Breathe Warsaw Low Emission Zone Assessment

Final Report

September 2023

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Date Issued:	08 September 2023
Document Number:	ED17121 – 2.1
Project:	ED17121
Client Project Ref.:	001330
Client:	Clean Air Fund

Breathe Warsaw Low Emission Zone Assessment

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Reference Number	Issued Date	Revision
ED17121 – D1	01 June 2023	1
ED17121 – D1.1	09 June 2023	1.1
ED17121 – D2	23 August 2023	2.0
ED17121 – 2.1	08 September 2023	2.1

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Introduction

The City of Warsaw is developing plans for the implementation of a Low Emission Zone in the centre of the city. The scheme would affect all vehicle types equally and be based on a full vehicle ban (with associated fines). The Clean Air Fund is providing support to the city to assist in the development of the scheme through two projects:

1. An assessment of the Warsaw vehicle fleet and their real-world emissions, being carried out by the International Council for Clean Transport (ICCT)
2. An impact assessment study to understand the air quality and economic impacts of the LEZ options, being carried out by Ricardo

The Ricardo study has three phases:

1. Phase 1 – assessment of available data and defining the scope and methodology for the assessment
2. Phase 2 – assessment of two LEZ options for the city
3. Phase 3 – provide recommendations for policy makers on a preferred LEZ option

This report presents the results of the phase 2 assessment and provides draft recommendations for policy makers on a preferred LEZ option

Understanding and scope of the assessment

Boundary of scheme and assessment

- The proposed boundary for the LEZ scheme is shown below in Figure 1
- However, to understand the full impact of the scheme the assessment boundary will be taken as that of the city authority as indicated in Figure 2

Figure 1: LEZ boundary

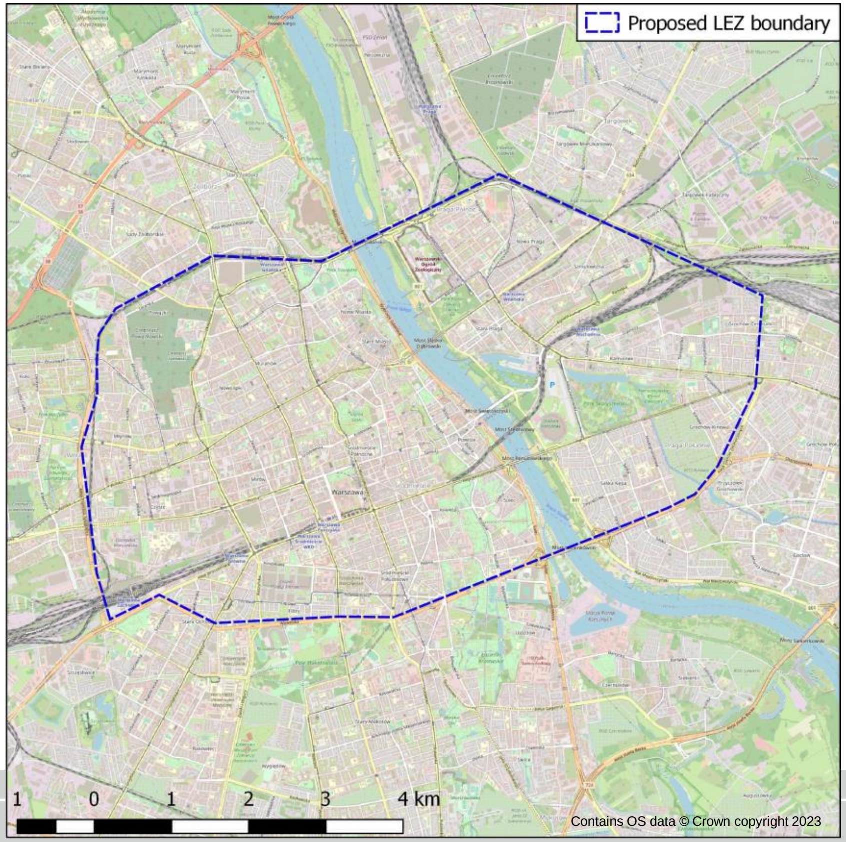
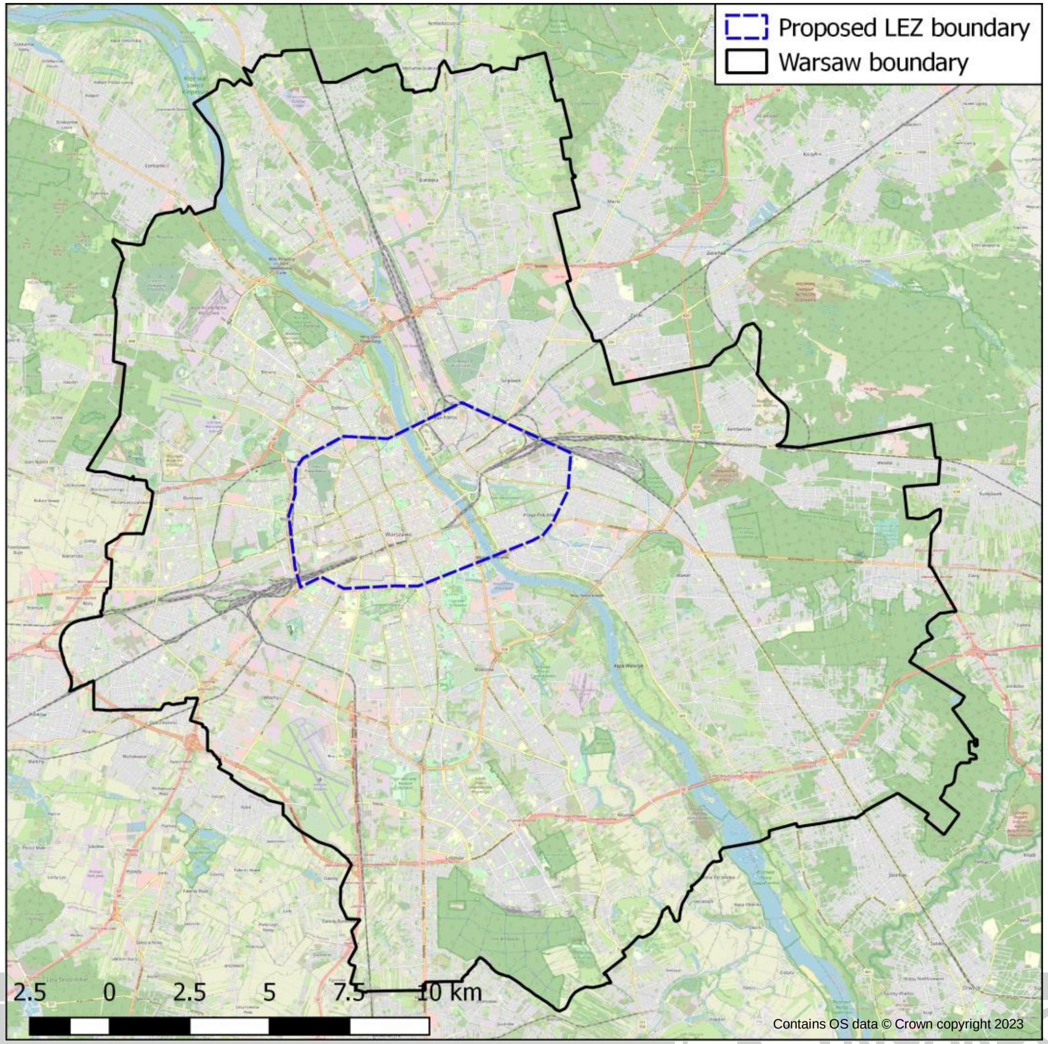


Figure 2: Assessment boundary covering the whole city



Assessment years

The assessment will use two assessment years:

- A **base year** with existing data on which to build and validate the air quality model
- A **future assessment year** in which the LEZ scheme will be implemented

The **base year** was taken as **2019**. This is the base year for the traffic model that will provide the main traffic activity data. It is also a year that will have been unaffected by the COVID-19 pandemic.

Currently the proposal is for a phased approach to the implementation of the LEZ (as shown opposite). We modelled **one future year** and focussed the assessment of scheme options on **2026.**

Rok wdrożenia / Pojazd z silnikiem	**2024**	**2026**	**2028**	**2030**	**2032**
	Etap 1	Etap 2	Etap 3	Etap 4	Etap 5
Benzynowym	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Euro 6**
	max. 27 lat	max. 20 lat	max. 17 lat	max. 15 lat	max. 13 lat
Diesla	**Euro 4**	**Euro 5**	**Euro 6**	**Euroo 6dT**	**Euro 6d**
	max. 18 lat	max. 11 lat	max. 9 lat	max. 9 lat	max. 9 lat
*% aut wg CEPIK 2021**	*13,20%*	*32,40%*	*48,90%*	*69,40%*	*76,80%*
% aut wg pom. ICCT**	**2%**	**9%**	**16%**	**23%**	**27%**
Spadek emisji NOx	-11%	-27%	-55%	-74%	-80%
Spadek emisji PM	-20%	-55%	-66%	-68%	-69%

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Scheme options

The current proposals are for a scheme that affects all vehicle types equally. The scheme will be based on a full vehicle ban (with associated fines) and enforced through either a sticker system or an automatic number plate recognition (ANPR) camera system.

The proposal is for a phased introduction with standards tightening over time. Two of the phases were modelled for the proposed future assessment year, these were:

- **Phase 2 – Euro 3 Petrol, Euro 5 Diesel**
- **Phase 3 – Euro 4 Petrol, Euro 6 Diesel**

The difference between the two phases was judged likely to be signficant. Modelling them both in 2026 allows them to be directly compared and will also indicate the impact and practically of bringing the more stringent standards in at an earlier date.

Rok wdrożenia / Pojazd z silnikiem	**2024**	**2026**	**2028**	**2030**	**2032**
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Spadek emisji PM	-20%	-55%	-66%	-68%	-69%

Behavioural assumptions

How will different vehicle types react to the scheme?

- Key to the assessment of the LEZ will be the assumptions on how different vehicle types will respond to the scheme
- The table below sets out the key responses that are likely to occur and the assumptions that will need to be made

	Cars	Vans	HGVs	City buses	Other buses
Change travel behaviour with a non-compliant vehicle					
Divert around zone*	✓ If not destination	✓ If not destination	✓ If not destination	X	X
Change destination	? Is this possible	X	X	X	X
Change mode	✓	? Shift to HGV	X	X	X
Cancel trip	✓	? Consolidate	? Consolidate	X	?
Change/Upgrade a non-compliant vehicle					
New vehicle	✓	✓	✓	✓	✓
Second hand vehicle	✓	✓	✓	✓	✓
Switch fuel	✓	✓	? Unlikely	?	?
Risk fine	✓	✓	✓	X	X

*Vehicles unlikely to divert on eastern side of zone owing to the unsuitability of alternative routes

Behavioural response assumptions

The following behavioural response assumptions were applied to assess the impact of the LEZ scheme and were split between activity within the LEZ and that outside the LEZ:

Vehicles within LEZ:

- Travel behaviour response - we first removed the following percentage of non-compliant vehicles before applying the upgrade response to account for vehicles potentially diverting, cancelling their trip or changing mode:

Vehicle type	Cars	Vans	HGVs	City buses	Other buses
Remove AADT (LEZ only)*	29%	16%	8%	0%	10%

- Upgrade response - percentage of the non-compliant fleet that upgrade to a compliant vehicle:

Vehicle type	Cars	Vans	HGVs	City buses	Other buses
Fleet upgrade*	90%	76%	90%	100%	89%

  - Vehicles upgrade to same mix as future year compliant mix

Vehicles outside LEZ:

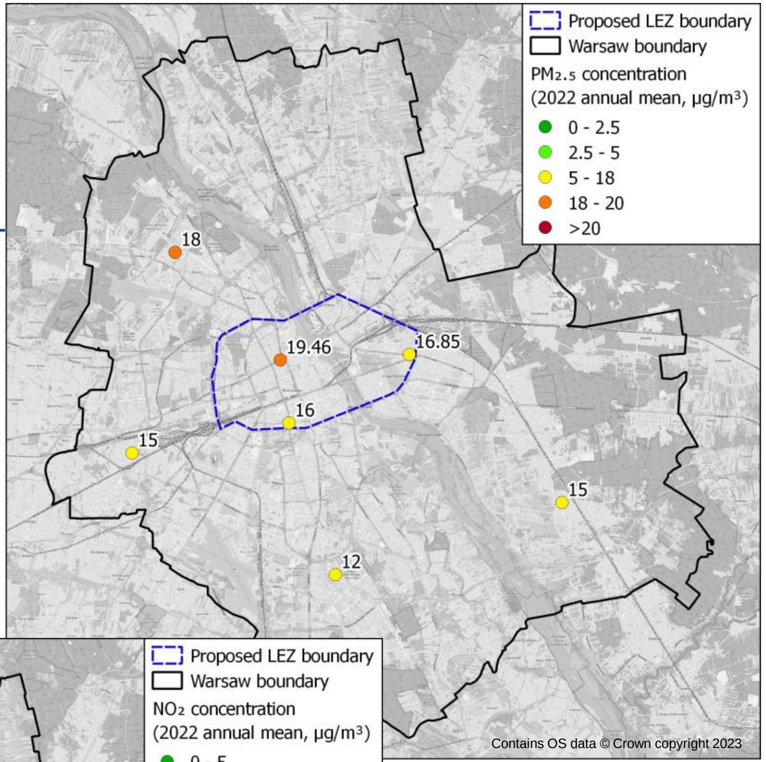
- Travel behaviour response - we did not apply any travel behaviour response as these are uncertain. Mode shift may therefore occur but it will not be included outside the LEZ
- Traffic diverted around the LEZ will not be allocated to roads outside the LEZ as we cannot reliably forecast where it will go
- Upgrade response - we have assumed that **19% of non-compliant vehicles will see an upgrade response**. This is because the transport model shows that an average of 19% of trips that start outside of the LEZ end in the LEZ

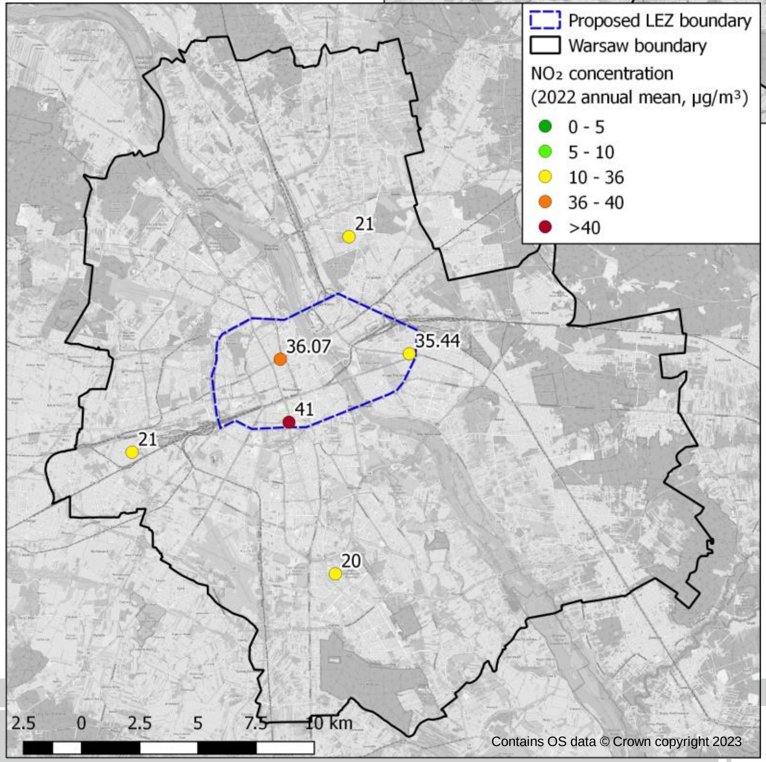
*Assumptions based on London ULEZ data (Ref: JAQU CAZ Appraisal Guidance 2019). Response shown in terms of VKM changes

