HEALTH IMPACT RESULTING FROM THE INTRODUCTION OF LOW-EMISSION ZONES

A COMPARATIVE INTERRUPTED TIME SERIES ANALYSIS OF A NATURAL EXPERIMENT IN THREE BELGIAN CITIES USING INDIVIDUAL-LEVEL HEALTH OUTCOMES

dr. Luk Bruyneel
Lead Scientific and Economic Matters, Independent Health Insurance Funds
Guest Professor, KU Leuven

onafhankelijke ziekenfondsen / mutualités libres

HEAL HEALTH AND ENVIRONMENT ALLIANCE

KU LEUVEN

irCELine

vito

RESEARCH CONSORTIUM

Luk Bruyneel
Mutualités Libres/KUL

Christian Horemans
Mutualités Libres

Ludo Vandenthoren
Mutualités Libres

Anne Stauffer
HEAL
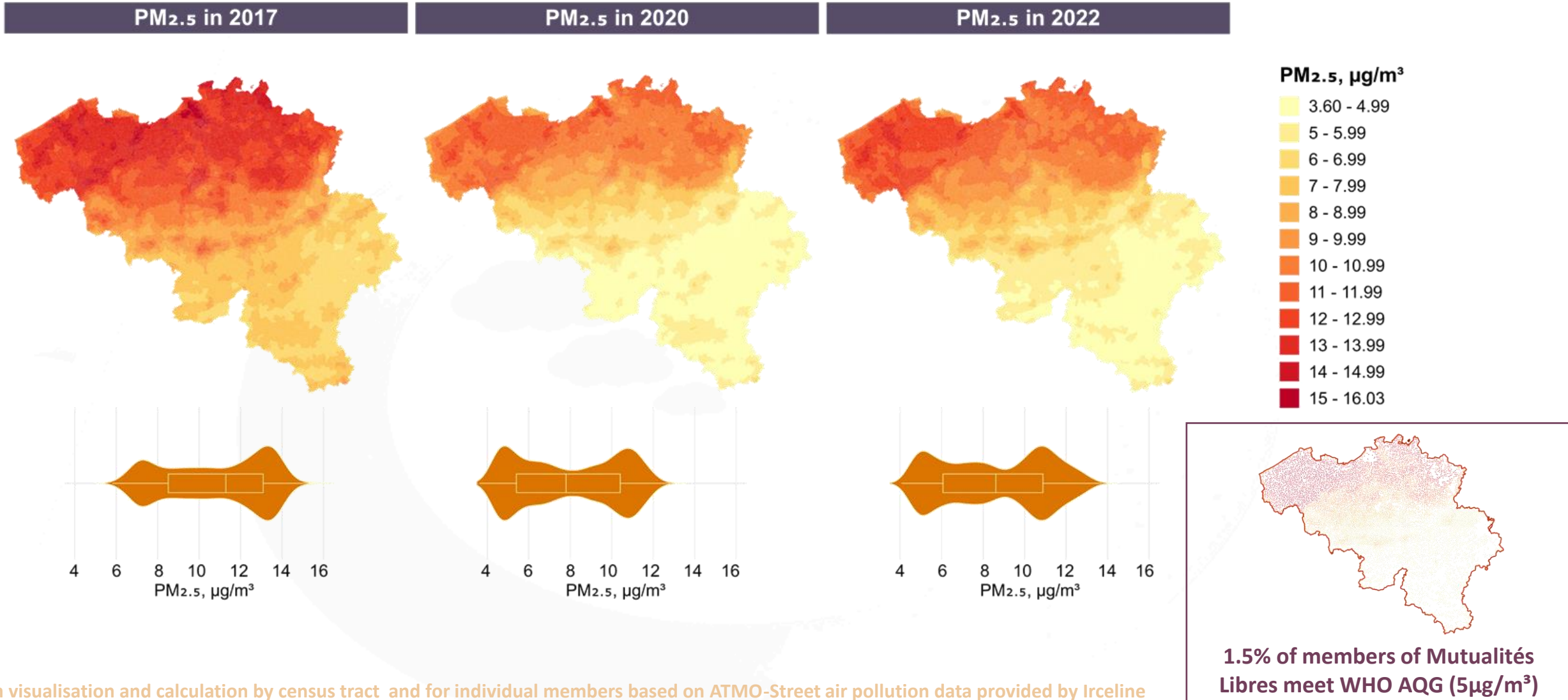
Tim Nawrot
UHasselt/KUL

Bianca Cox
VITO

Frans Fierens
IRCELINE

Ann Belmans
KUL

AIR QUALITY HAS IMPROVED, BUT THE MAJORITY OF BELGIANS ARE EXPOSED TO AIR POLLUTION LEVELS ABOVE WHO GUIDELINES

PM2.5 in 2017

PM2.5 in 2020

PM2.5 in 2022

PM2.5, µg/m³

| 3.60 - 4.99 |
| 5 - 5.99 |
| 6 - 6.99 |
| 7 - 7.99 |
| 8 - 8.99 |
| 9 - 9.99 |
| 10 - 10.99 |
| 11 - 11.99 |
| 12 - 12.99 |
| 13 - 13.99 |
| 14 - 14.99 |
| 15 - 16.03 |

PM2.5, µg/m³

PM2.5, µg/m³

PM2.5, µg/m³

1.5% of members of Mutualités Libres meet WHO AQG (5µg/m³)

Own visualisation and calculation by census tract and for individual members based on ATMO-Street air pollution data provided by Irceline

STRONG EVIDENCE ABOUT THE IMPACT OF AIR POLLUTION ON HEALTH IN BELGIUM

Residential green space, air pollution, socioeconomic deprivation and cardiovascular medication sales in Belgium: a nationwide ecological study
Aerts et al. Science of the total environment, 2020

Association of air pollution and green space with all-cause general practitioner and emergency room visits: a cross-sectional study of young people and adults living in Belgium
Vranken et al. Environmental Research, 2023

Impact of short-term exposure to air pollution on natural mortality and vulnerable populations: a multi-city case-crossover analysis in Belgium
Demoury et al. Environmental Health, 2024

Short-term exposure to ambient air pollution and onset of work incapacity related to mental health conditions
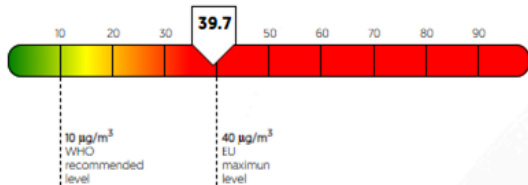Bruyneel et al. Environment International, 2022

In utero exposure to air pollutants and mitochondrial heteroplasmy in neonates
Cosemans et al. Environmental Science & Technology, 2023

REDUCING AIR POLLUTION LEVELS COULD PREVENT THOUSANDS OF DEATHS IN EUROPEAN CITIES EVERY YEAR (data for 2015)
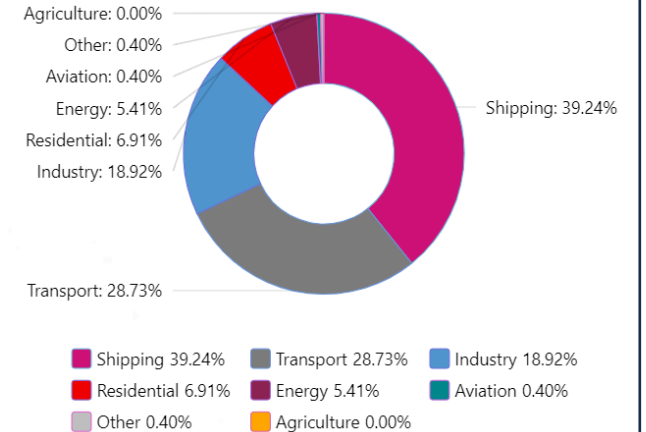
ANTWERP

