98	0.96, 1.00
Distance to Long-Distance Public Transport Stations (km)	**0.90**	**0.82, 0.99**	1.05	0.95, 1.16	0.91	0.83, 1.00	0.98	0.89, 1.08
Distance to Nearest Motorway Exit (km)	0.87	0.75, 1.00	1.05	0.93, 1.19	0.89	0.78, 1.03	1.04	0.92, 1.18
Road Travel Time to 100,000 jobs (hours)	1.03	0.98, 1.08	0.99	0.95, 1.04	1.03	0.97, 1.08	1.00	0.96, 1.04
Distance to General Practice (km)	0.80	0.51, 1.26	1.52	0.94, 2.45	1.10	0.71, 1.73	1.50	0.92, 2.43
Distance to Library (km)	1.02	0.74, 1.41	0.79	0.60, 1.05	0.79	0.55, 1.13	0.86	0.64, 1.17
Distance to Secondary Education (km)	0.89	0.77, 1.03	0.94	0.82, 1.08	0.94	0.81, 1.09	0.96	0.84, 1.11
Distance to Hospital (km)	1.04	0.92, 1.17	1.01	0.89, 1.13	1.07	0.94, 1.21	0.97	0.86, 1.10
Distance to Swimming Pool (km)	1.04	0.93, 1.15	1.04	0.90, 1.21	0.98	0.88, 1.09	0.94	0.81, 1.09
Distance to Daycare Center (km)	1.00	0.68, 1.46	0.98	0.75, 1.29	0.95	0.65, 1.40	1.12	0.85, 1.47
Ammonia (NH_3) (μg/m³)	0.98	0.91, 1.05	1.03	0.92, 1.15	0.91	0.83, 1.00	1.05	0.94, 1.17
Ozone (O_3) (μg/m³)	1.04	0.85, 1.26	1.09	0.88, 1.34	0.97	0.79, 1.19	1.00	0.82, 1.22
Nitrogen oxides (NO_x) (μg/m³)	1.01	0.97, 1.06	0.99	0.95, 1.03	1.01	0.97, 1.06	0.98	0.94, 1.02

Particulate Matter 2.5 Micrometers (µg/m³)	1.04	0.66, 1.66	0.97	0.58, 1.61	1.00	0.61, 1.62	1.26	0.77, 2.06
Monthly Temperature (July)°C	1.01	0.60, 1.70	0.68	0.39, 1.21	1.19	0.69, 2.05	0.63	0.37, 1.10
Daily Noise Levels (dB(A))	0.98	0.93, 1.03	1.05	1.00, 1.11	0.99	0.94, 1.04	1.04	0.99, 1.10
Neighbourhood Age 15-25 Years (%)	0.97	0.86, 1.10	1.04	0.92, 1.18	0.89	0.79, 1.01	1.03	0.92, 1.17
Neighbourhood Age 45-64 Years (%)	1.02	0.95, 1.10	1.04	0.97, 1.12	1.03	0.96, 1.11	1.02	0.95, 1.10
Neighbourhood Marital Status: Separated (%)	1.02	0.84, 1.25	0.98	0.81, 1.19	1.07	0.87, 1.30	0.92	0.77, 1.11
Neighbourhood Marital Status: Widowed (%)	0.97	0.86, 1.09	1.01	0.89, 1.14	0.94	0.83, 1.06	1.08	0.96, 1.22
Liveability Score								
Poor	—	—	—	—	—	—	—	—
Good	1.28	0.63, 2.61	0.65	0.31, 1.34	0.96	0.47, 1.97	0.67	0.33, 1.34
Immigrants from Western Countries (%)	1.01	0.92, 1.12	1.04	0.94, 1.16	1.00	0.91, 1.11	1.06	0.96, 1.17
Immigrants from Non-Western Countries (%)	1.00	0.96, 1.04	0.99	0.96, 1.03	1.00	0.96, 1.04	0.99	0.96, 1.03
Relative Migration Mobility (x1000 inhabitants)	1.00	0.99, 1.01	1.00	1.00, 1.01	1.00	0.99, 1.01	1.00	1.00, 1.01
Households without Children (%)	0.99	0.92, 1.06	1.05	0.98, 1.13	0.95	0.88, 1.01	1.02	0.95, 1.10
Home values (x1000€)	1.00	1.00, 1.01	1.00	0.99, 1.00	1.00	1.00, 1.01	1.00	0.99, 1.00
Incomes ≥ 80th Percentile of National Distribution (%)	0.97	0.90, 1.04	0.95	0.89, 1.02	1.02	0.95, 1.10	1.01	0.94, 1.08
Incomes ≤ 40th Percentile of National Distribution (%)	1.00	0.92, 1.09	0.94	0.86, 1.03	1.03	0.95, 1.12	0.93	0.86, 1.02
Income per Inhabitant (x1000€)	0.95	0.77, 1.19	1.12	0.88, 1.43	0.95	0.76, 1.18	0.84	0.66, 1.07