Air quality modelling

Current air quality in Warsaw

- Monitoring data provides annual mean concentrations of NO_2, PM_{10} & $PM_{2.5}$ at points across the city
  - City reference sites (2021 – present)
  - EA - European Air Quality Portal (2019 – present)(1)
- In 2022, the City of Warsaw had one automatic monitoring location in exceedance of the European annual limit value for NO_2 (red) and one location identified as at risk of exceeding (within 10% of) the limit value (orange). Two locations were also observed as being within 10% of the limit value for $PM_{2.5}$
- All measurements of NO_2, PM_{10} & $PM_{2.5}$ were above the World Health Organisation (WHO) Air Quality Guidelines(2) (yellow)





Measurement location	Site type	In LEZ?	Year	$PM_{2.5}$	PM_{10}	NO_2
244A Grochowska Street (City)	Urban roadside	Yes	2022	16.85	25.12	35.44
83/89 Solidarności Street (City)	Urban roadside	Yes	2022	19.46	29.46	36.07
Warszawa, al. Niepodległości	Urban roadside	Yes	2022	16.00	32.00	41.00
Warszawa, ul. Wokalna	Background	No	2022	12.00	17.00	20.00
Warszawa, ul. Kondratowicza	Background	No	2022			21.00
Warszawa, ul. Chrościckiego	Suburban roadside	No	2022	15.00	22.00	21.00
Warszawa, ul. Tołstoja	Background	No	2022	18.00	26.00	
Warszawa, ul. Bajkowa	Background	No	2022	15.00	22.00	
European limit value (µg/m^3)				20	40	40
WHO 2021 AQGs (µg/m^3)				5	15	10

(1) Source: EEA - Attainment viewer https://eeadmz1-cws-wp-air02.azurewebsites.net/index.php/users-corner/attainment-viewer/
(2) https://apps.who.int/iris/handle/10665/345329

Modelling overview

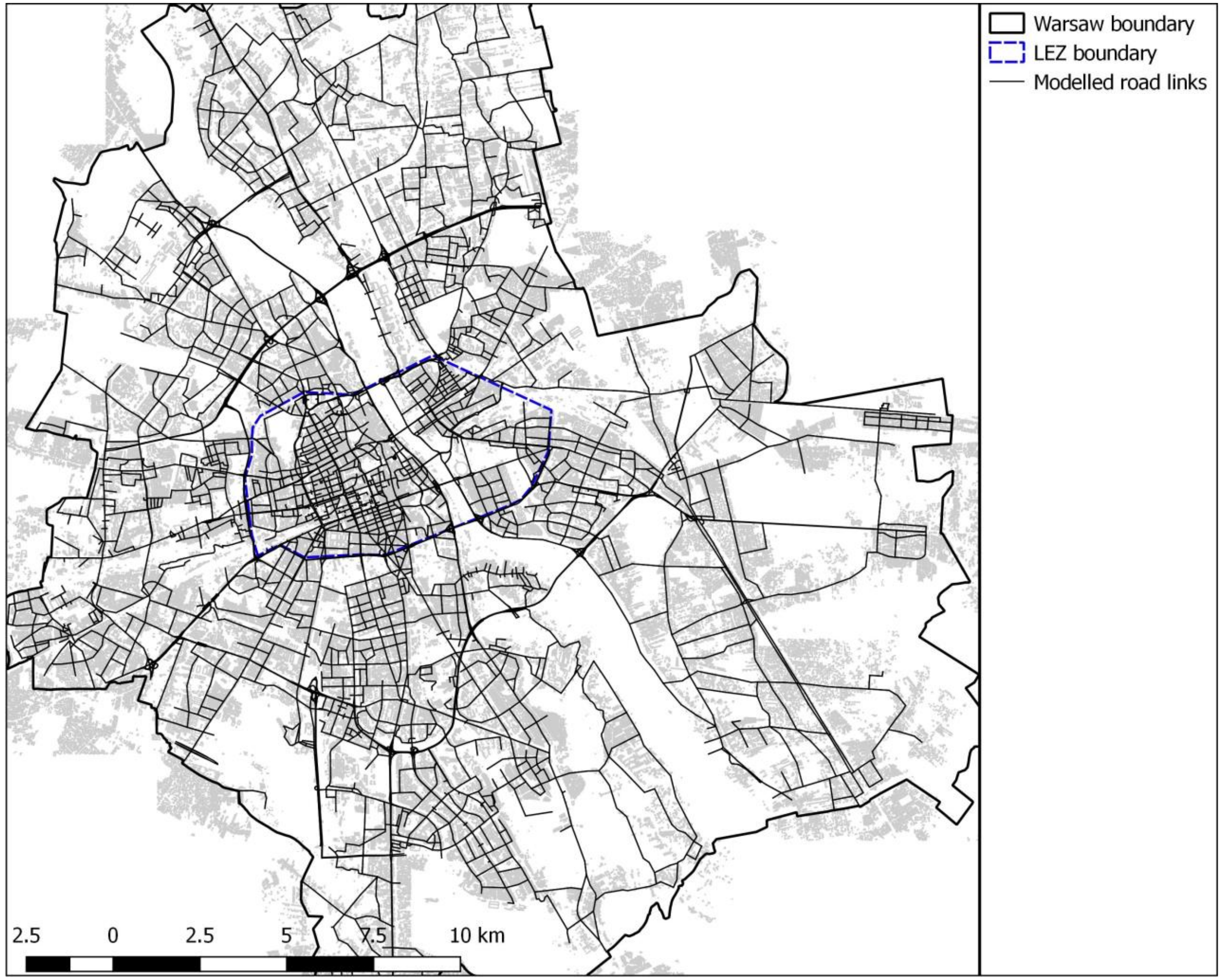
Scenarios

We have provided NO_2, PM_{10} and $PM_{2.5}$ annual mean concentration outputs for:

1. **2019 base year** for model validation against monitored data
2. **2026 Baseline** (or do nothing) future scenario against which to compare the LEZ scenarios
3. **2026 Option 1: LEZ Phase 2 with no travel behaviour response**
   - Phase 2 – Euro 3 Petrol, Euro 5 Diesel
4. **2026 Option 1: LEZ Phase 2 with travel behaviour (TB) response**
   - Phase 2 – Euro 3 Petrol, Euro 5 Diesel
5. **2026 Option 2: LEZ Phase 3 with no travel behaviour response**
   - Phase 3 – Euro 4 Petrol, Euro 6 Diesel
6. **2026 Option 2: LEZ Phase 3 with travel behaviour (TB) response**
   - Phase 3 – Euro 4 Petrol, Euro 6 Diesel

Sensitivity test

- The two LEZ scenarios (4 & 6) which include a travel behaviour response in addition to an upgrade response are deemed to represent the most likely response to the scheme
- Results from the two LEZ scenarios (3 & 5) which only include an upgrade response are provided as a sensitivity test



Model inputs

Model selection

- The RapidAIR©[1] Urban Air Quality Modelling Platform was used to predict air pollutant concentrations for this study. This is Ricardo Energy & Environment's proprietary modelling system developed for urban air pollution assessment
- The model approach is based on loose coupling of three elements:
  - Road traffic emissions model conducted using fleet specific COPERT 5 algorithms to prepare grams/kilometre/second (g/km/s) emission rates of air pollutants originating from traffic sources
  - Convolution of an emissions grid with dispersion kernels derived from the USEPA AERMOD[2] model, at resolutions ranging from 1 m to 20 m
  - The kernel based RapidAIR model running in GIS software to prepare dispersion fields of concentration for further analysis with a set of decision support tools coded in Python/arcpy

Meteorology

- RapidAIR includes an automated meteorological processor based on AERMET which obtains and processes meteorological data of a format suitable for use in AERMOD
- 2019 surface meteorological data was obtained from three stations (Warszawa-Okecie, Warsaw-Babice and Minsk Mazowiecki) and upper air meteorological data was obtained from two stations (Legionowo and Brest)
- RapidMet was used to carry out data filling where necessary according to methodology[3] provided by the USEPA Meteorological Monitoring Guidance for Regulatory Modelling Applications

(1) https://www.rapidair.co.uk/what-is-rapidair/
(2) https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models#aermod
(3) https://www.epa.gov/sites/default/files/2020-10/documents/mmgrma_0.pdf

Model inputs

Background concentrations

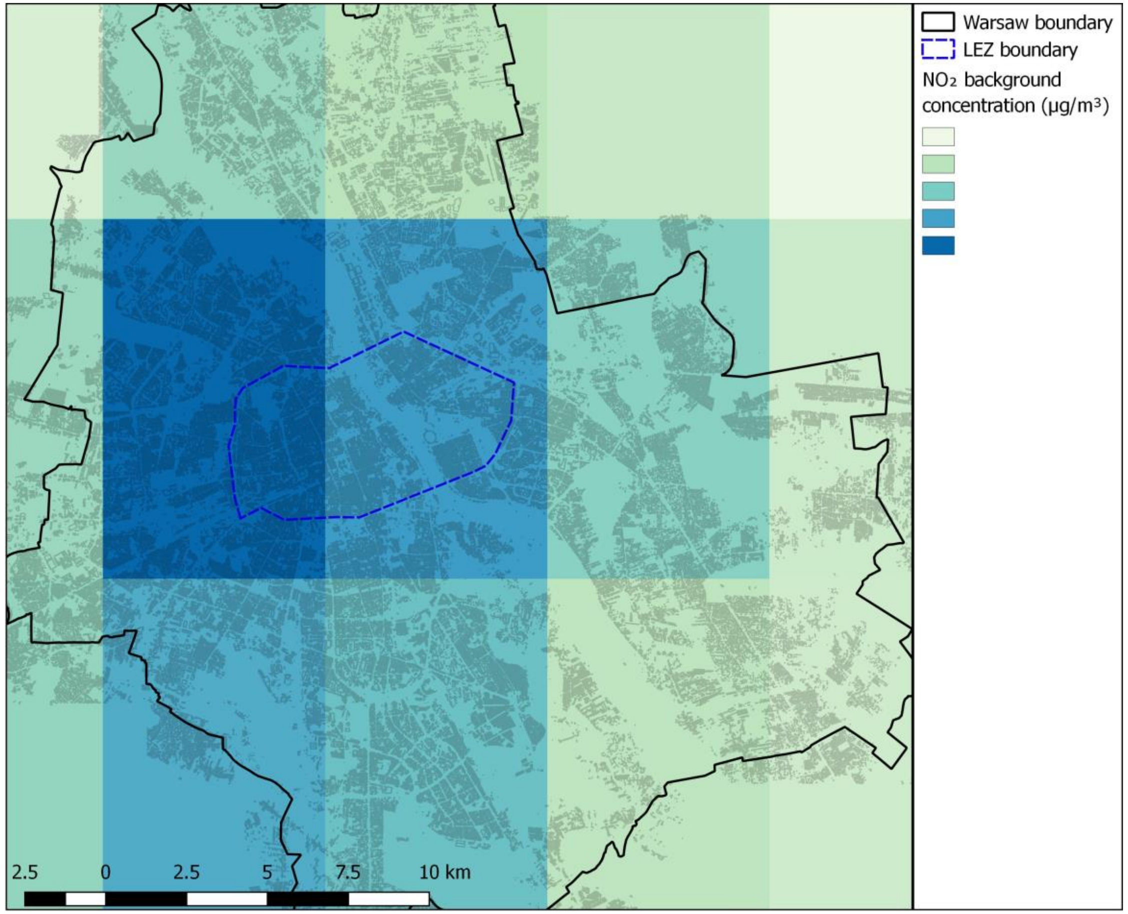
- The focus of the modelling study is road traffic emissions. Emissions from sources not included in the model were estimated using data from the following sources:
  - Air quality monitoring data recorded at background sites
  - 2022 concentrations of NO_2, PM_{10} & $PM_{2.5}$ provided by CAMS(1) at a resolution of 0.1 degrees (approximately 10 km)

Canyon modelling

- The presence of buildings either side of a road can introduce ‘street canyon’ effects which result in pollutants becoming trapped, leading to increased pollutant concentrations
- Street canyon impacts were modelled using the RapidAIR canyon module. Building heights were obtained from OpenStreetMap Buildings for Europe(2)

Road gradients

- Gradient effects were included in the modelling, based on elevation data from the Light Detection and Ranging (LIDAR) Digital Surface Model (DSM)(3)



(1) Copernicus Atmosphere Monitoring Service data downloaded from https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-europe-air-quality-forecasts?tab=overview
(2) https://hub.arcgis.com/datasets/652793c501a145b992a4cfd35b4c910e_0/about
(3) Downloaded from: https://mapy.geoportal.gov.pl/imap/Imgp_2.html

Model inputs

Traffic activity and speed data

- Annual average daily traffic (AADT) flows and 24-hour average speeds for each modelled road link were sourced from the local traffic model data provided by the City
- A traffic flow diurnal profile was applied as time varying emissions in AERMOD when creating the RapidAIR dispersion kernel. The profile was developed using a combination of Warsaw traffic count data(1) and UK Department for Transport statistics(2)

Vehicle fleet composition

- Vehicle age (Euro class) and fuel splits for the different vehicle types were compiled using data obtained from the following data sources:

Vehicle type	Source
Cars	ANPR data from Warsaw provided by the International Council on Clean Transportation (ICCT) / The Real Urban Emissions (TRUE) Initiative(3)
LGVs	
Taxis	
HGVs	National fleet for Poland from Geostatistics Portal Data(4)
Public buses	Warsaw specific data provided by the City(5)
Private buses	National fleet for Poland from Geostatistics Portal Data

Emission factors

- Real-world emissions data provided by TRUE / ICCT(3) were applied to adjust COPERT emissions factors for nitrogen oxides (NOx)
- Default COPERT emission factors were used to model $PM_{2.5}$ and PM_{10}

(1) https://zdm-warszawa.maps.arcgis.com/apps/dashboards/bfb474713c9b4c8591a60da87648af05
(2) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/801205/tra0307.ods
(3) https://theicct.org/wp-content/uploads/2022/04/true-warsaw-emissions-apr22.pdf
(4) https://bdl.stat.gov.pl/bdl/start
(5) Informator Statystyczny Listopad 2022, Zarzad Transportu Miejskiego W Warszawie

Projected future year scenario modelling

NOx/NO_2 emissions assumptions

- NOx to NO_2 chemistry was modelled using the Defra NOx to NO_2 calculator (v8.1)[1] using inputs which were determined to best replicate the background conditions in the Warsaw LEZ. Modelled annual mean road NOx concentrations were combined with background NO_2 concentrations at each discrete receptor to calculate NO_2 annual mean concentrations
- Where NO_2 concentration maps were required, total NO_2 was derived from background NO_2 and road NOx concentrations using a specific polynomial equation