NO2 (ANNUAL MEAN)

39.7

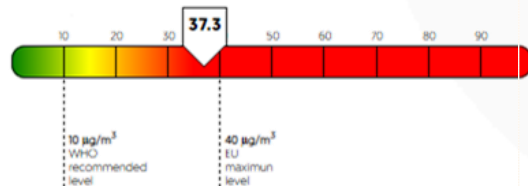10 20 30 40 50 60 70 80 90

10 μg/m³ WHO recommended level
40 μg/m³ EU maximun level

RANKING POSITION

2 /858

DEATHS THAT COULD BE AVOIDED

254
IF NEW WHO GUIDELINES (2021) WERE MET

Agriculture: 0.00%
Other: 0.40%
Aviation: 0.40%
Energy: 5.41%
Residential: 6.91%
Industry: 18.92%
Shipping: 39.24%
Transport: 28.73%

- Shipping 39.24%
- Transport 28.73%
- Industry 18.92%
- Residential 6.91%
- Energy 5.41%
- Aviation 0.40%
- Other 0.40%
- Agriculture 0.00%

BRUSSELS

NO2 (ANNUAL MEAN)

37.3

10 20 30 40 50 60 70 80 90

10 μg/m³ WHO recommended level
40 μg/m³ EU maximun level

RANKING POSITION

8 /858

DEATHS THAT COULD BE AVOIDED

433
IF NEW WHO GUIDELINES (2021) WERE MET

Agriculture: 0.00%
Other: 0.20%
Aviation: 2.70%
Shipping: 5.69%
Energy: 6.59%
Industry: 7.69%
Residential: 15.08%
Transport: 62.04%

- Transport 62.04%
- Residential 15.08%
- Industry 7.69%
- Energy 6.59%
- Shipping 5.69%
- Aviation 2.70%
- Other 0.20%
- Agriculture 0.00%
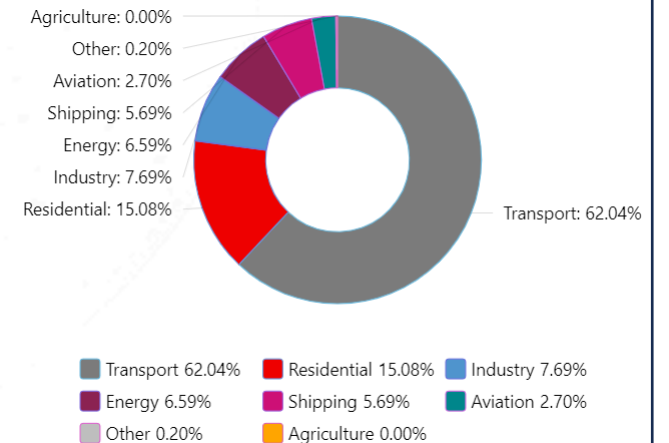
URBAN VEHICLE ACCESS REGULATIONS
TO IMPROVE ISSUES SUCH AS AIR QUALITY
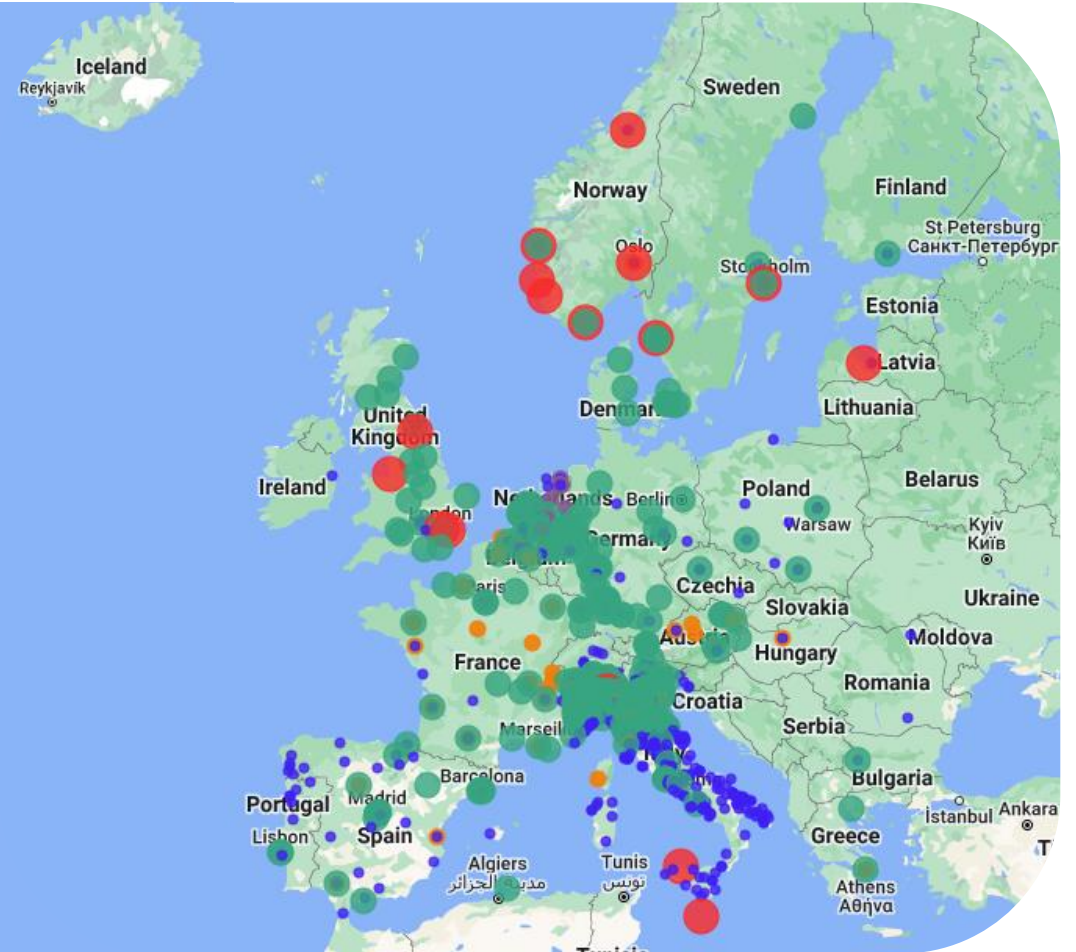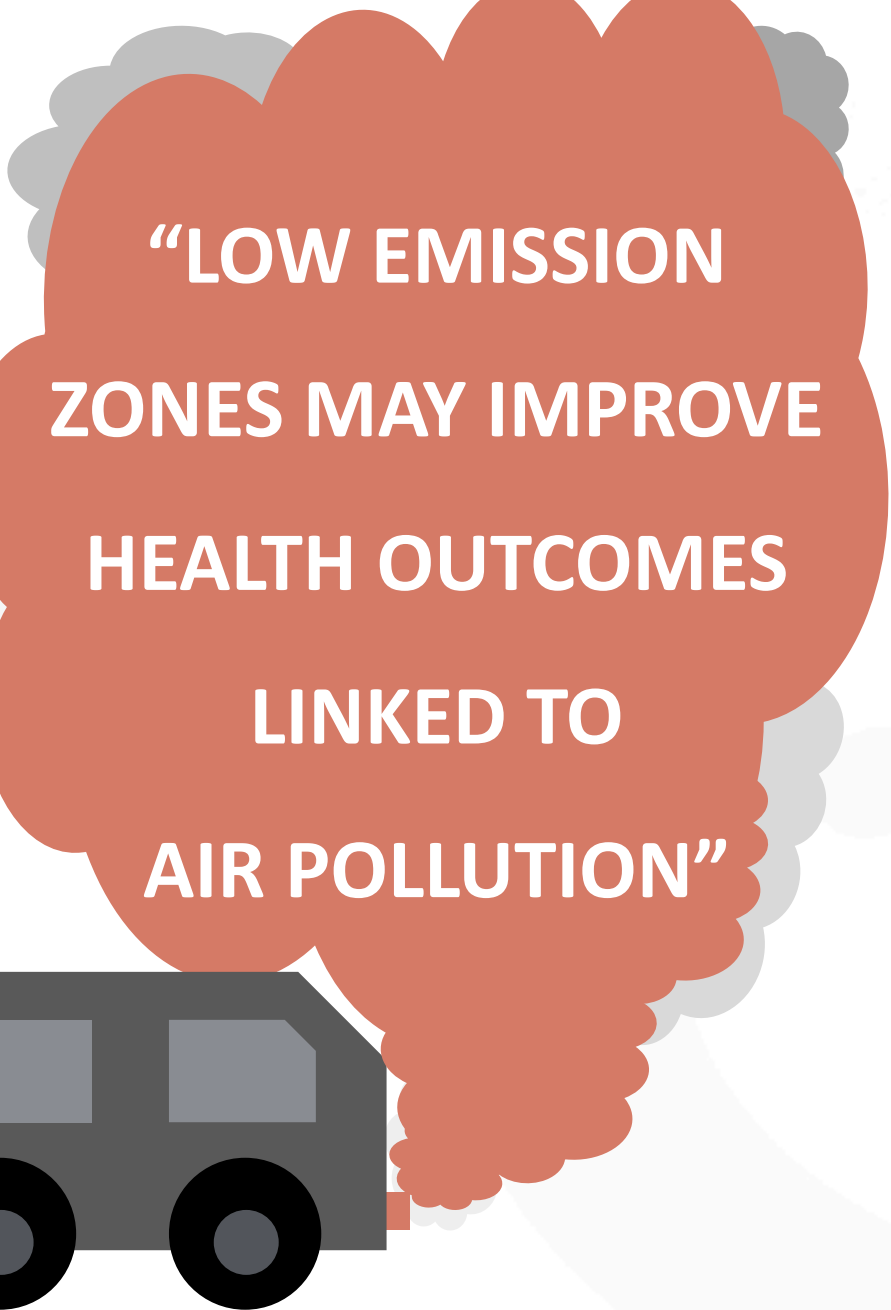
"LOW EMISSION ZONES MAY IMPROVE HEALTH OUTCOMES LINKED TO AIR POLLUTION"