Households Below or Around Social Minimum (%)	1.01	0.88, 1.15	1.07	0.94, 1.22	1.05	0.92, 1.21	1.00	0.88, 1.13
Motorcycles at a Neighbourhood Level	1.00	1.00, 1.00	1.00	1.00, 1.00	1.00	1.00, 1.00	1.00	1.00, 1.00
Passenger Cars per Household	0.37	0.05, 2.57	**0.05**	**0.01, 0.35**	0.96	0.35, 1.98	**0.07**	**0.01, 0.42**

[1] Model C: Stratified by sex, adjusted for age, education, and income and all domain exposures, Reference: No NCD
Bold represent those with a p-value less than 0.05
OR: Odds Ratio, CI: Confidence Interval
NCD: Noncommunicable Disease

Table S14. Age Stratification: Adjusted Multivariate Multinomial Regression of All Environment Exposures and NCDs

	Model C[1]							
	Age 60-71		**Age 72-100**		**Age 60-71**		**Age 72-100**	
	1 NCD				**2 NCD or more**			
Variable[1]	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**
Density of Green Space within 0.5km (Z-score)	**0.52**	**0.29, 0.95**	**0.38**	**0.19, 0.75**	0.82	0.45, 1.51	0.59	0.31, 1.10
Land Use Mix Entropy Index 0.5km (Z-score)	0.93	0.76, 1.13	1.16	0.86, 1.57	0.98	0.79, 1.21	1.13	0.85, 1.51
Density of Public Transport Stops within 0.5km (Z-score)	1.07	0.97, 1.17	0.91	0.81, 1.03	1.03	0.93, 1.13	0.92	0.82, 1.03
Density of Sports Facilities within 0.5km (Z-score)	1.03	0.97, 1.09	0.94	0.86, 1.02	1.00	0.94, 1.07	0.96	0.89, 1.03
Ratio of Registered Cars to Available Parking Spaces	1.80	0.72, 4.50	0.87	0.24, 3.23	1.25	0.46, 3.39	0.60	0.17, 2.17
Paid Parking Spaces within 1km Radius (%)	0.99	0.98, 1.00	1.00	0.99, 1.02	0.99	0.97, 1.00	1.01	0.99, 1.03
Driving Destination Accessibility Index Score (0-100)	1.01	0.99, 1.03	1.01	0.98, 1.05	0.98	0.96, 1.01	1.01	0.98, 1.04