Vehicle fleet projections

- Vehicle fleets were projected to be representative of the 2026 Baseline using data obtained from the following data sources:

Vehicle type	Source
Cars	Projections for Warsaw provided by the International Council on Clean Transportation (ICCT) / The Real Urban Emissions (TRUE) Initiative[3]
LGVs	
Taxis	Car projection factors for Warsaw
HGVs	LGV projection factors for Warsaw
Private buses	
Public buses	Fleet upgrade schedule provided by the City

Non-road transport projections

- Background concentrations were assumed constant for all modelled scenarios

(1) https://laqm.defra.gov.uk/air-quality/air-quality-assessment/nox-to-no2-calculator/

Model verification and adjustment

Methodology

- NO_2 measurements from 41 monitoring locations were used for the model verification. These consisted of two automatic monitoring sites operated by the City and 39 diffusion tube measurements provided by Polski Alarm Smogowy(1). Diffusion tube measurements were not available for a full year and were therefore annualised through comparison with measurements from the automatic monitoring sites
- RapidAIR was used to generate a map of NOx concentrations arising from road traffic sources across the study area at a 1 m x 1 m resolution, based on the traffic activity data from the 2019 base year scenario and 2019 meteorological data. Background NO_2 values were obtained from CAMS data
- It was appropriate to verify the RapidAIR model in terms of primary pollutant emissions of nitrogen oxides (NOx = NO + NO_2). The model output of road NOx (the total NOx originating from road traffic) was compared to the measured road NOx, where the measured road NOx contribution is calculated as the difference between the total NOx and the background NOx value. Total measured NOx for each diffusion tube was calculated from the measured NO_2 concentration using the latest version of the Defra NOx to NO_2 calculator
- This initial comparison indicated that the model was under-predicting the NOx arising from road emissions at most locations. Refinements were subsequently made to the model inputs to improve model performance where possible, and a linear adjustment factor of **1.14** was calculated for the road emissions component of the NOx model
- Total NOx was calculated as the sum of the adjusted road NOx contribution from RapidAIR and the background maps. Total NO_2 concentrations at specified receptors were subsequently obtained from background and adjusted road NOx concentrations using the NOx to NO_2 calculator
- To evaluate model performance and uncertainty, the Root Mean Square Error (RMSE) for the observed vs predicted NO_2 annual mean concentrations was calculated. Defra Technical Guidance (TG22)(2) indicates that for an annual model, an RMSE of up to 4 µg/m^3 is ideal, and an RMSE of up to 10 µg/m^3 is acceptable. In this case the RMSE value was **7.50 µg/m^3**, which shows good agreement between modelled and measured concentrations
- In the absence of a sufficient number of PM monitoring sites, the NOx adjustment factor of **1.14** was also applied to adjust the modelled road PM_{10} and $PM_{2.5}$ concentrations

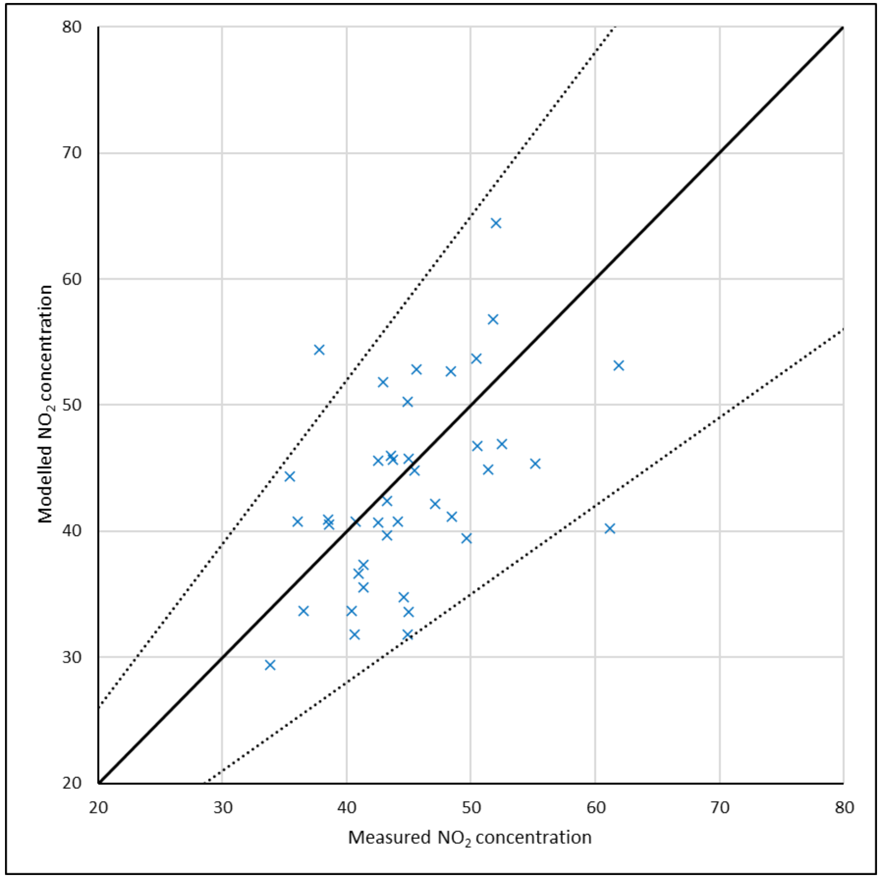
(1) Pomiary stezen dwutlenku azotu za pomoca probnikow pasywnych na terenie Krakowa i Warszawy
(2) https://laqm.defra.gov.uk/wp-content/uploads/2022/08/LAQM-TG22-August-22-v1.0.pdf

Model verification and adjustment

Model verification points and NO_2 concentrations

Site ID	Latitude (°)	Longitude (°)	Measured NO_2 (µg/m³)	Modelled NO_2 (µg/m³)	Measured – Modelled
DT_8	52.2492	21.0443	61.90	53.17	8.73
DT_10	52.2466	21.0150	61.18	40.19	20.99
DT_20	52.2299	21.0220	55.19	45.39	9.80
DT_26	52.2557	21.0346	52.51	46.88	5.63
DT_28	52.2370	20.9804	52.00	64.45	-12.45
DT_29	52.2354	21.0090	51.79	56.80	-5.01
DT_31	52.2474	21.0531	51.38	44.92	6.46
DT_32	52.2369	21.0177	50.55	46.77	3.78
DT_33	52.2257	20.9888	50.45	53.70	-3.25
DT_35	52.2195	20.9895	49.62	39.44	10.18
DT_39	52.2624	21.0377	48.49	41.17	7.32
DT_40	52.2422	20.9941	48.38	52.66	-4.28
DT_43	52.2576	20.9942	47.15	42.20	4.95
DT_51	52.2202	21.0154	45.60	52.87	-7.27
DT_52	52.2628	21.0220	45.50	44.79	0.71
DT_54	52.2461	21.0122	44.98	33.58	11.40
DT_55	52.2174	20.9821	44.98	45.76	-0.78
DT_57	52.2353	20.9728	44.88	50.29	-5.41
DT_58	52.2536	21.0221	44.88	31.78	13.10
DT_59	52.2302	21.0625	44.57	34.77	9.80
DT_60	52.2234	21.0167	44.15	40.74	3.41
DT_62	52.2174	20.9824	43.74	45.67	-1.93
DT_64	52.2442	21.0015	43.54	45.96	-2.42
DT_67	52.2259	21.0143	43.23	42.42	0.81
DT_68	52.2372	21.0257	43.23	39.67	3.56
DT_72	52.2307	20.9842	42.92	51.83	-8.91
DT_75	52.2476	21.0473	42.50	45.63	-3.13
DT_76	52.2547	20.9721	42.50	40.65	1.85
DT_82	52.2548	20.9825	41.37	35.54	5.83
DT_83	52.2350	20.9908	41.37	37.32	4.05
DT_84	52.2238	21.0205	40.96	36.67	4.29
DT_86	52.2444	20.9661	40.75	40.76	-0.01
DT_87	52.2511	21.0353	40.65	31.81	8.84
DT_88	52.2508	20.9982	40.44	33.65	6.79
DT_94	52.2502	20.9805	38.58	40.55	-1.97
DT_95	52.2375	21.0522	38.48	40.89	-2.41
DT_98	52.2408	20.9862	37.76	54.42	-16.66
DT_101	52.2467	21.0641	36.52	33.67	2.85
DT_108	52.2373	21.0000	33.84	29.42	4.42
244A Grochowska Street	52.2457	21.0804	35.44	44.31	-8.87
83/89 Solidarnosci Street	52.2436	20.9992	36.07	40.78	-4.71
				RMSE	**7.50**

Modelled vs measured NO_2 annual mean concentrations at receptors



*The dashed lines represent 30% difference between the measured and modelled concentrations

Model uncertainty

- Some clear outliers were apparent during the model verification process, whereby the model inputs could not be refined sufficiently to achieve good model performance at these locations. There are a number of reasons why this could be the case, including:

Model inputs

- Uncertainties in the traffic model outputs
- Local HGV and private bus fleet data were not available for Warsaw, so based on the national average
- Uncertainties in future vehicle fleet projections
- Uncertainties introduced by modelling background concentrations at a low resolution over a large model domain

Monitoring data

- Limited number of annualised concentration measurements available for model verification
- Sites may be located next to a large car park, bus stop or other emission source that has not been explicitly modelled due to unknown activity data
- Sites may be located in unsuitable locations for diffusion tubes to measure NO_2 concentrations effectively

Limitations for modelling LEZ scenarios

- The potential rerouting of traffic as a result of implementation of the LEZ is not included in the transport data for the 2026 LEZ Phase 2 and Phase 3 scenarios, but some increase in traffic is likely around the zone

Air quality modelling results – annual mean concentration maps

Annual mean concentration maps

Introduction

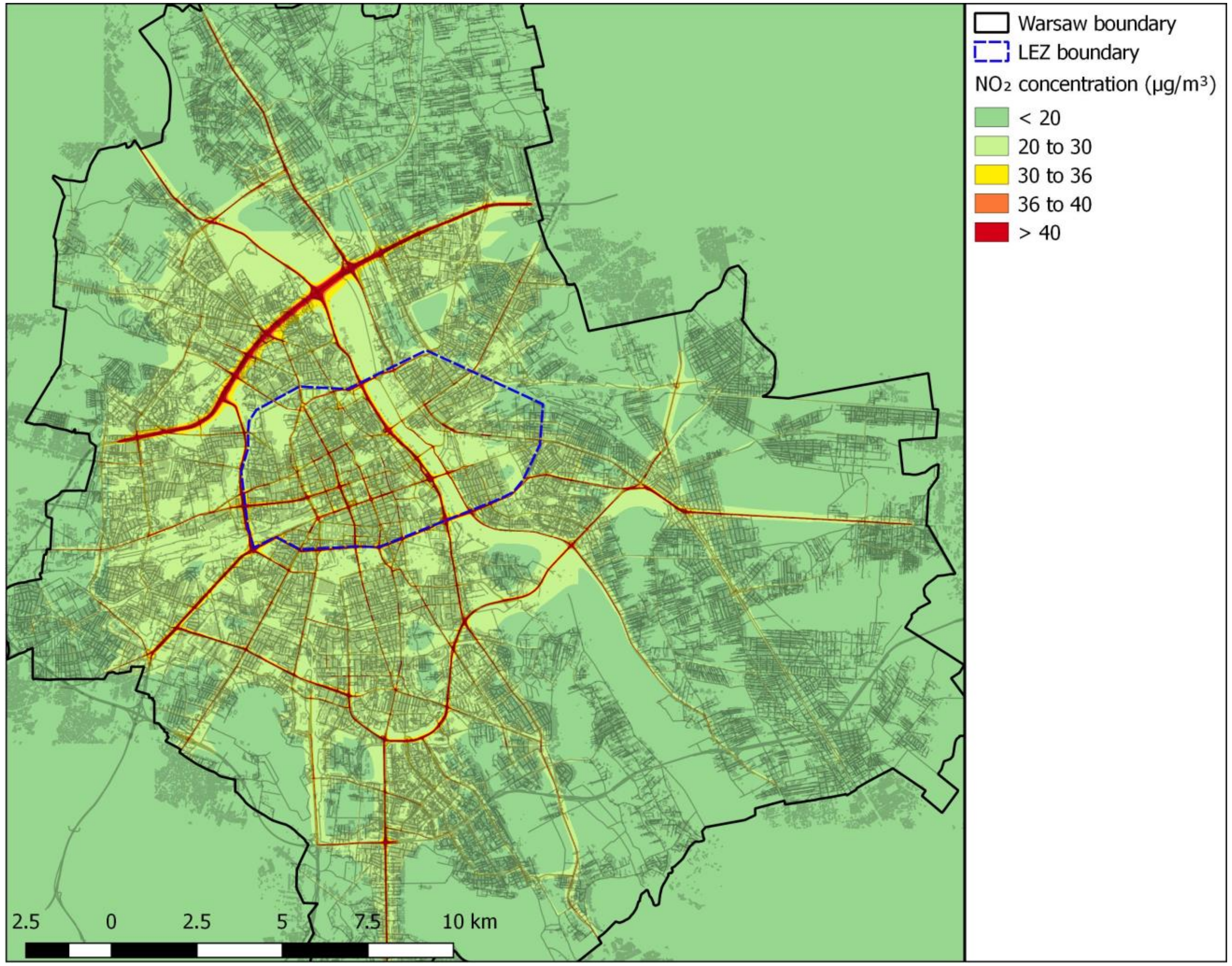
- The following maps show the modelled NO_2, $PM_{2.5}$ and PM_{10} annual mean concentrations across the full model domain for the 2026 Baseline, 2026 LEZ Phase 2 and 2026 LEZ Phase 3 scenarios
- Both LEZ scenarios include the impacts associated with both travel behaviour and upgrade response on the road links within the LEZ and upgrade response on roads outside of the LEZ
- Areas in red have concentrations in exceedance of the European annual limit value (40 μg/m^3 for NO_2 and PM_{10}, 20 μg/m^3 for $PM_{2.5}$) and areas in orange are within 10% of the limit value (36 – 40 μg/m^3 for NO_2 and PM_{10}, 18 – 20 μg/m^3 for $PM_{2.5}$)