- Systematic review of **8 STUDIES** covering Low-Emission Zones in Germany, Japan and the UK

- 5 of 6 studies: reductions in **CARDIOVASCULAR DISEASE** subcategories

- 2 of 5 studies: improvements in **RESPIRATORY OUTCOMES**

- 2 German studies showed that **HEALTH BENEFITS TENDED TO GROW OVER 3- AND 5-YEAR PERIODS**

- 1 study in Japan detected **IMPROVEMENTS IN LUNG CANCER RATES 6 TO 9 YEARS LATER**

SOCIOECONOMIC POSITION,
AIR POLLUTION AND BENEFITS FROM LEZ

ROME

Wealthy residents…

✓ are more likely to live in the city centre

✓ are exposed more than disadvantaged groups

to higher air pollution concentrations

✓ because the LEZ targeted the central area of
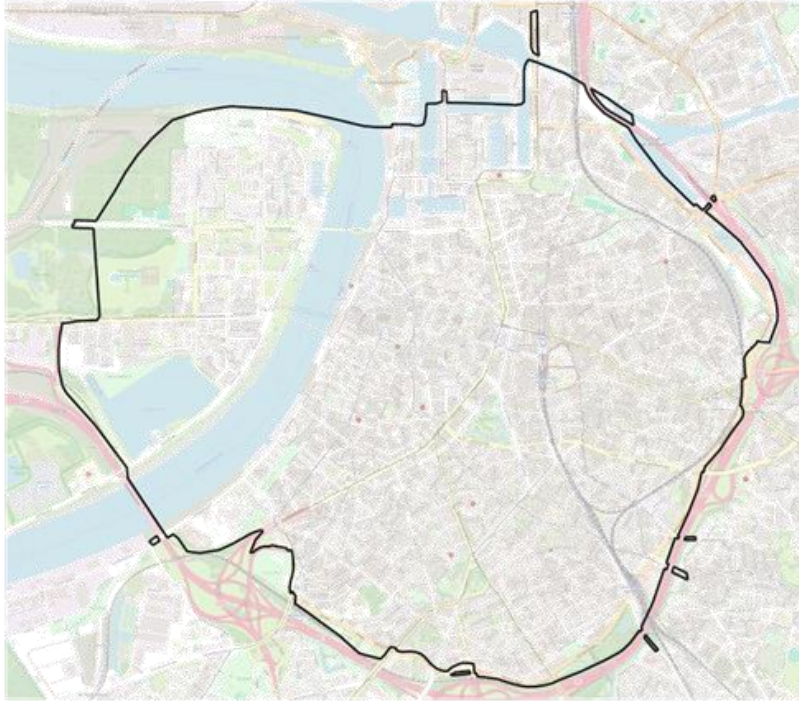
the city, they profited more

LONDON

More deprived areas…

✓ have higher air pollution concentrations

✓ experienced greater air pollution reductions

and mortality benefits compared to the least

deprived areas

Note: contradicting findings have also emerged likely resulting from different levels of analyses

and deprivation measures, see Verbeek & Hinckx, 2022.

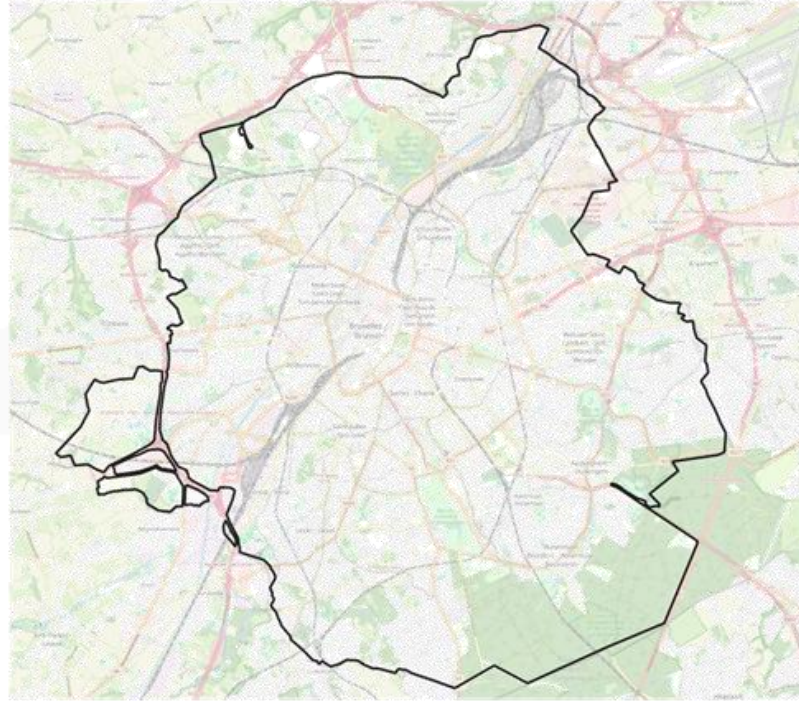Cesaroni et al. Health benefits of traffic-related air pollution reduction in different socioeconomic groups: the effect of low-emission zoning in Rome. Occup Environ Med, 2011
Logika Consultants. Air Pollution and Inequalities in London: 2019 Update, Greater London Authority, 2021