Distance to Long-Distance Public Transport Stations (km)	1.06	0.97, 1.15	0.94	0.84, 1.05	1.02	0.93, 1.11	0.93	0.83, 1.03
Distance to Nearest Motorway Exit (km)	0.95	0.85, 1.07	0.97	0.84, 1.11	1.00	0.88, 1.14	0.97	0.85, 1.11
Road Travel Time to 100,000 jobs (hours)	1.02	0.98, 1.07	1.01	0.96, 1.06	1.01	0.96, 1.06	1.01	0.96, 1.05
Distance to General Practice (km)	1.22	0.82, 1.81	1.01	0.61, 1.68	1.24	0.82, 1.88	1.32	0.81, 2.15
Distance to Library (km)	0.82	0.61, 1.11	0.97	0.76, 1.23	0.85	0.61, 1.19	0.85	0.64, 1.12
Distance to Secondary Education (km)	0.84	0.74, 1.02	0.95	0.81, 1.12	0.96	0.83, 1.11	1.00	0.85, 1.16
Distance to Hospital (km)	0.94	0.85, 1.05	1.06	0.93, 1.21	0.97	0.86, 1.08	1.06	0.94, 1.21
Distance to Swimming Pool (km)	1.08	0.98, 1.33	0.93	0.81, 1.06	1.09	0.95, 1.25	0.84	0.74, 1.00
Distance to Daycare Center (km)	0.99	0.76, 1.30	1.10	0.72, 1.68	1.04	0.78, 1.38	1.04	0.69, 1.59
Ammonia (NH_3) (µg/m³)	0.97	0.90, 1.05	0.93	0.82, 1.06	0.94	0.86, 1.03	0.92	0.81, 1.05
Ozone (O_3) (µg/m³)	1.13	0.95, 1.35	1.02	0.81, 1.28	1.00	0.83, 1.21	0.89	0.72, 1.11
Nitrogen oxides (NO_x) (µg/m³)	1.00	0.96, 1.03	0.99	0.94, 1.04	1.00	0.97, 1.04	0.99	0.94, 1.03
Particulate Matter 2.5 Micrometers (µg/m³)	1.09	0.71, 1.65	1.07	0.58, 1.95	1.19	0.76, 1.87	1.03	0.57, 1.83
Monthly Temperature (July)°C	0.78	0.48, 1.26	0.94	0.48, 1.85	0.98	0.58, 1.64	0.88	0.45, 1.70
Daily Noise Levels (dB(A))	1.02	0.98, 1.07	1.00	0.94, 1.07	1.01	0.96, 1.06	1.02	0.95, 1.08
Neighbourhood Age 15-25 Years (%)	0.99	0.89, 1.10	1.04	0.90, 1.20	0.96	0.85, 1.07	0.97	0.85, 1.11
Neighbourhood Age 45-65 Years (%)	1.03	0.97, 1.09	1.05	0.96, 1.15	1.00	0.93, 1.07	1.10	1.00, 1.21

Neighbourhood Marital Status: Separated (%)	0.97	0.82, 1.15	0.93	0.74, 1.16	0.96	0.80, 1.15	0.92	0.75, 1.13
Neighbourhood Marital Status: Widowed (%)	0.97	0.87, 1.08	0.99	0.86, 1.14	1.02	0.91, 1.14	0.98	0.86, 1.12
Liveability Score								
Poor	—	—	—	—	—	—	—	—
Good	1.01	0.53, 1.90	0.80	0.34, 1.88	0.67	0.35, 1.29	0.92	0.41, 2.06
Immigrants from Western Countries (%)	1.05	0.96, 1.16	1.02	0.92, 1.15	1.05	0.95, 1.16	1.01	0.90, 1.12
Immigrants from Non-Western Countries (%)	0.99	0.96, 1.03	0.99	0.95, 1.04	1.00	0.96, 1.03	1.00	0.95, 1.04
Relative Migration Mobility (x1000 inhabitants)	1.00	0.99, 1.01	1.00	0.99, 1.01	1.00	0.99, 1.01	1.01	1.00, 1.02
Households without Children (%)	1.03	0.96, 1.10	0.99	0.91, 1.08	0.96	0.90, 1.03	0.97	0.90, 1.05
Home values (x1000€)	1.00	0.99, 1.00	1.01	1.00, 1.01	1.00	1.0, 1.01	1.00	1.0, 1.01
Incomes ≥ 80th Percentile of National Distribution (%)	0.97	0.91, 1.03	0.92	0.84, 1.00	1.02	0.95, 1.09	0.97	0.89, 1.05
Incomes ≤ 40th Percentile of National Distribution (%)	0.97	0.90, 1.04	0.94	0.85, 1.04	0.94	0.87, 1.01	1.02	0.93, 1.13
Income per Inhabitant (x1000€)	1.07	0.88, 1.30	0.96	0.73, 1.27	0.83	0.66, 1.04	1.03	0.79, 1.34
Households Below or Around Social Minimum (%)	1.10	0.97, 1.24	0.97	0.84, 1.12	**1.16**	**1.02, 1.33**	0.92	0.81, 1.05
Motorcycles at a Neighbourhood Level	1.00	1.00, 1.00	1.00	1.00, 1.01	1.00	1.00, 1.00	1.00	1.00, 1.01
Passenger Cars per Household	**0.03**	**0.01, 0.18**	**0.28**	**0.03, 0.64**	**0.15**	**0.10, 0.69**	**0.10**	**0.01, 0.87**