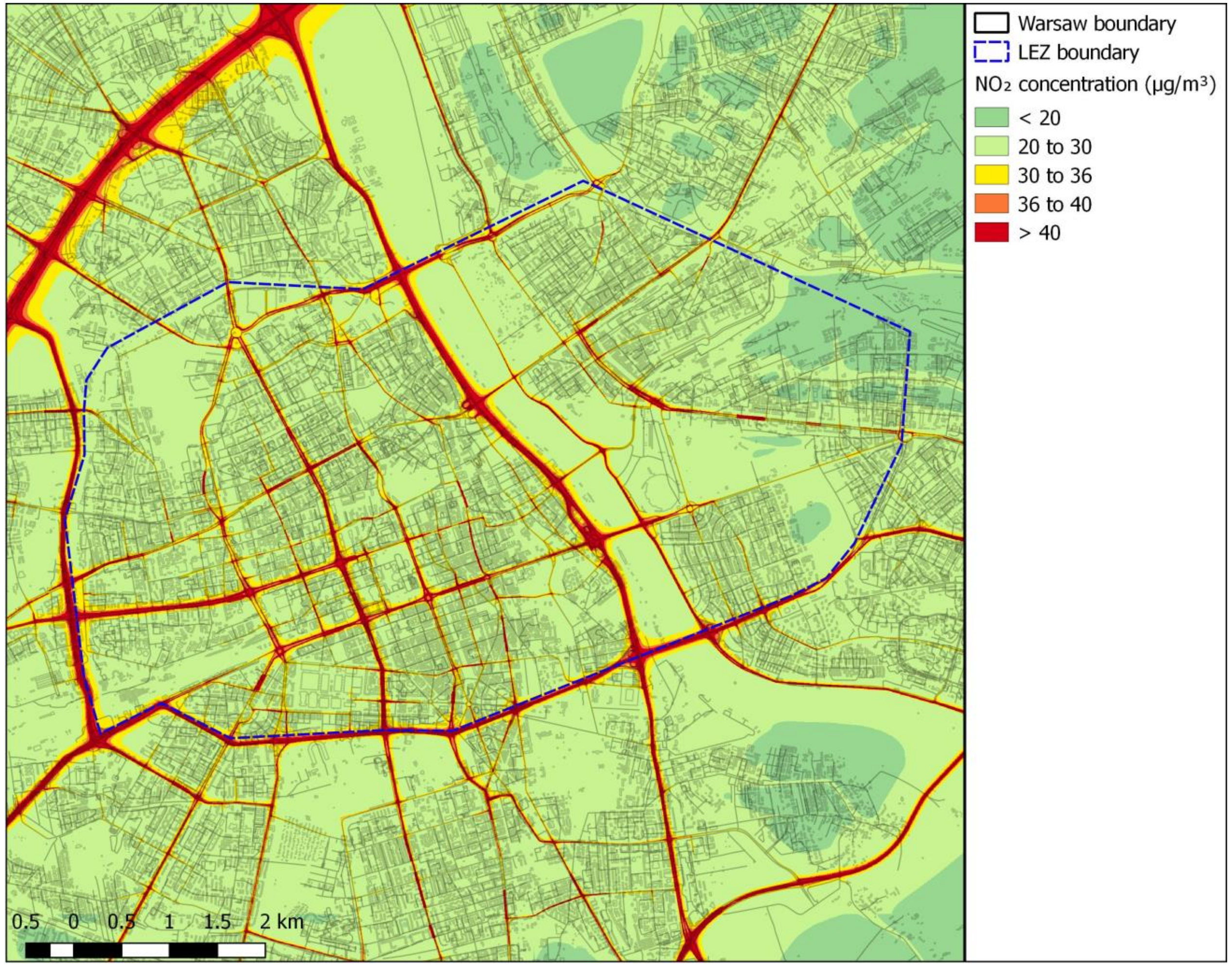
Results summary

- An initial comparison of the 2026 Baseline and 2026 LEZ Phase 2 and Phase 3 scenarios shows the impact of the LEZ scheme in reducing pollutant concentrations across the city
- The largest decrease in concentrations is observed with the LEZ boundary owing to both the upgraded fleet and reduction in vehicles on central roads in the city
- The decrease in NO_2 concentrations is more significant than for PM as road transport emissions make up a larger proportion of total NOx emissions than total PM
- The relative decrease in concentrations between Phase 2 and Phase 3 is also larger for NO_2 than PM as the difference between emissions from the Euro standards permitted by both phases is larger for NOx than PM