THERE ARE 3 LOW-EMISSION ZONES IN BELGIUM

ANTWERP LEZ

BRUSSELS LEZ

GHENT LEZ

LEZ since 2017

LEZ since 2018

LEZ since 2020

stricter regulations in 2020

stricter regulations in 2019, 2020 and 2022
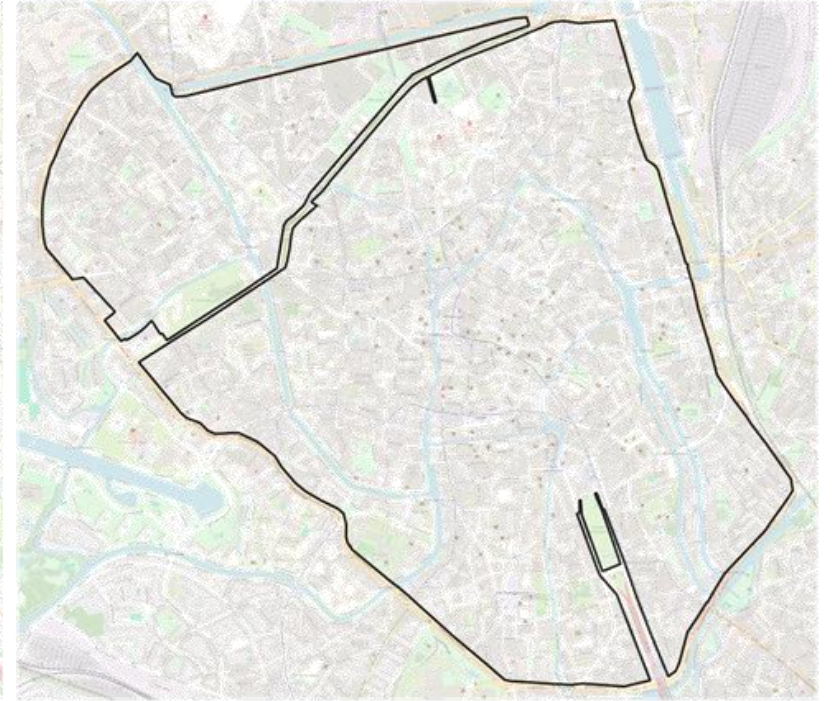
LOW-EMISSION ZONES PLAUSIBLY CREATE EXOGENOUS VARIATION IN AIR POLLUTION, AND SUBSEQUENTLY IMPACT HEALTH

Study objectives

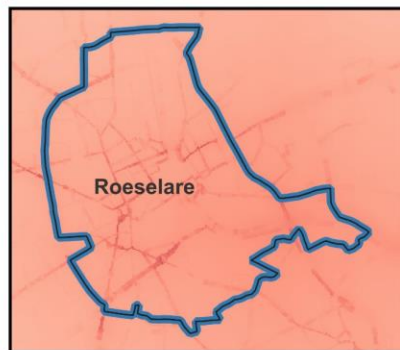I. Evolution of **AIR QUALITY** since the implementation of the LEZs,

compared to other cities

II. Differential exposure to air pollution according to **SOCIOECONOMIC POSITION**,

and the evolution thereof since the implementation of the LEZ

III. **HEALTH IMPACT** of the implementation of the LEZs, compared to other cities

NO₂ (2022)