[1] Model C: Stratified for age, adjusted by sex, education, and income and all domain exposures, Reference: No NCD
Bold represent those with a p-value less than 0.05
OR: Odds Ratio, CI: Confidence Interval

NCD: Noncommunicable Disease

Table S15. Complete Case Analysis: Adjusted Multivariate Multinomial Regression of BE Exposures and NCDs

	Model B[1]			
	1 NCD		2 or more NCDs	
Variable	**OR**	**95% CI**	**OR**	**95% CI**
Density of Green Space within 0.5km (Z-score)	**0.48**	**0.29, 0.80**	0.64	0.40, 1.05
Land Use Mix Entropy Index 0.5km (Z-score)	0.95	0.79, 1.14	1.0	0.83, 1.19
Density of Public Transport Stops within 0.5km (Z-score)	1.01	0.94, 1.09	0.97	0.90, 1.04
Density of Sports Facilities within 0.5km (Z-score)	0.99	0.95, 1.04	0.99	0.94, 1.04
Paid Parking Spaces within 1km Radius (%)	1.00	0.99, 1.01	1.00	1.00, 1.01
Driving Destination Accessibility Index Score (0-100)	0.99	0.97, 1.02	1.00	0.97, 1.03
Distance to Long-Distance Public Transport Stations (km)	0.97	0.92, 1.01	**0.96**	**0.92, 1.00**
Distance to Nearest Motorway Exit (km)	1.01	0.95, 1.08	1.04	0.97, 1.10
Distance to General Practice (km)	1.06	0.75, 1.49	1.13	0.80, 1.59
Distance to Library (km)	0.95	0.76, 1.21	0.89	0.70, 1.14
Distance to Secondary Education (km)	0.98	0.90, 1.07	0.93	0.84, 1.02
Distance to Swimming Pool (km)	0.94	0.87, 1.01	0.91	0.84, 1.00

Distance to Daycare Center (km)	1.26	0.96, 1.65	1.04	0.77, 1.41

[1] Model B: Adjusted for age, sex, education, and income and all other BE exposures in the domain, Reference: No NCD
Bold represent those with a p-value less than 0.05
OR: Odds Ratio, CI: Confidence Interval
NCD: Noncommunicable Disease

Table S16. Complete Case Analysis: Adjusted Multivariate Multinomial Regression of PC Environment Exposures and NCDs

	Model B[1]			
	1 NCD		**2 or more NCDs**	
Variable[1]	**OR**	**95% CI**	**OR**	**95% CI**
Ammonia (NH_3) (μg/m³)	1.00	0.95, 1.05	**0.95**	**0.89, 1.00**
Ozone (O_3) (μg/m³)	1.03	0.93, 1.16	**0.89**	**0.81, 1.00**
Nitrogen oxides (NO_x) (μg/m³)	0.99	0.96, 1.02	0.99	0.95, 1.02
Particulate Matter 2.5 Micrometers (μg/m³)	0.84	0.52, 1.37	0.93	0.57, 1.51
Monthly Temperature (July)°C	1.32	0.97, 1.79	1.37	1.00, 1.89
Daily Noise Levels (dB(A))	1.02	0.98, 1.05	1.02	0.98, 1.06

[1] Model B: Adjusted for age, sex, education, and income and all other PC exposures in the domain, Reference: No NCD
Bold represent those with a p-value less than 0.05
OR: Odds Ratio, CI: Confidence Interval
NCD: Noncommunicable Disease

Table S17. Complete Case Analysis: Adjusted Multivariate Multinomial Regression of SocDemo Environment Exposures and NCD

	Model B[1]			
	1 NCD		2 or more NCDs	
Variable[1]	**OR**	**95% CI**	**OR**	**95% CI**
Neighbourhood Age 15-24 Years (%)	1.01	0.91, 1.11	1.04	0.94, 1.15
Neighbourhood Age 45-64 Years (%)	1.05	0.98, 1.12	1.04	0.97, 1.11
Neighbourhood Marital Status: Separated (%)	1.10	0.94, 1.28	1.09	0.94, 1.28
Neighbourhood Marital Status: Widowed (%)	1.04	0.93, 1.16	1.06	0.95, 1.17
Liveability Score				
Poor	—	—	—	—
Good	1.06	0.59, 1.88	1.02	0.58, 1.81
Immigrants from Western Countries (%)	0.93	0.87, 1.01	0.94	0.87, 1.01
Immigrants from Non-Western Countries (%)	0.99	0.96, 1.02	0.98	0.95, 1.01
Relative Migration Mobility (x1000 inhabitants)	0.99	0.98, 1.00	1.0	0.99, 1.00
Households without Children (%)	1.05	0.99, 1.11	1.04	0.99, 1.10
Home values (x1000€)	1.00	1.0, 1.00	1.00	1.00, 1.01
Incomes ≥ 80th Percentile of National Distribution (%)	0.98	0.92, 1.05	0.99	0.92, 1.06
Incomes ≤ 40th Percentile of National Distribution (%)	0.99	0.93, 1.05	0.97	0.91, 1.03