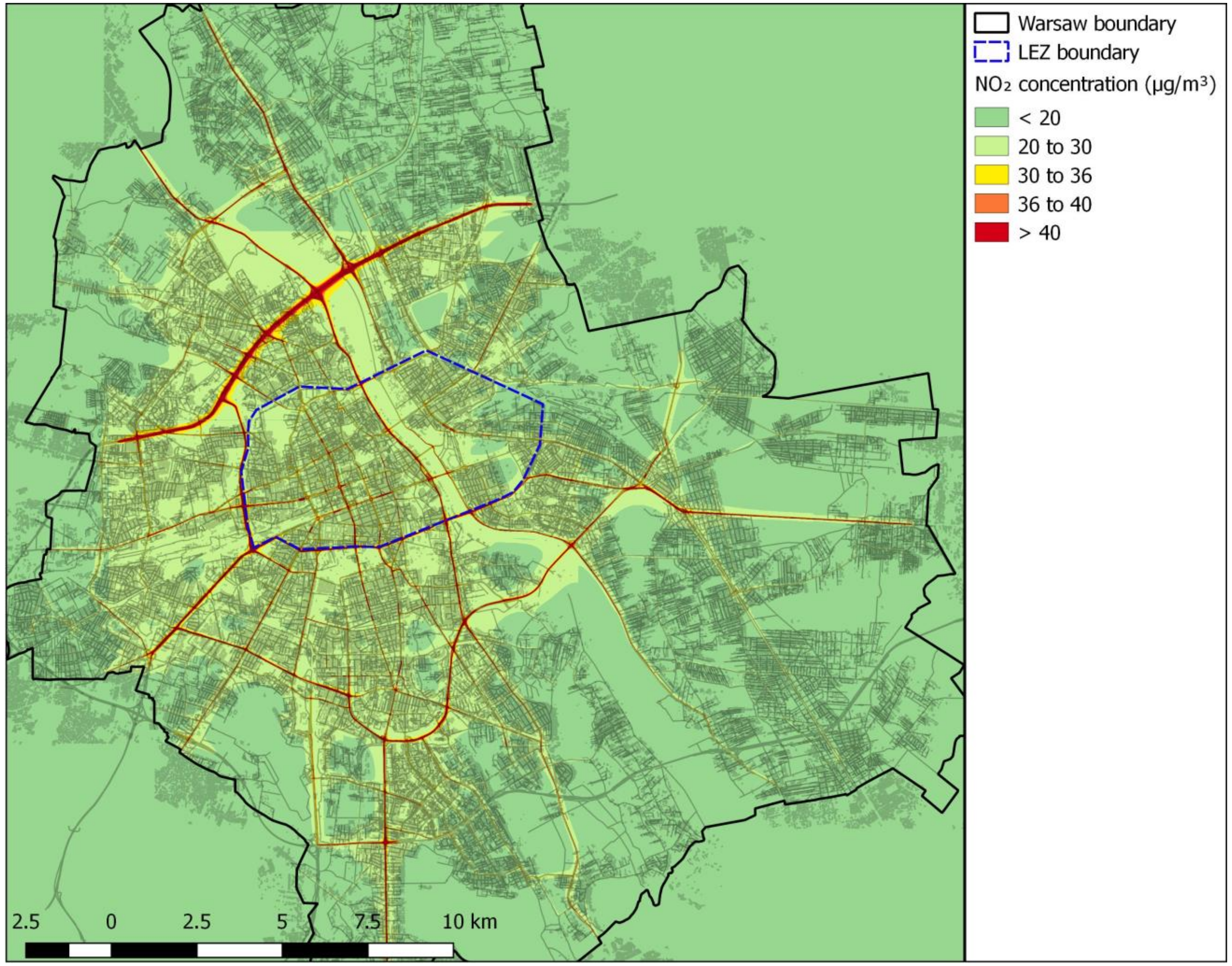
NO_2 results

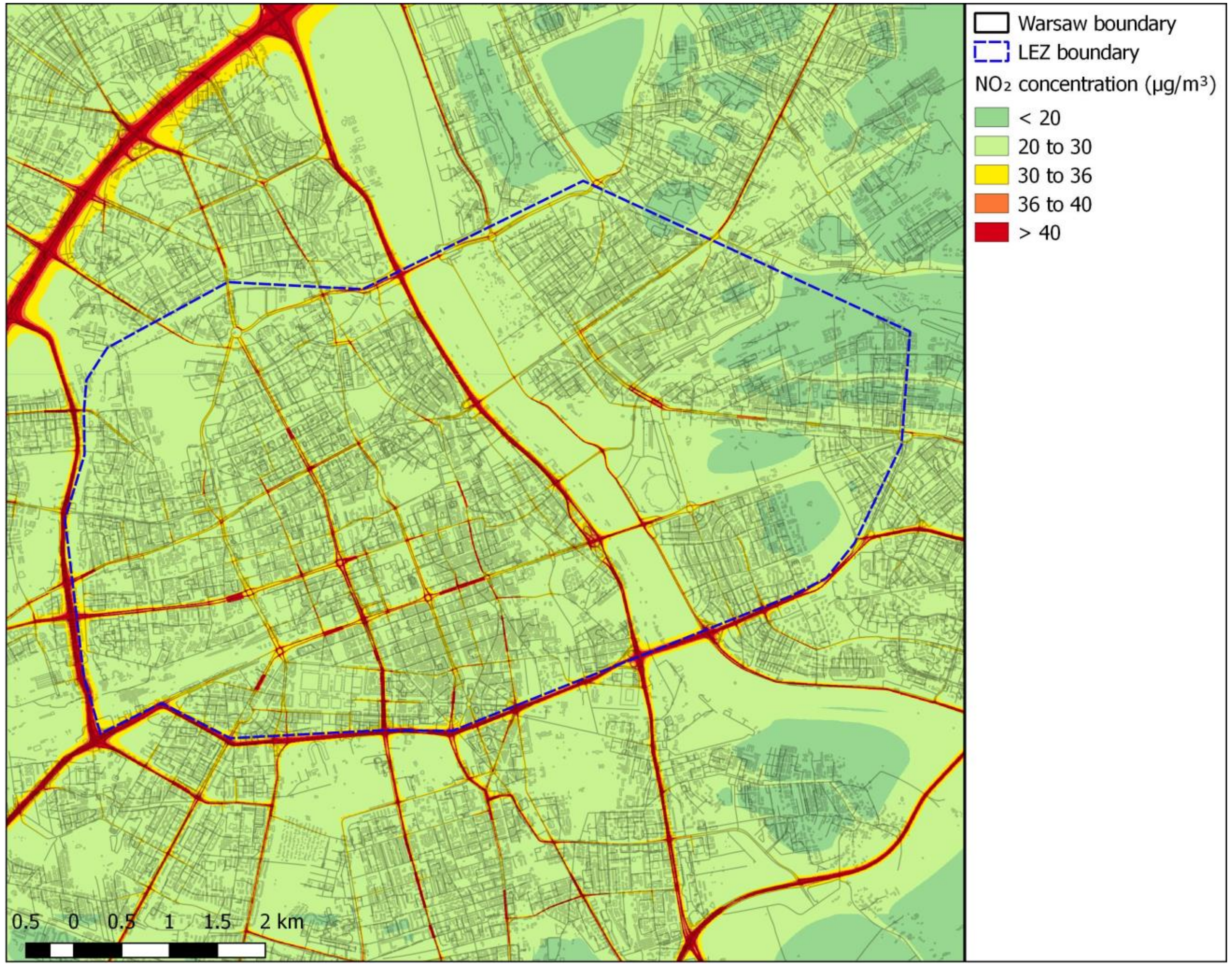
2026 Baseline NO_2 concentration



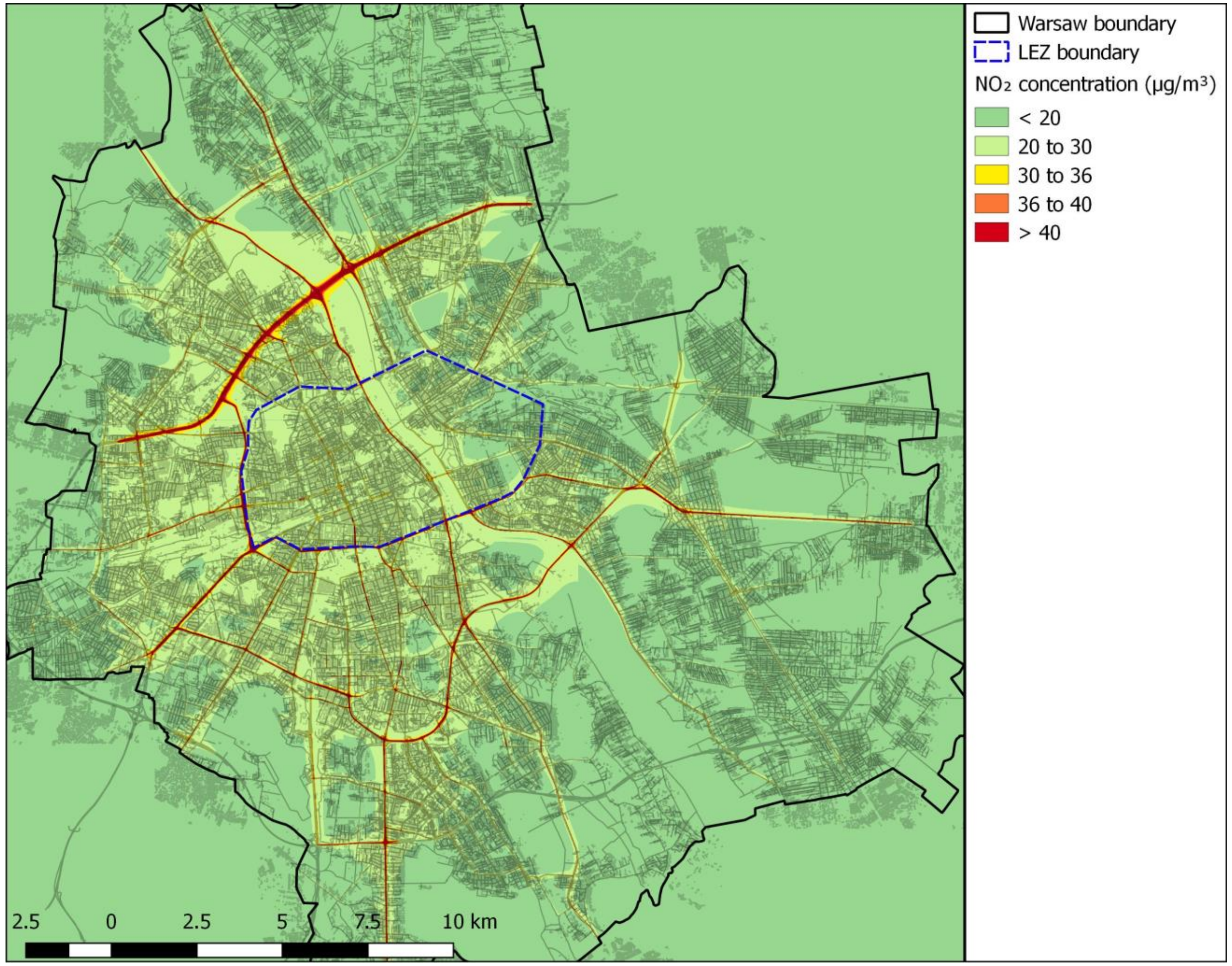


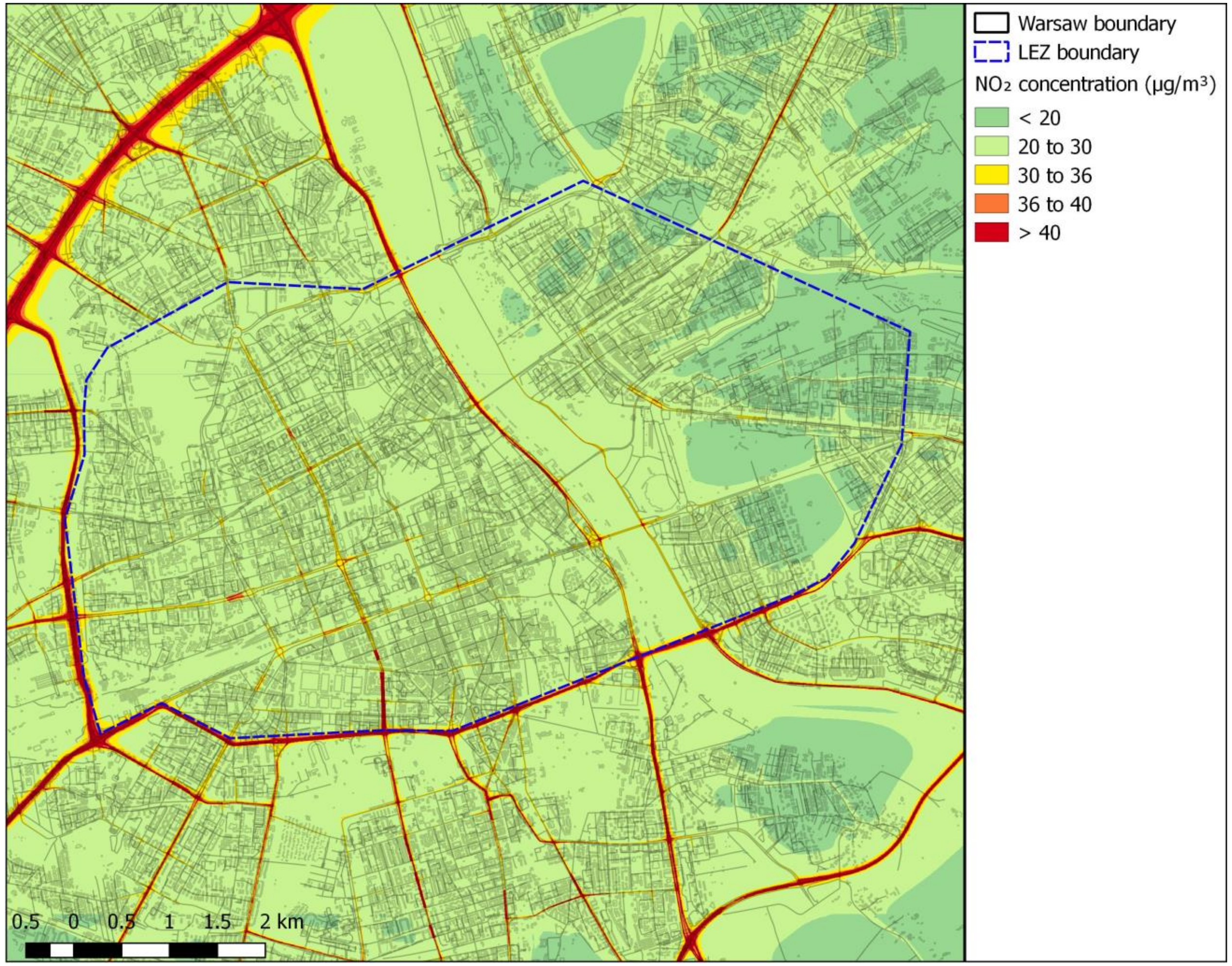
2026 LEZ Phase 2 (with TB) NO_2 concentration





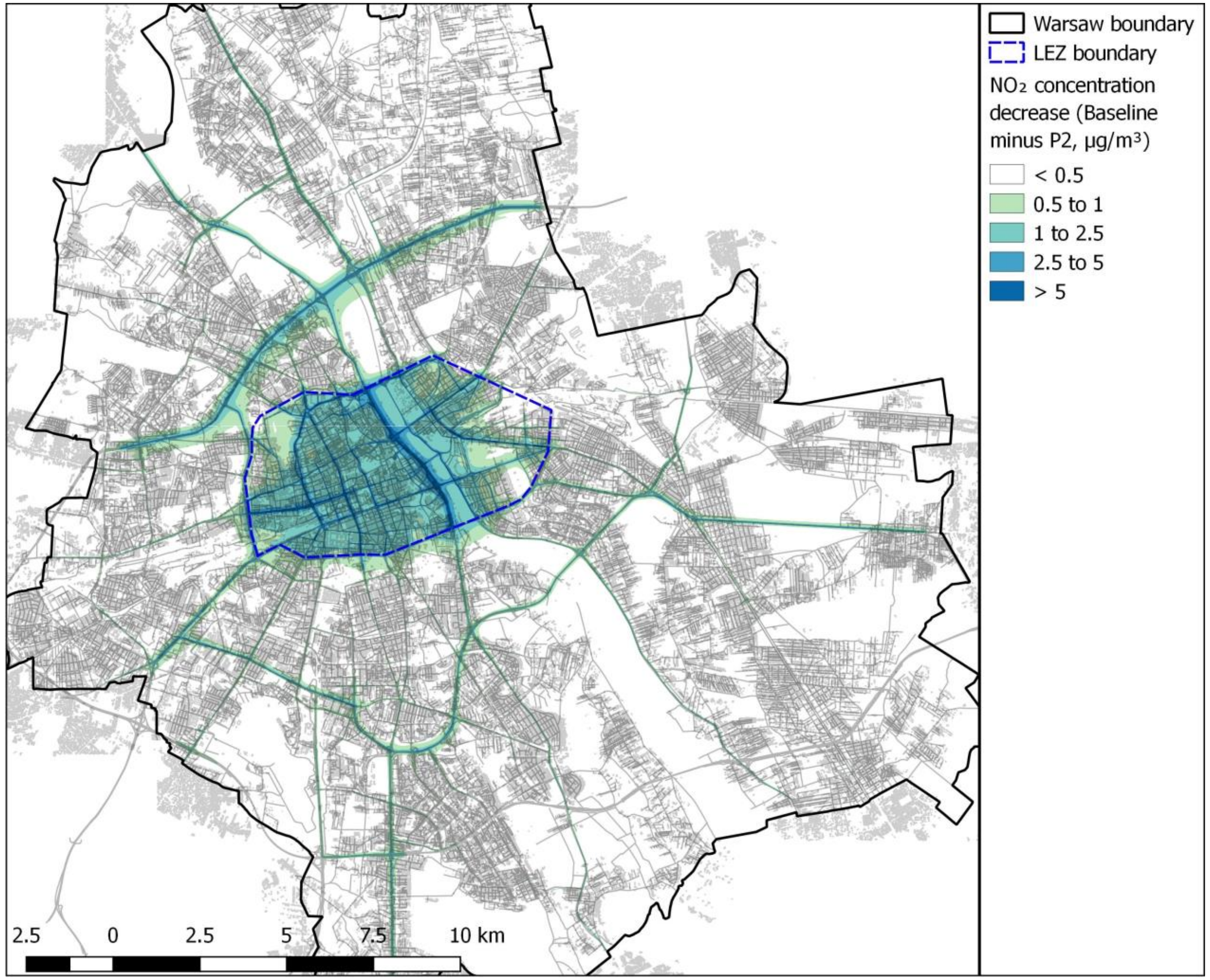
2026 LEZ Phase 3 (with TB) NO_2 concentration