Range

3.19µg/m³ 30.49µg/m³
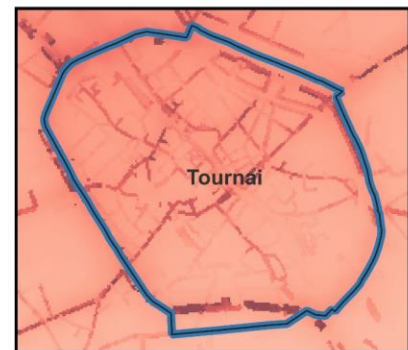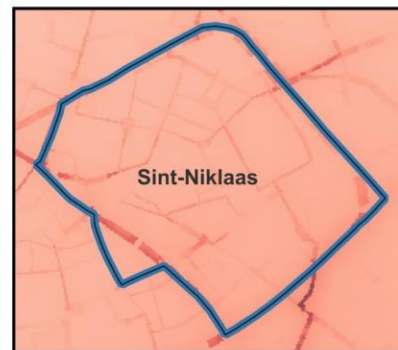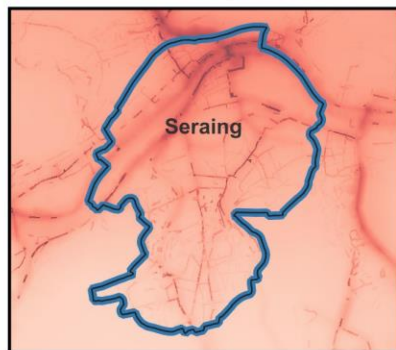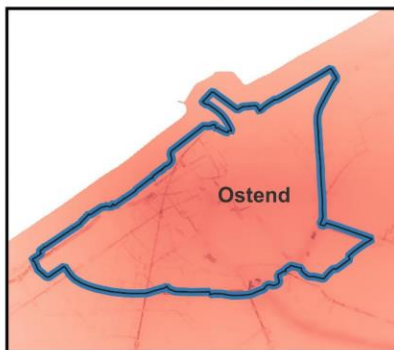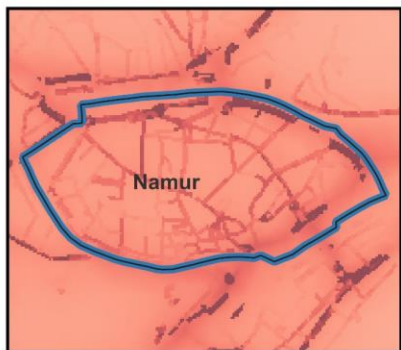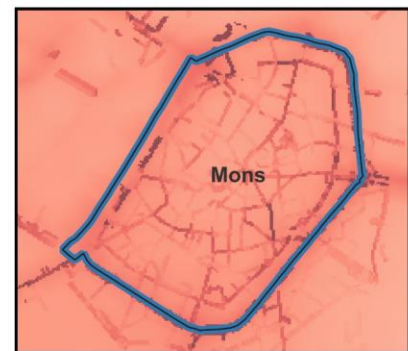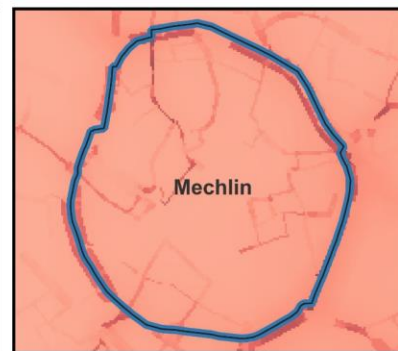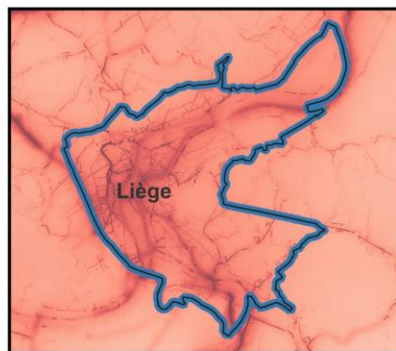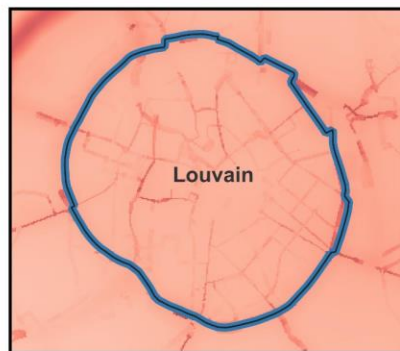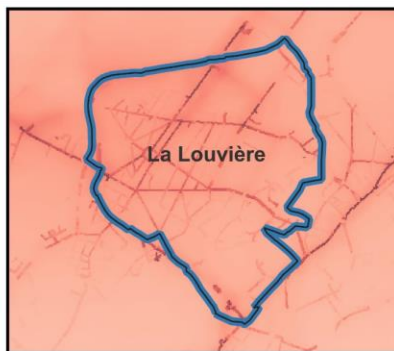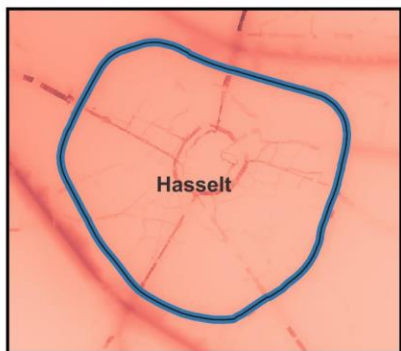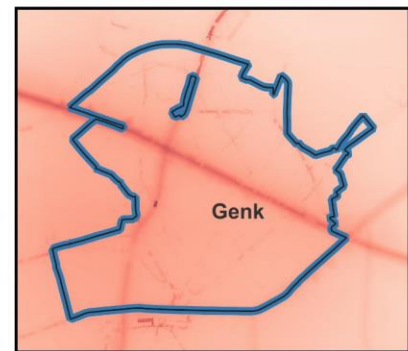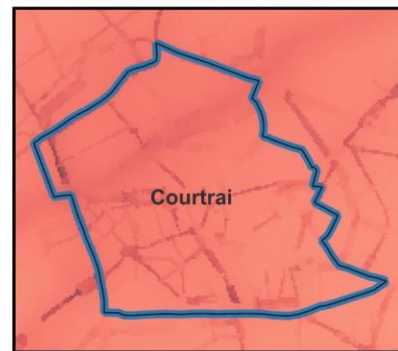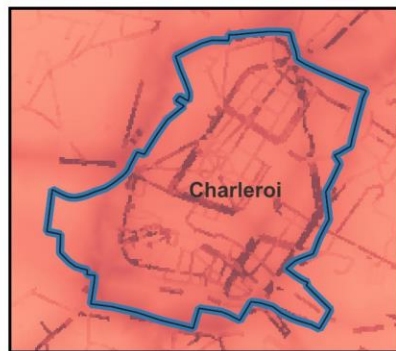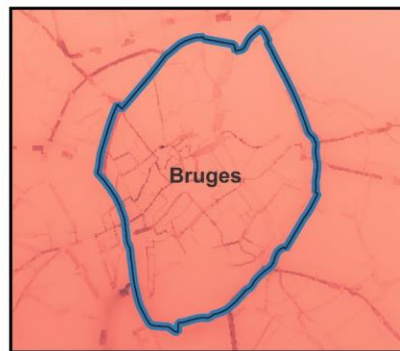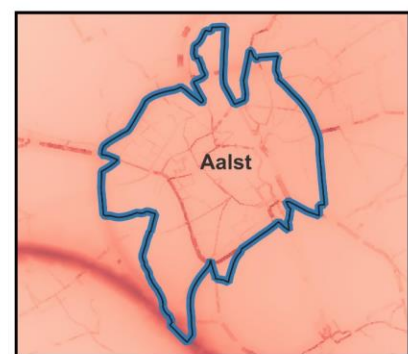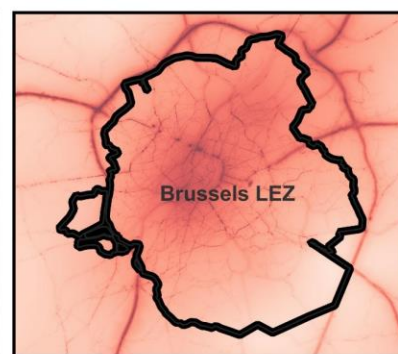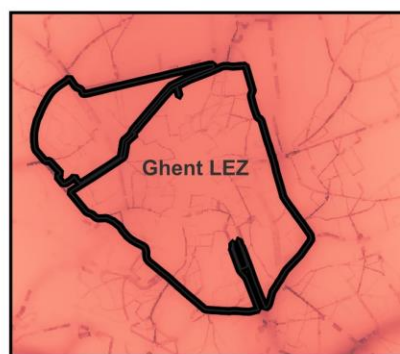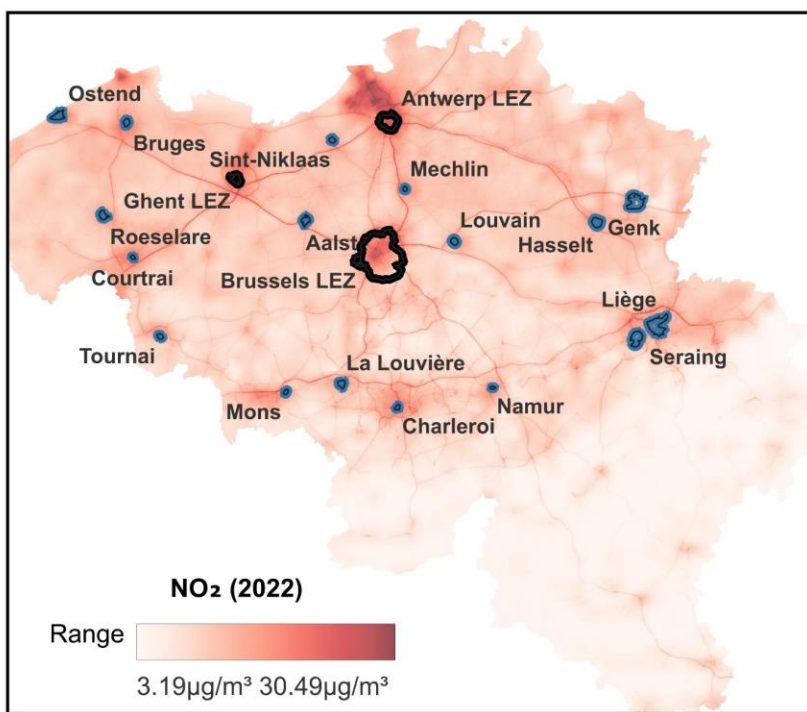
STUDY POPULATION

The study population comprises **175.691**

MEMBERS of the Independent Health

Insurance Funds (~2.2 million members)

LIVING AT THE SAME ADDRESS DURING THE

STUDY PERIOD (01-01-2014 TO 31-12-2023)

within either the 3 LEZ or 17 control cities

Example of geolocation of members of the Independent Health Insurance Funds

I. IMPROVEMENT OF **AIR QUALITY** IN THE LEZ CITIES, COMPARED TO CONTROL CITIES

AIR QUALITY MEASURES ARE DERIVED FROM HIGH SPATIAL RESOLUTION AIR QUALITY MODELS

Air quality measures include average annual concentrations of **$PM_{2.5}$, PM_{10}, NO_2 AND BC FOR 2016-2022**, and are **CALCULATED FOR ALL INCLUDED INDIVIDUAL MEMBERS** from ATMO-Street data provided by the Belgian Interregional Environment Agency