Income per Inhabitant (x1000€)	1.11	0.91, 1.37	0.95	0.77, 1.16
Households Below or Around Social Minimum (%)	1.03	0.91, 1.17	1.08	0.96, 1.22
Motorcycles at a Neighbourhood Level	1.00	1.00, 1.00	1.00	1.00, 1.00
Passenger Cars per Household	**0.08**	**0.02, 0.36**	**0.14**	**0.03, 0.67**

[1] Model B: Adjusted for age, sex, education, and income and all other contextual SocDemo exposures in the domain, Reference: No NCD
Bold represent those with a p-value less than 0.05
OR: Odds Ratio, CI: Confidence Interval
NCD: Noncommunicable Disease

Table *S*18. Complete Case Analysis: Adjusted Multivariate Multinomial Regression of All Environment Exposures and NCDs

	Model C[1]			
	1 NCD		**2 or more NCDs**	
Variable	**OR**	**95% CI**	**OR**	**95% CI**
Density of Green Space within 0.5km (Z-score)	**0.32**	**0.16, 0.66**	**0.46**	**0.23, 0.90**
Land Use Mix Entropy Index 0.5km (Z-score)	1.12	0.86, 1.46	1.16	0.90, 1.51
Density of Public Transport Stops within 0.5km (Z-score)	1.02	0.93, 1.13	0.93	0.84, 1.03
Density of Sports Facilities within 0.5km (Z-score)	1.00	0.94, 1.06	0.98	0.92, 1.04
Paid Parking Spaces within 1km Radius (%)	0.99	0.98, 1.01	1.00	0.99, 1.02
Driving Destination Accessibility Index Score (0-100)	1.01	0.97, 1.05	1.02	0.98, 1.07
Distance to Long-Distance Public Transport Stations (km)	1.01	0.93, 1.10	1.00	0.92, 1.09

Distance to Nearest Motorway Exit (km)	0.91	0.79, 1.04	1.03	0.90, 1.17
Road Travel Time to 100,000 jobs (hours)	0.99	0.95, 1.04	0.99	0.94, 1.03
Distance to General Practice (km)	1.30	0.75, 2.27	1.38	0.79, 2.41
Distance to Library (km)	1.06	0.70, 1.60	0.87	0.57, 1.30
Distance to Secondary Education (km)	0.85	0.74, 1.00	0.88	0.76, 1.01
Distance to Hospital (km)	1.07	0.95, 1.20	1.00	0.89, 1.12
Distance to Swimming Pool (km)	1.06	0.94, 1.19	1.00	0.89, 1.12
Distance to Daycare Center (km)	1.03	0.70, 1.51	0.81	0.53, 1.22
Ammonia (NH_3) (µg/m³)	1.03	0.92, 1.15	0.99	0.88, 1.10
Ozone (O_3) (µg/m³)	1.07	0.87, 1.33	0.98	0.80, 1.21
Nitrogen oxides (NO_x) (µg/m³)	0.99	0.95, 1.03	0.98	0.94, 1.02
Particulate Matter 2.5 Micrometers (µg/m³)	0.98	0.64, 1.52	1.00	0.64, 1.56
Monthly Temperature (July)°C	0.65	0.38, 1.10	0.89	0.52, 1.52
Daily Noise Levels (dB(A))	1.07	1.00, 1.13	1.05	0.99, 1.11
Neighbourhood Age 15-25 Years (%)	0.98	0.85, 1.12	1.01	0.88, 1.16
Neighbourhood Age 45-65 Years (%)	0.99	0.91, 1.07	1.01	0.93, 1.10
Neighbourhood Marital Status: Separated (%)	1.13	0.92, 1.39	1.10	0.89, 1.35