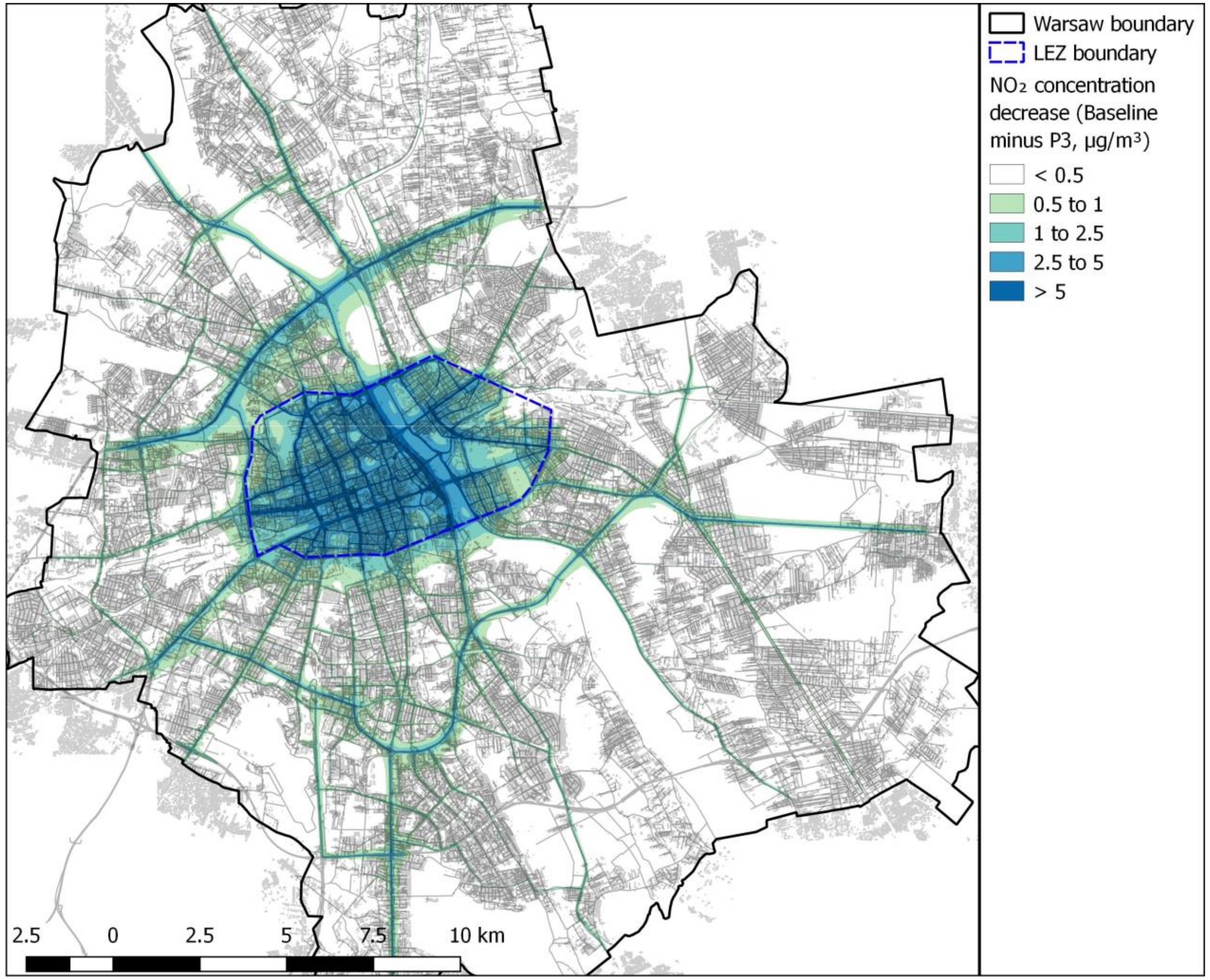


NO_2 concentration decrease as a result of LEZ implementation

Phase 2

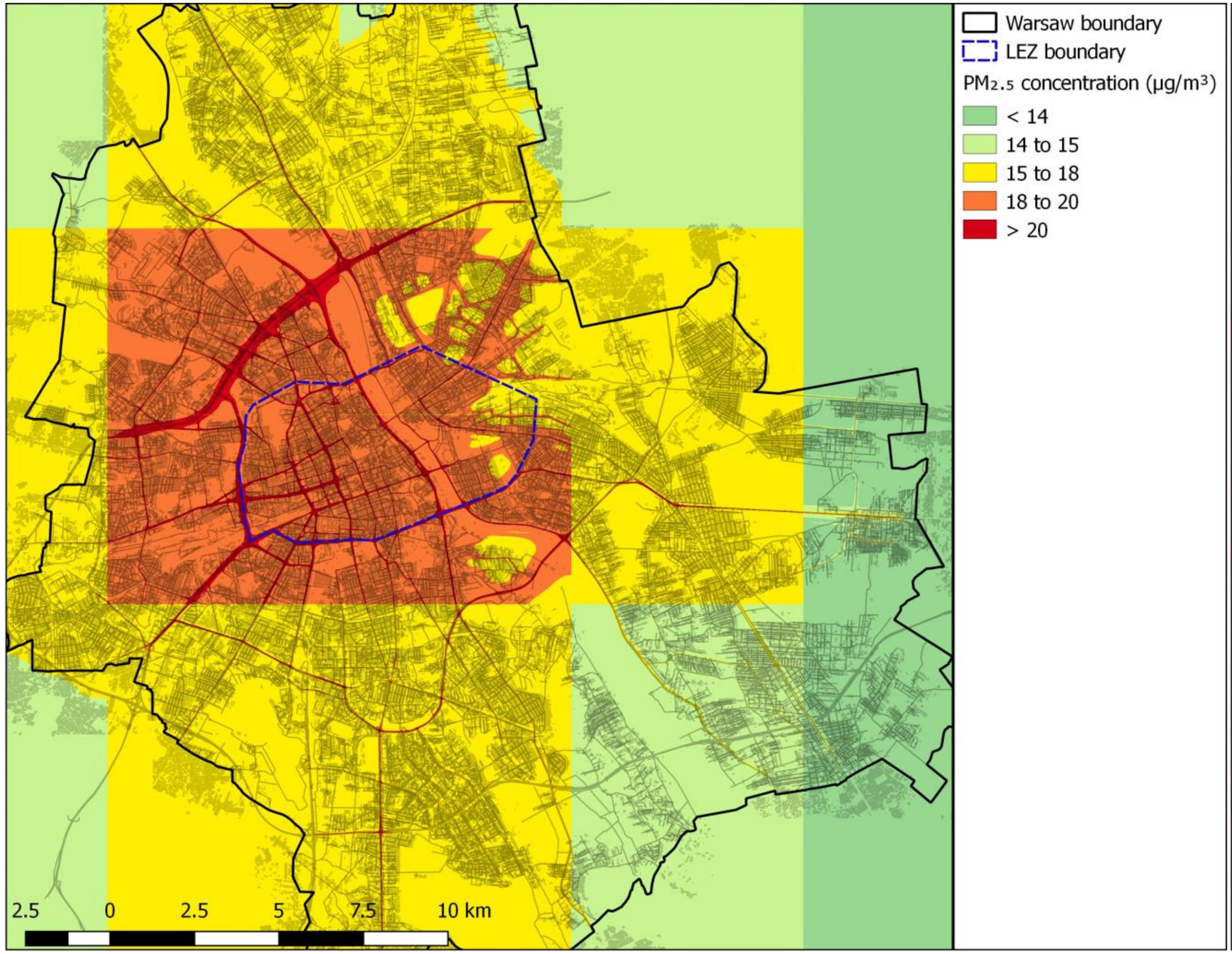


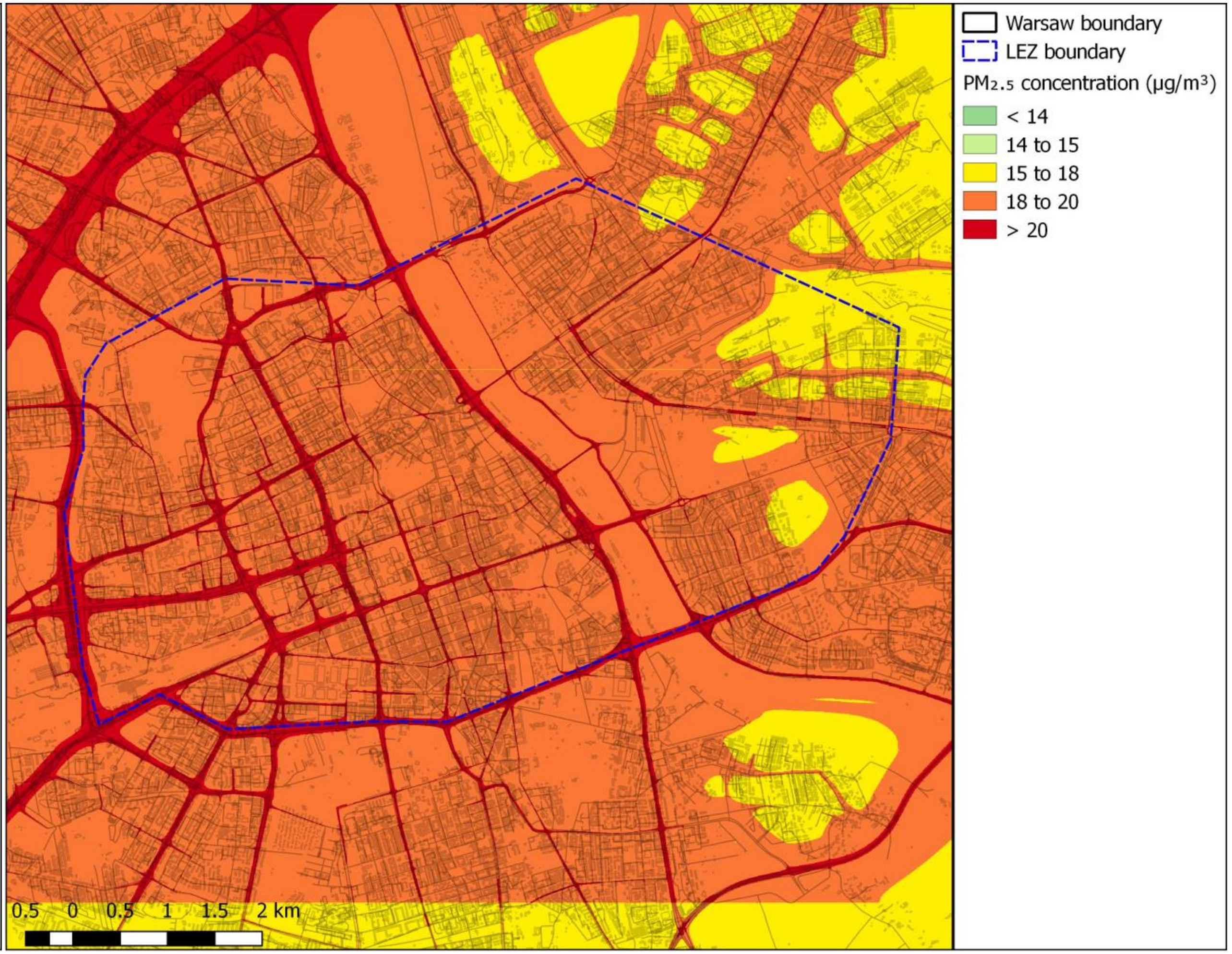
Phase 3



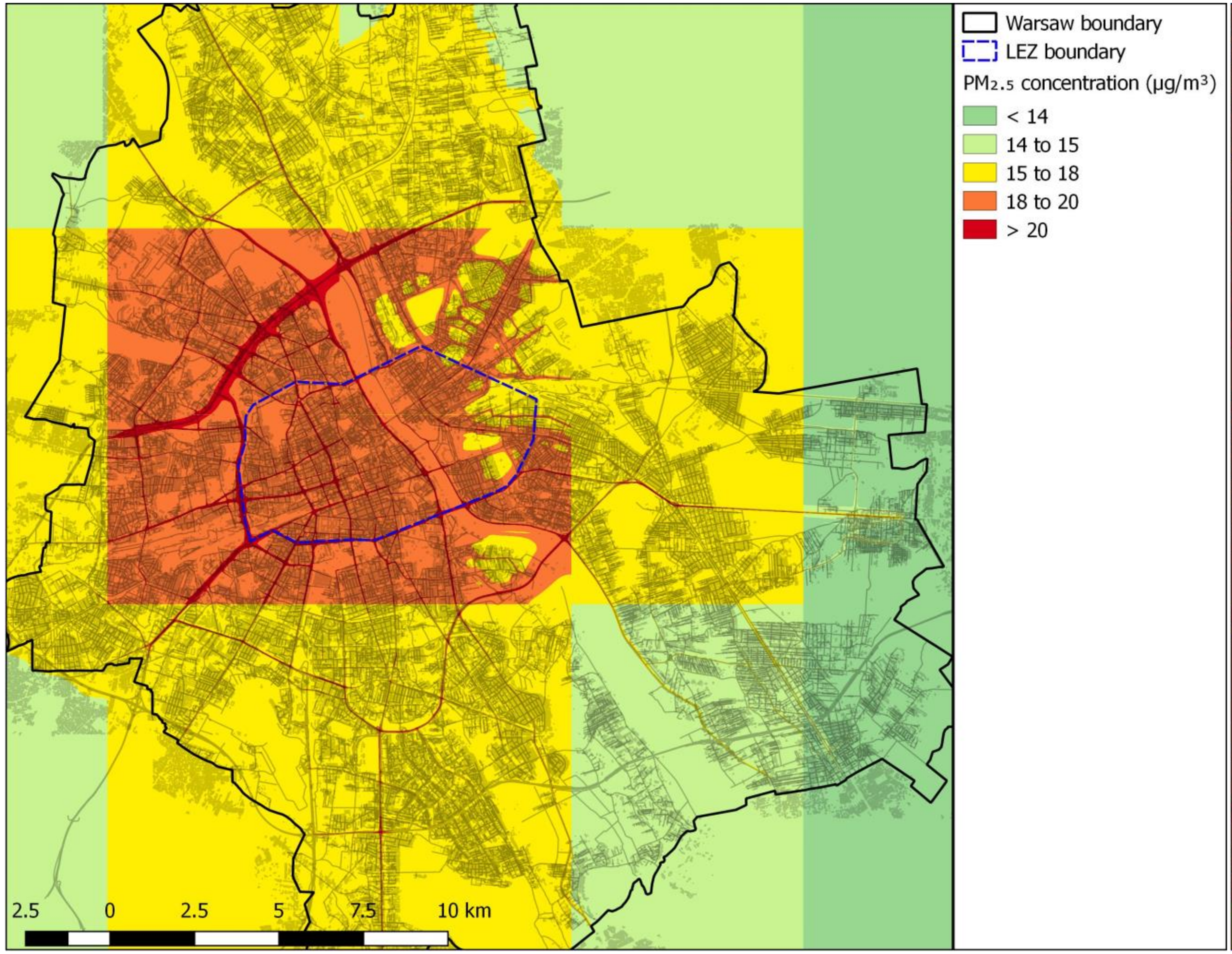
$PM_{2.5}$ results

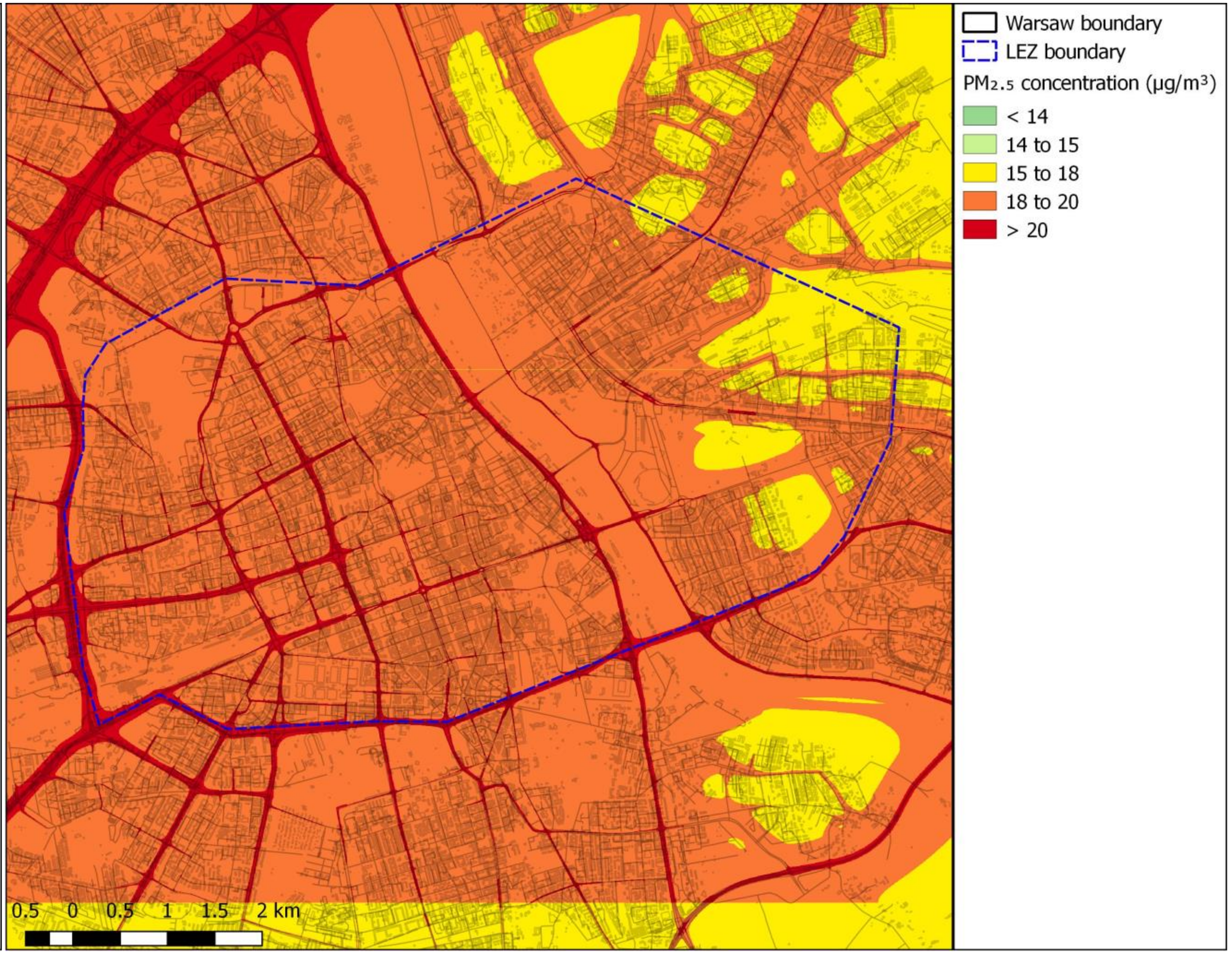