Note: average annual concentrations for the pollutants were **ALSO CALCULATED FOR THE FULL GEOGRAPHICAL AREA** for the 3 LEZs and 17 control cities – findings did not statistically significantly differ from findings based on the concentrations calculated for our members

*Modelled data used in this study originate from ATMO-Street, an integrated model chain that models air quality at high resolution

STATISTICAL ANALYSIS:
REPEATED MEASURES ANCOVA

✓ Random coefficient model approach, with **BASELINE** as covariate

(sensitivity analysis: baseline*year)

✓ **ANTWERP COMPARED WITH FLEMISH CONTROL CITIES** since LEZ was implemented in 2017

and no pre-LEZ ATMO-Street data for Wallonia available in 2016 (so no baseline available)

✓ **BRUSSELS COMPARED WITH FLEMISH AND WALLOON CONTROL CITIES**

✓ **GHENT NOT EVALUATED**, for now, as LEZ implementation coincided with COVID-19, and few

post-measures are available

FINDINGS: AIR POLLUTION OVER TIME FOR LEZ AND CONTROL CITIES
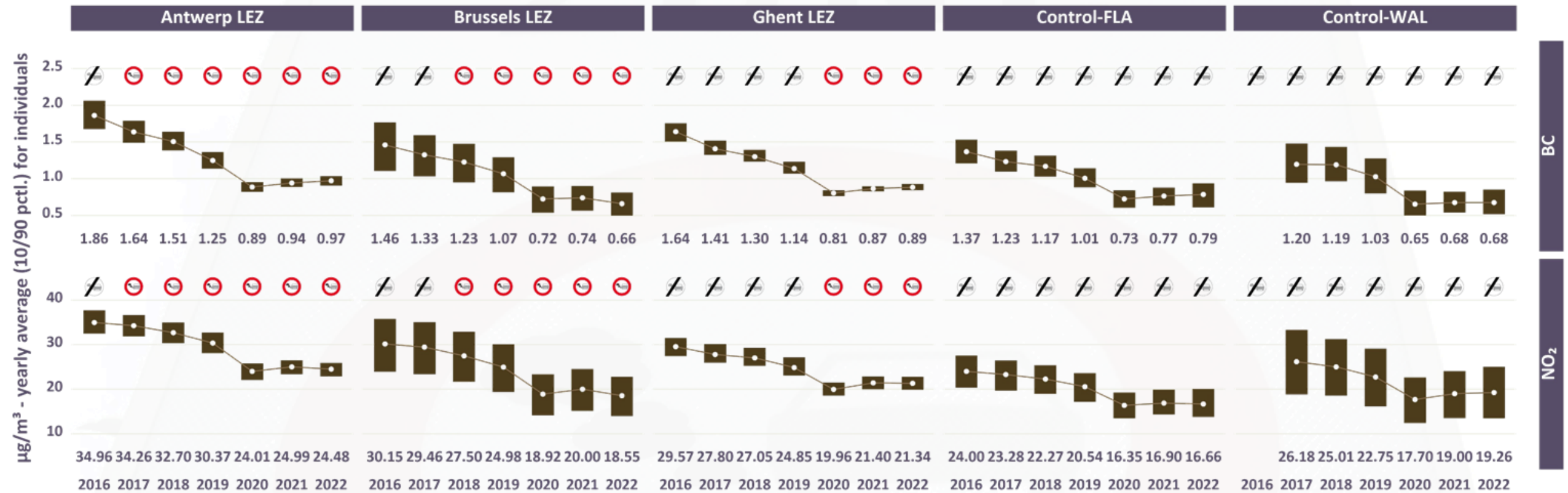
ANTWERP vs CONTROL CITIES IN FLANDERS	BC	NO₂
pre-LEZ (2016)	—	—
LEZ (2022)	—	—
change 2017-2022	⬇	⬇

BRUSSELS vs CONTROL CITIES IN FLANDERS	BC	NO₂
pre-LEZ (2017)	—	—
LEZ (2022)	+	—
change 2018-2022	⬇	⬇

BRUSSELS vs CONTROL CITIES IN WALLONIA	BC	NO₂
pre-LEZ (2017)	—	—
LEZ (2022)	+	+
change 2018-2022	⬇	⬇

— (pre-)LEZ worse than control   + (pre-)LEZ better than control   ⬇ Larger improvement in LEZ than in control

FINDINGS: AIR POLLUTION OVER TIME FOR LEZ AND CONTROL CITIES

	Antwerp LEZ	Brussels LEZ	Ghent LEZ	Control-FLA	Control-WAL

PM₁₀ (µg/m³ – yearly average (10/90 pctl.) for individuals)

Antwerp LEZ: 22.73, 23.35, 24.51, 22.74, 21.46, 21.68, 22.35
Brussels LEZ: 19.79, 19.46, 20.49, 18.08, 16.08, 16.99, 17.42
Ghent LEZ: 23.39, 22.89, 24.21, 22.28, 20.66, 21.22, 22.37
Control-FLA: 21.15, 21.13, 22.56, 20.71, 19.64, 19.87, 20.80
Control-WAL: 17.47, 19.08, 16.08, 14.04, 15.68, 15.83

PM₂.₅

Antwerp LEZ: 14.03, 14.30, 14.38, 12.90, 11.27, 12.00, 11.66
Brussels LEZ: 13.77, 13.00, 13.07, 11.34, 9.28, 10.65, 10.14
Ghent LEZ: 14.33, 14.00, 14.69, 13.24, 11.24, 12.00, 12.10
Control-FLA: 13.46, 13.36, 14.07, 12.56, 10.98, 11.75, 11.73
Control-WAL: 10.15, 10.61, 8.68, 6.58, 8.62, 7.63

Years: 2016 2017 2018 2019 2020 2021 2022

ANTWERP vs CONTROL CITIES IN FLANDERS

	PM₁₀	PM₂.₅
pre-LEZ (2016)	−	−
LEZ (2022)	−	+
change 2017-2022	⬇	⬇

BRUSSELS vs CONTROL CITIES IN FLANDERS

	PM₁₀	PM₂.₅
pre-LEZ (2017)	+	+
LEZ (2022)	+	+
change 2018-2022	⬇	⬇

BRUSSELS vs CONTROL CITIES IN WALLONIA

	PM₁₀	PM₂.₅
pre-LEZ (2017)	−	−
LEZ (2022)	−	−
change 2018-2022	⬇	⬇

− (pre-)LEZ worse than control   + (pre-)LEZ better than control   ⬇ Larger improvement in LEZ than in control

II. SOCIOECONOMIC POSITION &
(THE EVOLUTION OF) EXPOSURE TO AIR POLLUTION

STATISTICAL ANALYSIS:
REPEATED MEASURES ANCOVA

✓ Measure of deprivation: **BELGIAN INDICES OF MULTIPLE DEPRIVATION (BIMD) DECILES**

(for the year 2011), with a focus on **BRUSSELS**

✓ BIMD (income, employment, education, housing) without the health deprivation domain

✓ BIMD deciles were categorized as 1 – Most deprived (n=263), 2 (n=146), 3 (n=112), 4 (n=75),

≥5 – Least deprived (n=94), for a total of 690 census tracts

✓ Random coefficient model approach, with **BASELINE** as covariate

(sensitivity analysis: baseline*year)

FINDINGS: DIFFERENTIAL EVOLUTION OF AIR POLLUTION WITHIN LEZ ACCORDING TO SOCIOECONOMIC STATUS (IN BRUSSELS)

BIMD DECILES · **BIMD DECILES & NO₂ OVERLAY** · **TREE COVER** · **CAR OWNERSHIP**

BIMD deciles (2011)
- 1 (Most deprived)
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10 (Least deprived)
- Not calculated