Neighbourhood Marital Status: Widowed (%)	0.91	0.80, 1.04	0.98	0.86, 1.11
Liveability Score				
Poor	—	—	—	—
Good	1.23	0.63, 2.40	1.07	0.56, 2.05
Immigrants from Western Countries (%)	0.96	0.86, 1.06	0.93	0.85, 1.03
Immigrants from Non-Western Countries (%)	0.99	0.95, 1.03	0.97	0.93, 1.01
Relative Migration Mobility (x1000 inhabitants)	0.99	0.98, 1.00	0.99	0.98, 1.01
Households without Children (%)	0.98	0.91, 1.06	1.00	0.92, 1.08
Home values (x1000€)	1.00	0.99, 1.01	1.00	1.00, 1.01
Incomes ≥ 80th Percentile of National Distribution (%)	0.98	0.90, 1.06	0.97	0.90, 1.06
Incomes ≤ 40th Percentile of National Distribution (%)	0.99	0.90, 1.10	0.94	0.85, 1.04
Income per Inhabitant (x1000€)	1.14	0.88, 1.50	0.97	0.75, 1.26
Households Below or Around Social Minimum (%)	1.05	0.89, 1.24	1.12	0.96, 1.32
Motorcycles at a Neighbourhood Level	1.00	1.00, 1.00	1.00	1.00, 1.00
Passenger Cars per Household	**0.02**	**0.01, 0.05**	**0.04**	**0.01, 0.13**

1 Model C: Adjusted for age, sex, education, and income and all domain exposures, Reference: No NCD
Bold represent those with a p-value less than 0.05
OR: Odds Ratio, CI: Confidence Interval
NCD: Noncommunicable Disease

Résumé

Facteurs de l'exposome associés à la multimorbidité chez les personnes âgées : une analyse transversale exploratoire dans l'étude longitudinale sur le vieillissement à Amsterdam.

Contexte : Le vieillissement de la population et l'augmentation de l'espérance de vie exercent une pression sur les systèmes de santé en raison de la prévalence croissante des maladies non transmissibles (MNT) et de la multimorbidité. Comprendre l'influence des facteurs environnementaux sur la prévalence des MNT est crucial.

Objectifs : Cette étude utilise le cadre de l'exposome pour examiner comment les domaines environnementaux construits, physico-chimiques et contextuels sociodémographiques influencent les MNT et la multimorbidité chez les personnes âgées, tout en tenant compte des variables sociodémographiques telles que l'âge, le sexe, l'éducation et le revenu.

Méthodes : Les données de 1 465 personnes âgées issues de la cohorte de l'Étude Longitudinale sur le Vieillissement à Amsterdam, vague 2008-2009, appariées aux données environnementales du Consortium Néerlandais de Géosciences et de Santé, ont été analysées. Des régressions multinomiales multivariées non ordonnées ont été réalisées pour chaque domaine environnemental et dans un modèle global, ajusté pour les variables sociodémographiques. Des analyses de sensibilité ont été effectuées.

Résultats : Les statistiques descriptives ont révélé un âge moyen de 72,8 ans, une prédominance féminine (55 %) avec une répartition équilibrée entre les catégories d'éducation et la majorité appartenant au groupe de revenu du ménage élevé. La plupart des répondants ont déclaré avoir deux maladies chroniques ou plus. Les analyses de régression multinomiale multivariée ont montré une association entre une densité de verdure accrue et des chances plus faibles de maladies chroniques singulières (OR : 0,51, IC à 95 % : 0,34 - 0,77), une tendance à la proximité des services essentiels tels que les cabinets médicaux avec une multimorbidité plus faible, une exposition réduite aux polluants atmosphériques, et des conditions favorables telles que des températures optimales et des destinations attrayantes dans la réduction de la prévalence des maladies chroniques, avec des facteurs sociodémographiques individuels jouant un rôle crucial.

Conclusion : L'utilisation du cadre de l'exposome permet d'explorer de manière exhaustive la relation entre les expositions environnementales et la prévalence des MNT chez les personnes âgées, fournissant des perspectives pour la recherche future et informant les interventions de santé publique pour promouvoir un vieillissement en bonne santé.

Mots-clés : Caractéristiques environnementales, Maladies non transmissibles, Cadre de l'exposome