2026 Baseline $PM_{2.5}$ concentration



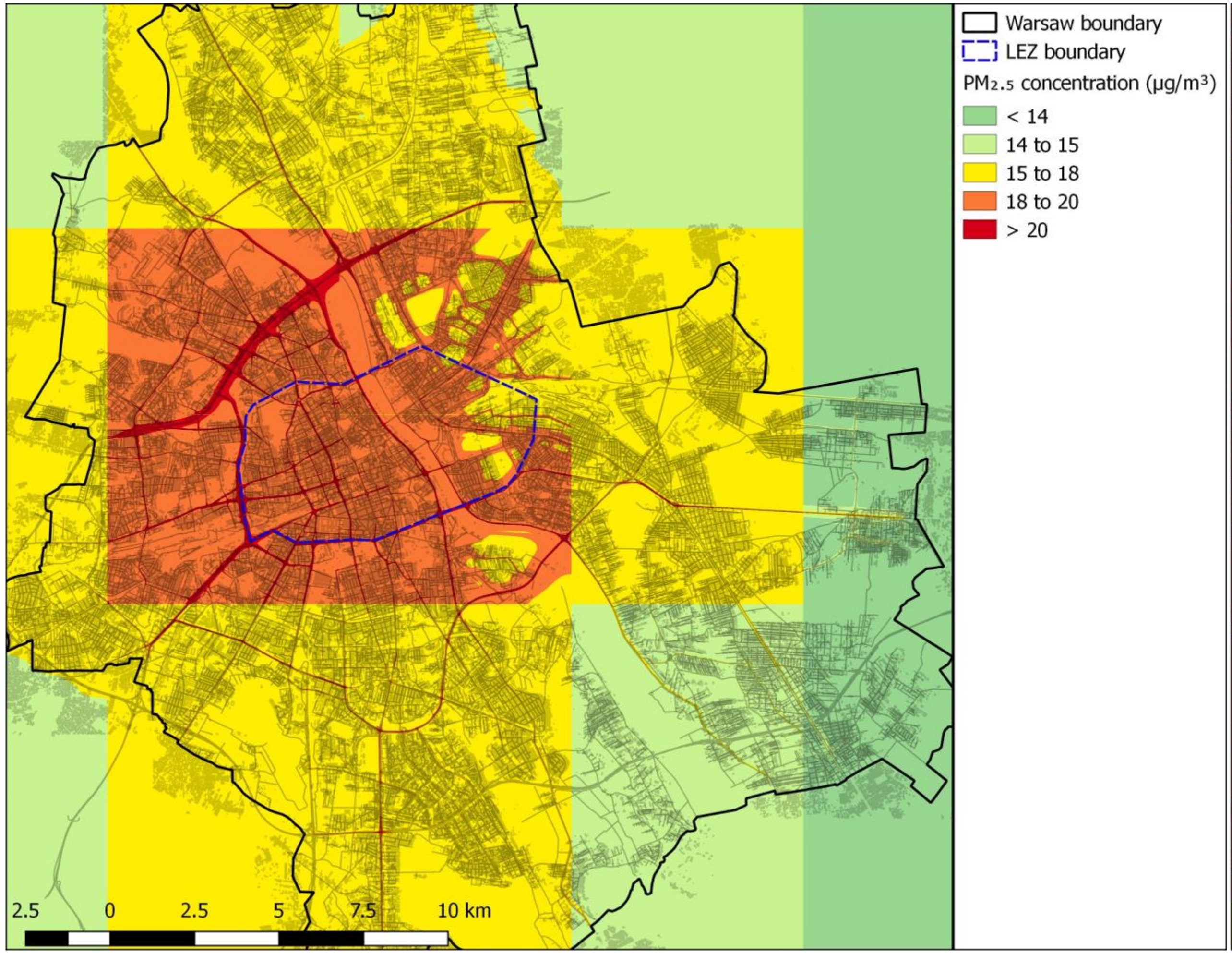


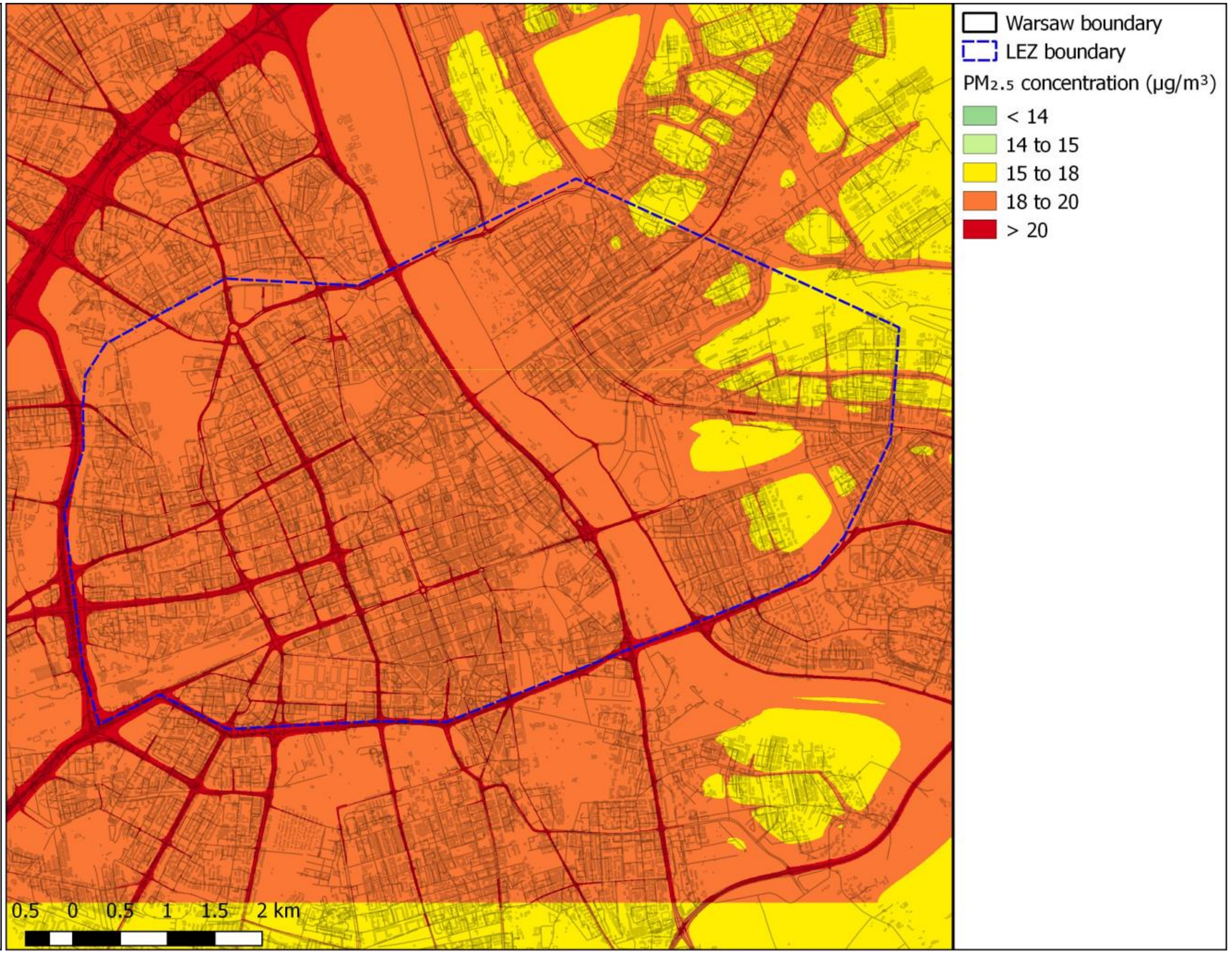
2026 LEZ Phase 2 (with TB) $PM_{2.5}$ concentration





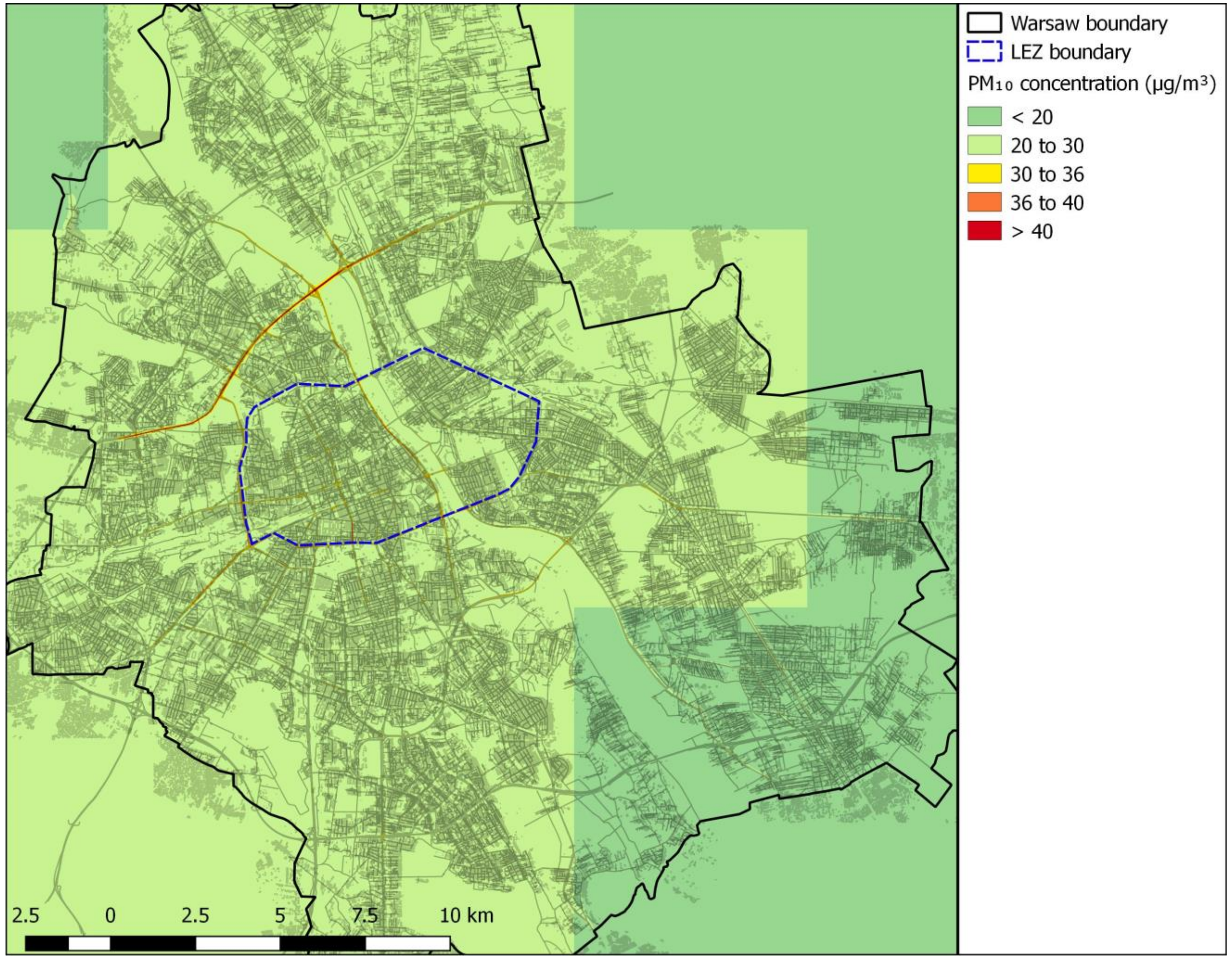
2026 LEZ Phase 3 (with TB) $PM_{2.5}$ concentration