NO₂ (2022)
Range 3.19µg/m³ 30.49µg/m³

Tree cover (2018)
- 0 - 9.99%
- 10 - 10.99%
- 20 - 20.99%
- ≥30%

Cars by household (2022)
- 0 - 0.93
- 0.93 - 1.12
- 1.12 - 1.24
- 1.24 - 1.33
- 1.33 - 1.41
- 1.41 - 1.51
- ≥1.51
- Not calculated

FINDINGS: DIFFERENTIAL EVOLUTION OF AIR POLLUTION WITHIN LEZ ACCORDING TO SOCIOECONOMIC STATUS (IN BRUSSELS)

Air pollution ($\mu g/m^3$) average

BC

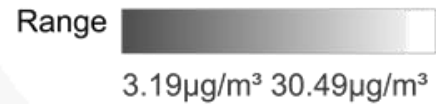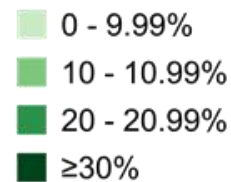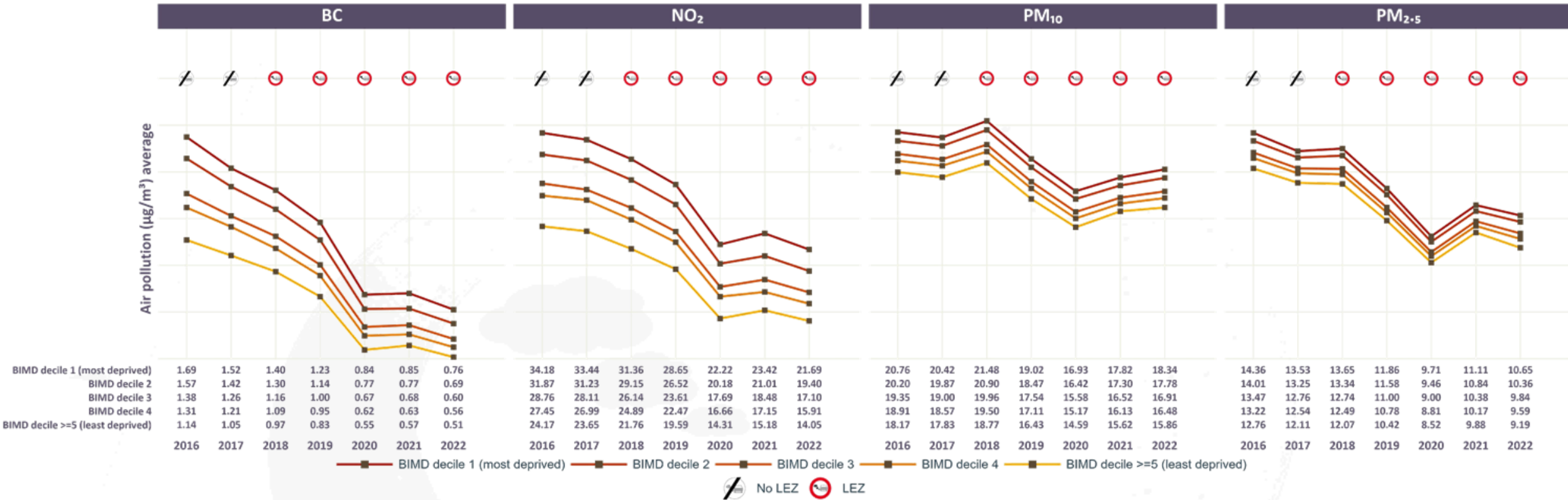|	2016	2017	2018	2019	2020	2021	2022
BIMD decile 1 (most deprived)	1.69	1.52	1.40	1.23	0.84	0.85	0.76
BIMD decile 2	1.57	1.42	1.30	1.14	0.77	0.77	0.69
BIMD decile 3	1.38	1.26	1.16	1.00	0.67	0.68	0.60
BIMD decile 4	1.31	1.21	1.09	0.95	0.62	0.63	0.56
BIMD decile >=5 (least deprived)	1.14	1.05	0.97	0.83	0.55	0.57	0.51

NO_2

	2016	2017	2018	2019	2020	2021	2022
BIMD decile 1 (most deprived)	34.18	33.44	31.36	28.65	22.22	23.42	21.69
BIMD decile 2	31.87	31.23	29.15	26.52	20.18	21.01	19.40
BIMD decile 3	28.76	28.11	26.14	23.61	17.69	18.48	17.10
BIMD decile 4	27.45	26.99	24.89	22.47	16.66	17.15	15.91
BIMD decile >=5 (least deprived)	24.17	23.65	21.76	19.59	14.31	15.18	14.05

PM_{10}

	2016	2017	2018	2019	2020	2021	2022
BIMD decile 1 (most deprived)	20.76	20.42	21.48	19.02	16.93	17.82	18.34
BIMD decile 2	20.20	19.87	20.90	18.47	16.42	17.30	17.78
BIMD decile 3	19.35	19.00	19.96	17.54	15.58	16.52	16.91
BIMD decile 4	18.91	18.57	19.50	17.11	15.17	16.13	16.48
BIMD decile >=5 (least deprived)	18.17	17.83	18.77	16.43	14.59	15.62	15.86

$PM_{2.5}$

	2016	2017	2018	2019	2020	2021	2022
BIMD decile 1 (most deprived)	14.36	13.53	13.65	11.86	9.71	11.11	10.65
BIMD decile 2	14.01	13.25	13.34	11.58	9.46	10.84	10.36
BIMD decile 3	13.47	12.76	12.74	11.00	9.00	10.38	9.84
BIMD decile 4	13.22	12.54	12.49	10.78	8.81	10.17	9.59
BIMD decile >=5 (least deprived)	12.76	12.11	12.07	10.42	8.52	9.88	9.19

Legend: BIMD decile 1 (most deprived) — BIMD decile 2 — BIMD decile 3 — BIMD decile 4 — BIMD decile >=5 (least deprived)

No LEZ | LEZ

✓ Controlling for the pre-LEZ value (in 2017), there is a **STATISTICALLY SIGNIFICANT DIFFERENCE IN THE CHANGE IN BC AND NO_2** over time across BIMD deciles | for BC there is a systematically slower decrease with lesser deprivation | for NO_2 there is a slower decrease for BIMD decile ≥5 → **MORE DEPRIVATION = MORE RAPID DECREASE**

✓ Controlling for the pre-LEZ value (in 2017) there is **NO STATISTICALLY SIGNIFICANT DIFFERENCE IN THE CHANGE IN PM_{10} AND $PM_{2.5}$** over time across BIMD deciles

✓ Exposure to these **POLLUTANTS REMAINS STATISTICALLY SIGNIFICANTLY HIGHER IN MORE DEPRIVED BIMD DECILES**

III. HEALTH IMPACT FROM THE INTRODUCTION OF LEZs

AIR POLLUTION-RELATED HEALTH OUTCOMES ARE MEASURED FROM INDIVIDUAL-LEVEL HEALTH CARE EXPENDITURE DATA

Repeated measurements, equally spaced by year, were created for:

✓ Number of all-cause **IN-HOURS/OUT-OF-HOURS GENERAL PRACITIONER VISITS**

✓ Number of all-cause **EMERGENCY ROOM VISITS**

✓ Chronic (≥90 DDD) use of drugs:

DIABETES (A10A & A10B)

CARDIOVASCULAR DISEASE (C01 C02 C03 C07 C08 C09)

OBSTRUCTIVE AIRWAY DISEASES (R03)

ANTIDEPRESSANTS (N06A)

ANTITHROMBOTIC AGENTS (B01)

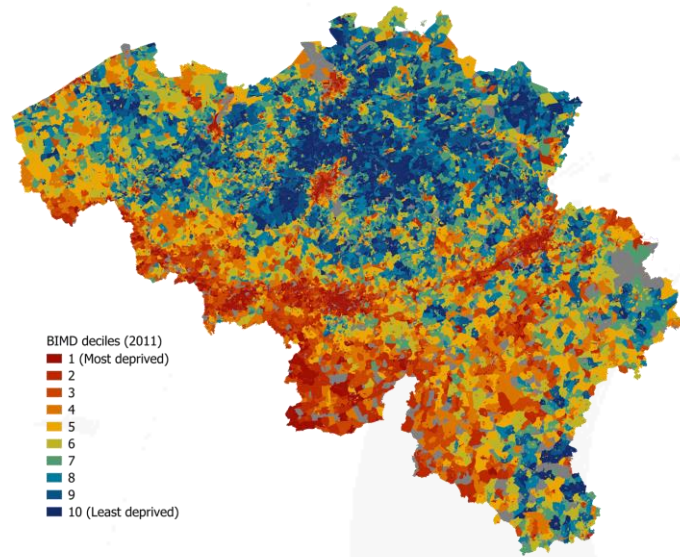# PROPENSITY MATCHING TO BALANCE MEMBERS LIVING IN LEZ AND CONTROL CITIES

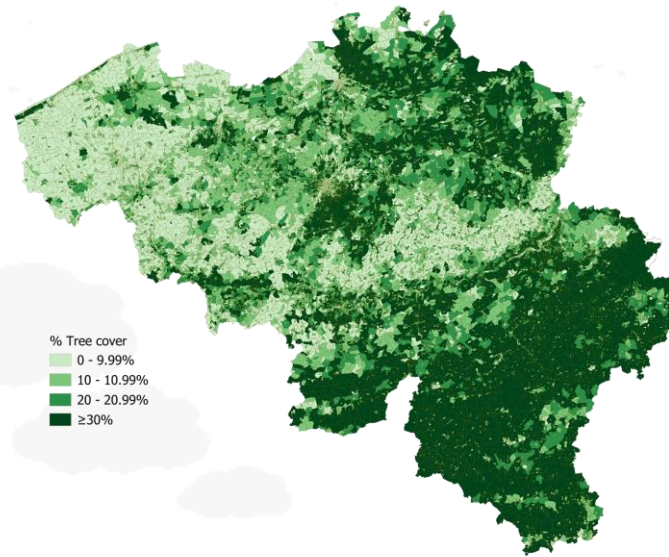## BELGIAN INDICES OF MULTIPLE DEVRIVATION

BIMD deciles (2011)
- 1 (Most deprived)
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10 (Least deprived)

BIMD deciles combine information from 6 domains: income, employment, education, housing, health and crime
Data for 2011

TREE COVER

% Tree cover
- 0 - 9.99%
- 10 - 10.99%
- 20 - 20.99%
- ≥30%

High Resolution Layers from the Copernicus Land Monitoring Service Dominant Leaf Type and Grassland 10 × 10 m raster data
Data for 2018

## URBAN/RURAL

Density
- Rural
- Urban
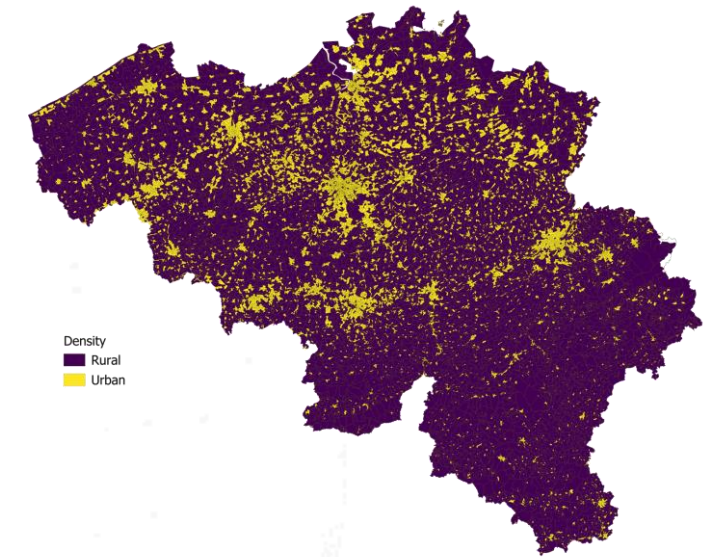
Having a population density of more or less than 600 inhabitants/km^2 at the level of the census tract, respectively
Data for 2014

Individual-level characteristics included in the analysis are AGE GENDER and NATIONALITY

STATISTICAL ANALYSIS: INTERRUPTED TIME SERIES ANALYSIS WITH CONTROL GROUP

✓ Generalized Estimating Equations (GEE) to account for repeated outcome measures

✓ Negative binomial GEE to the count outcomes

✓ Binary logistic GEE to the binary outcomes

✓ Estimation and testing on the event probability scale

✓ Subgroup analyses by age categories and BIMD
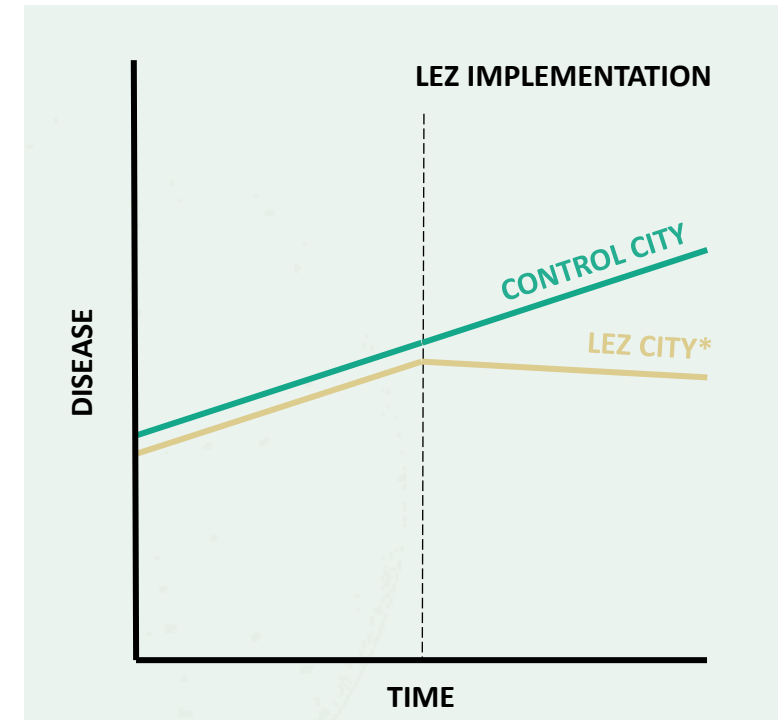
* The curve may take a different shape e.g. a slope change following a lag

CONCLUSION

- ✓ Air pollution concentrations in Belgium **STILL LARGELY EXCEED WHO AQG LEVELS**

- ✓ Compared to control cities, **BC, NO$_2$, PM$_{10}$ and PM$_{2.5}$ SHOWED A LARGER DECREASE IN ANTWERP AND BRUSSELS SINCE THE IMPLEMENTATION OF THE LEZ**

- ✓ In Brussels, **MORE DEPRIVED NEIGHBOURHOODS BEAR THE HEAVIEST BURDEN**, but for NO$_2$ and BC more deprived neighbourhoods **BENEFITED MOST** since the implementation of the LEZ