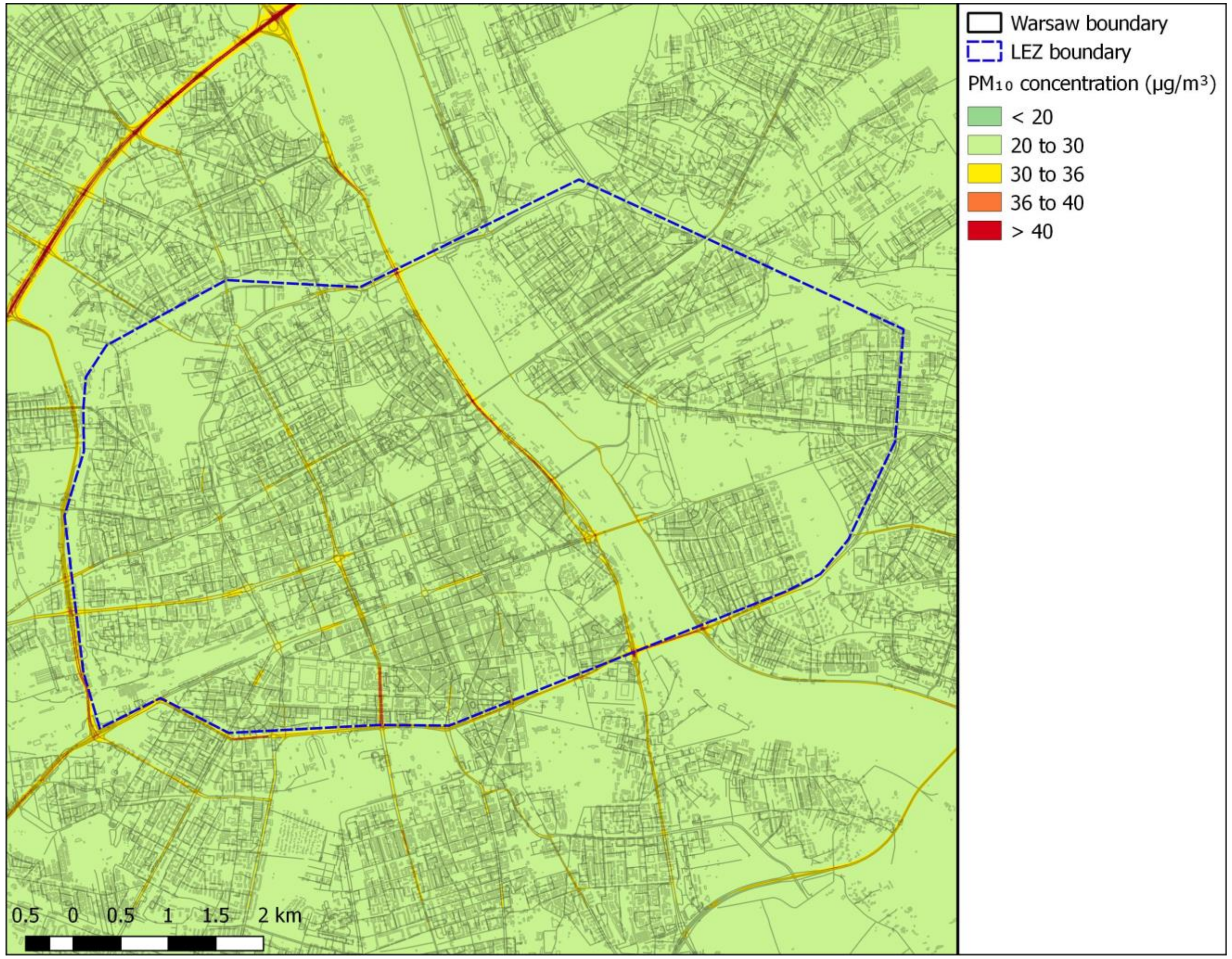




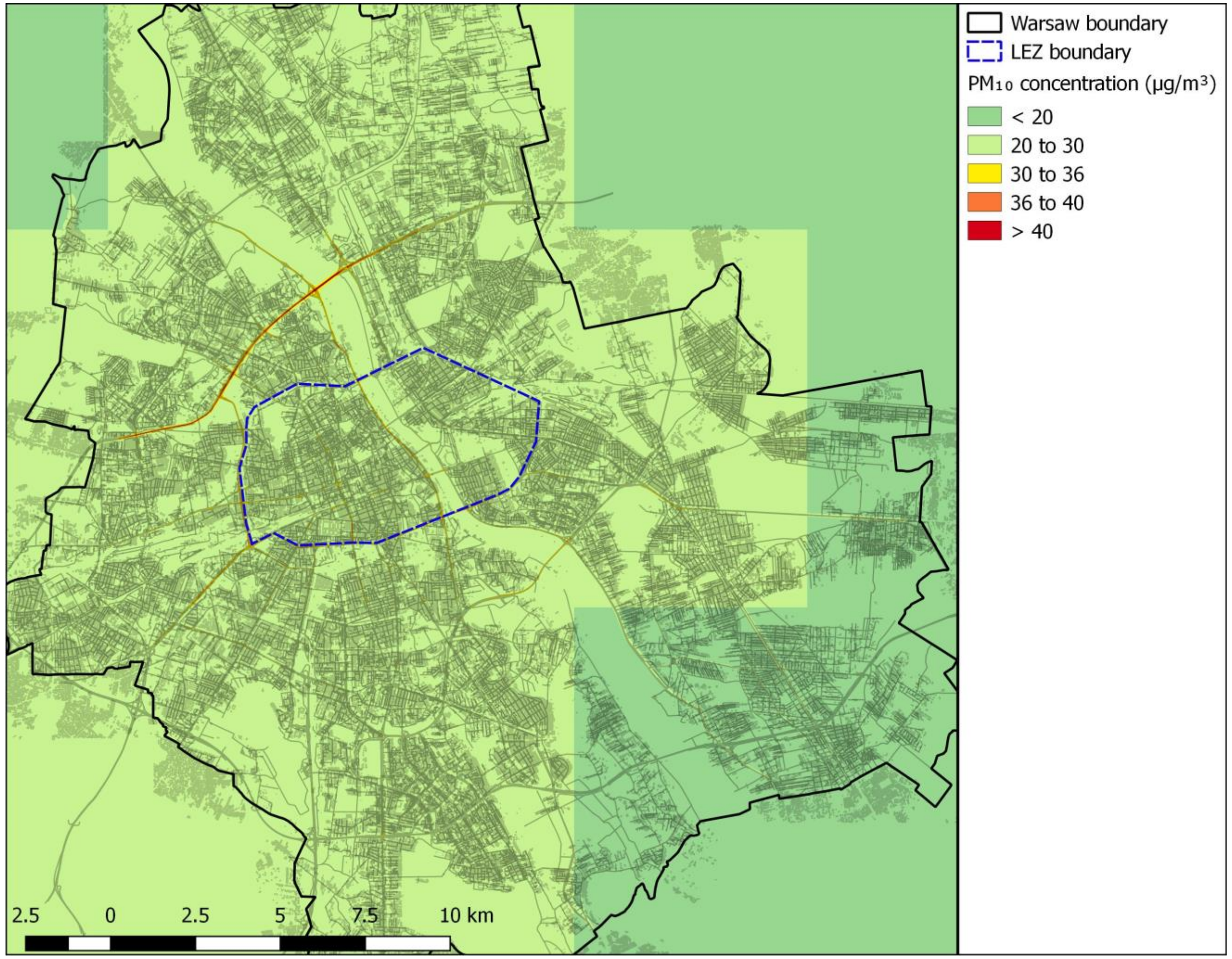
PM_{10} results

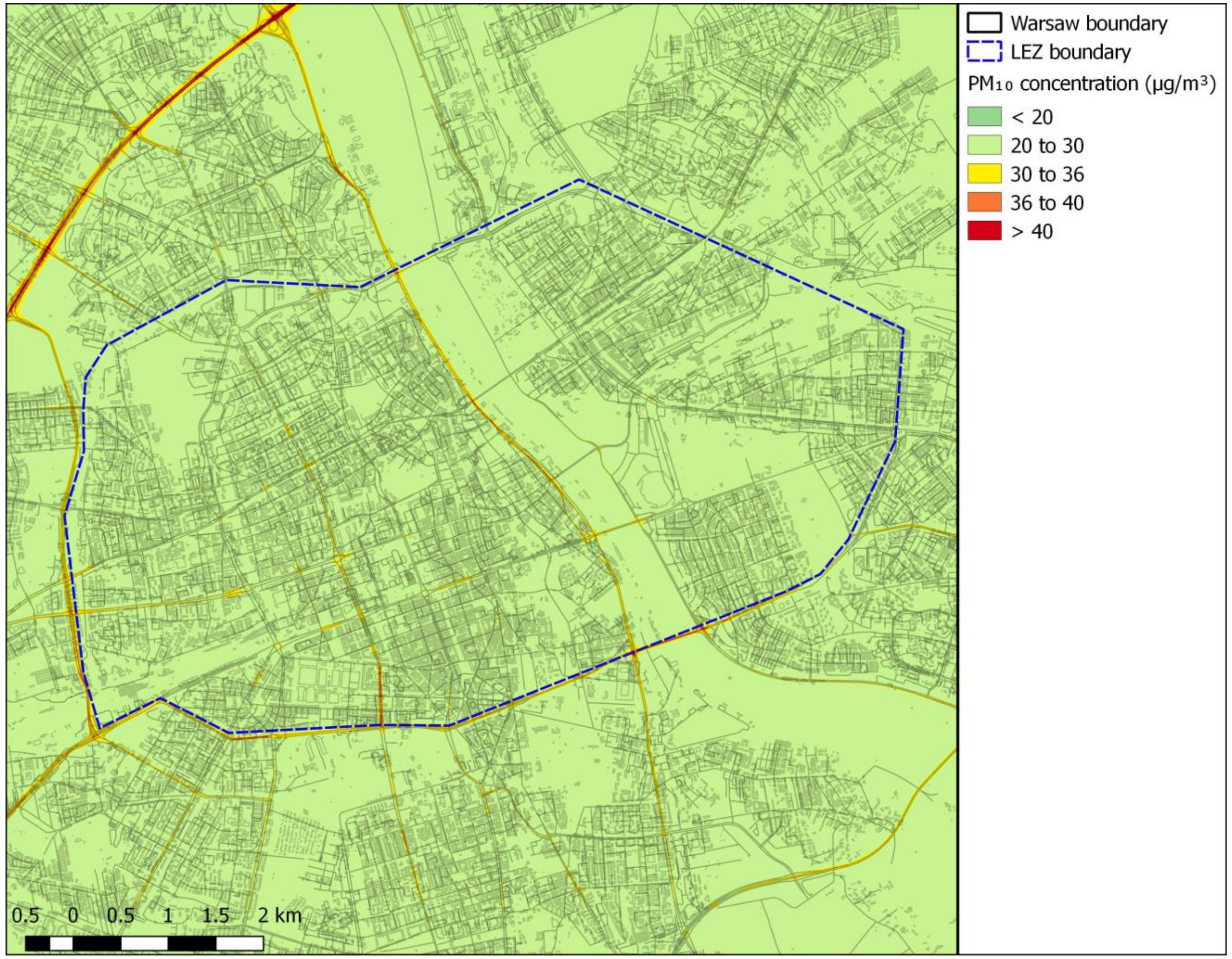
2026 Baseline PM_{10} concentration



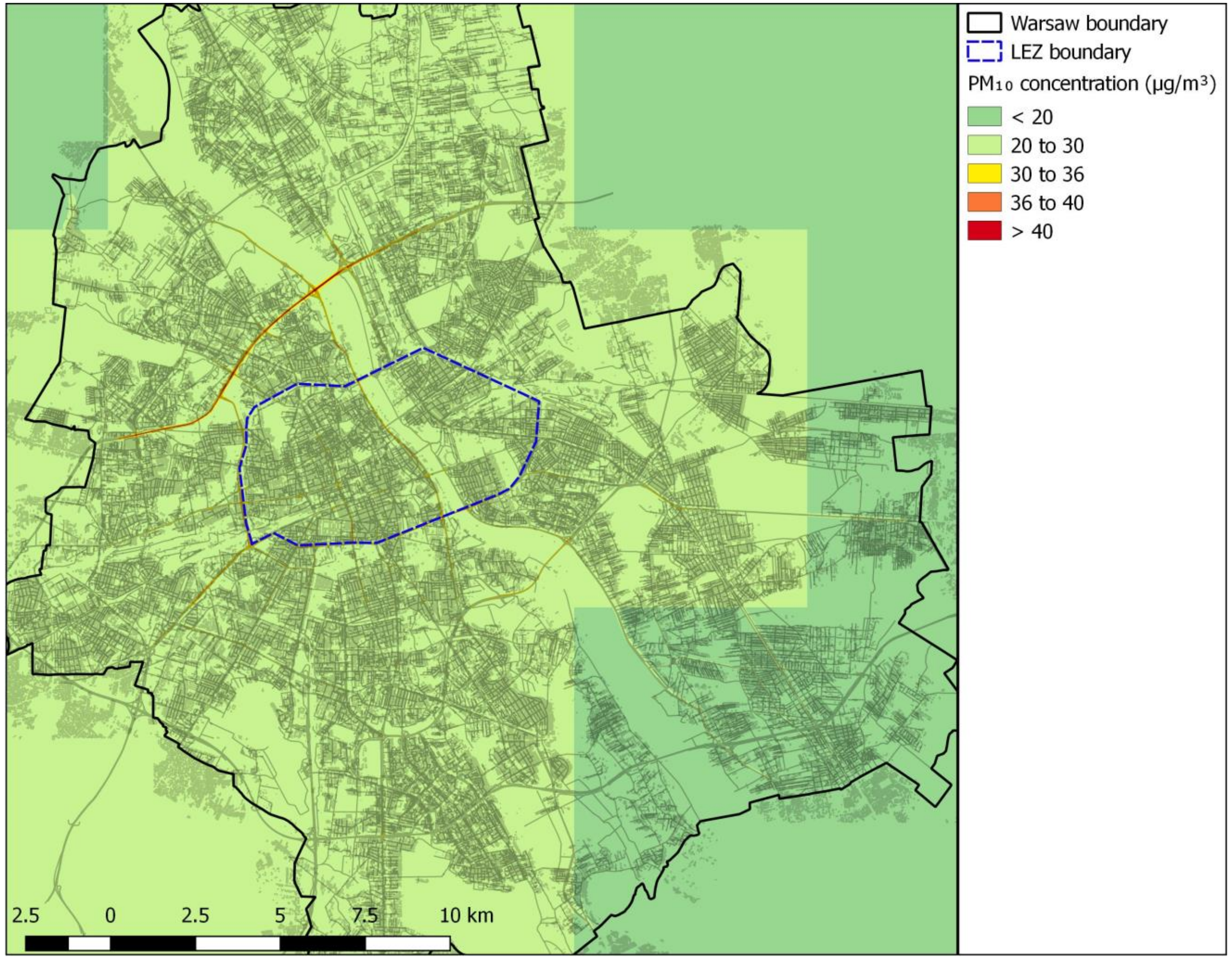


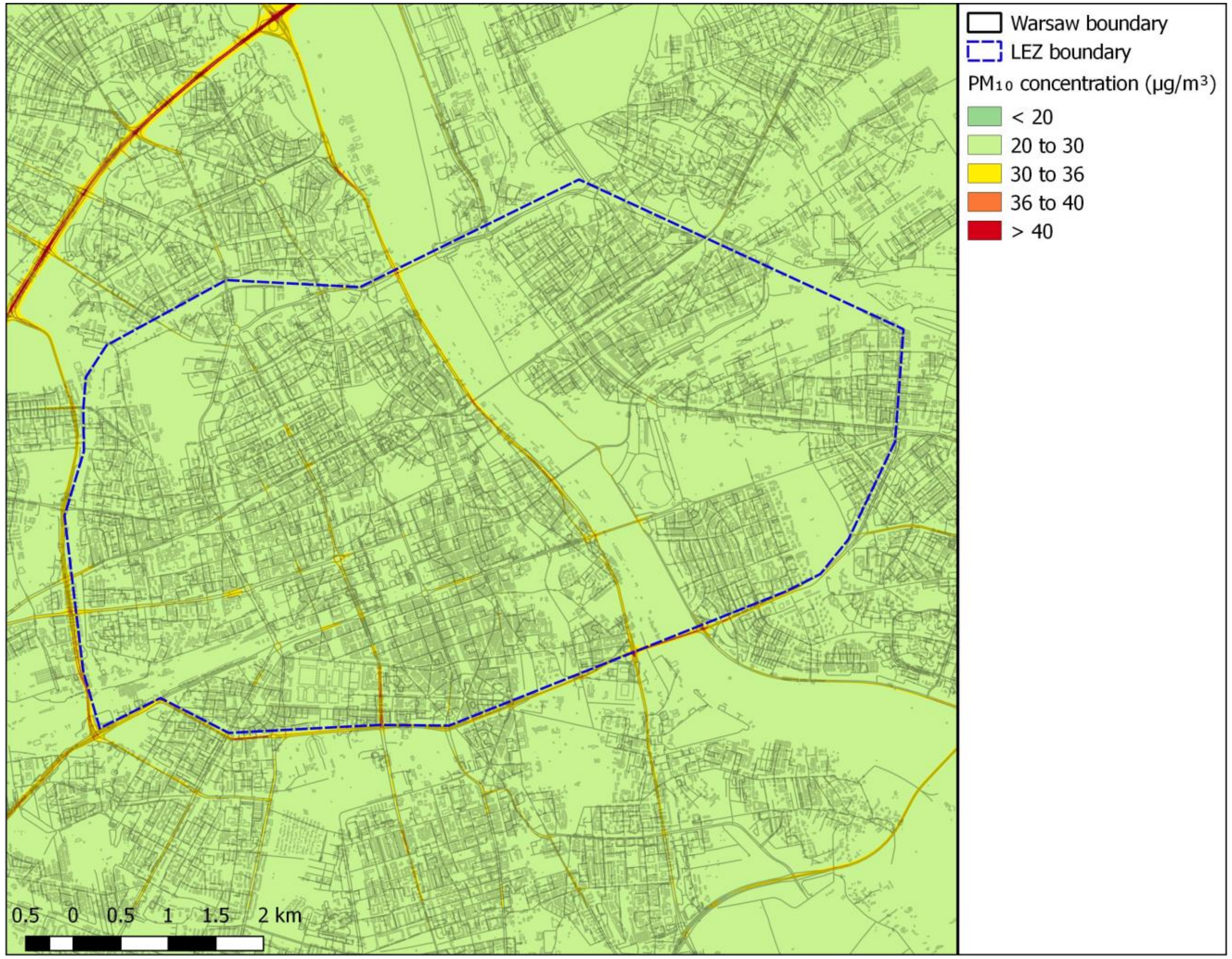
2026 LEZ Phase 2 (with TB) PM_{10} concentration





2026 LEZ Phase 3 (with TB) PM_{10} concentration





Air quality modelling results – at monitoring locations

Results at monitoring locations

Introduction

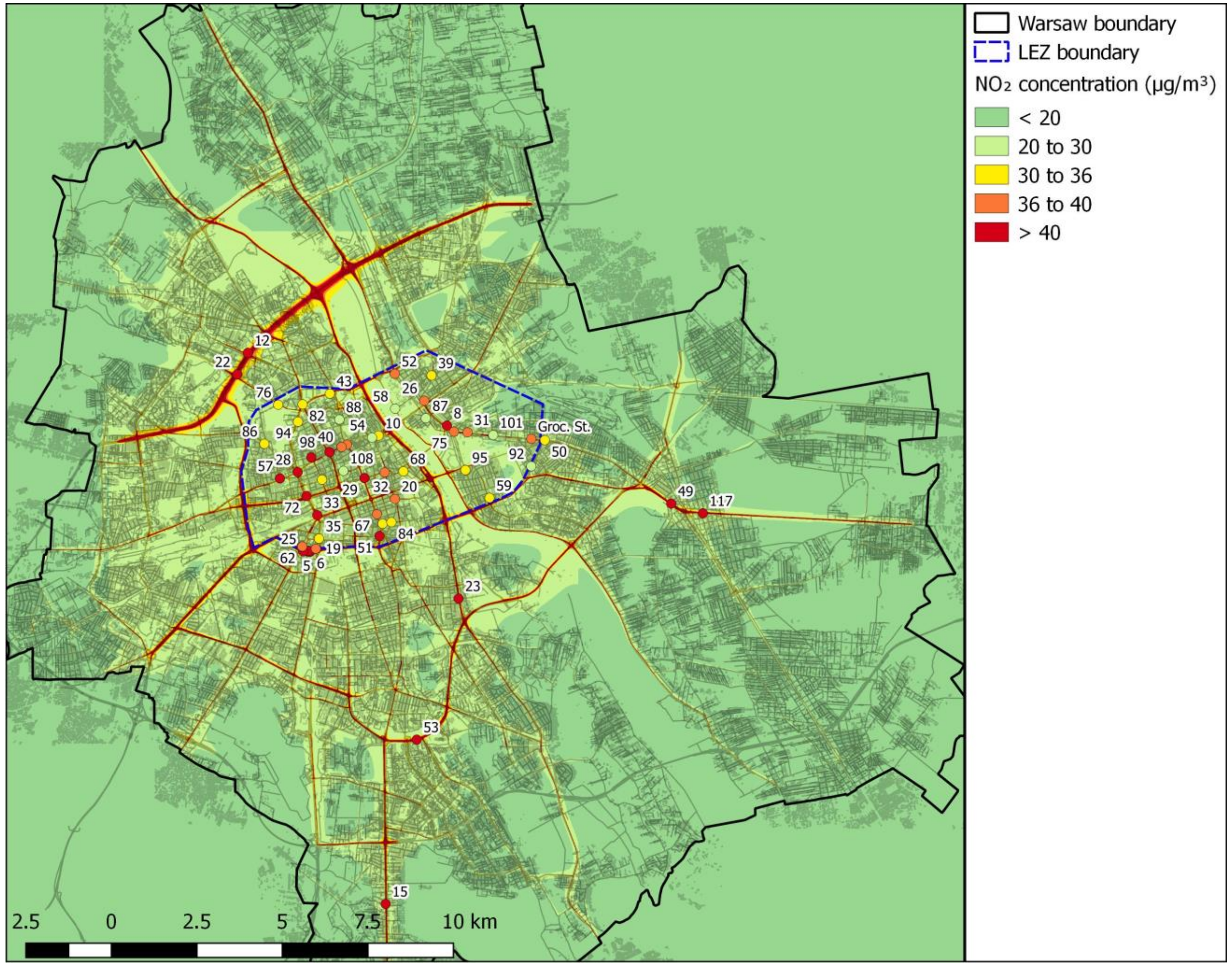
- An alternative way to view the modelling results is to consider the results at monitoring site locations
- Automatic monitoring stations and diffusion tubes are likely to have been sited to capture the worst-case exceedance locations on road links within the City of Warsaw
- Pollutant concentrations at these locations therefore provide a good indication of local air quality and potential exceedances in relation to the local air quality management regime
- The following data tables show the modelled pollutant concentrations at specified monitoring site locations in 2019 and 2026 for the Baseline, LEZ Phase 2 and LEZ Phase 3 scenarios
- Points are labelled as ‘LEZ’ or ‘Outside’ depending on their location in relation to the LEZ

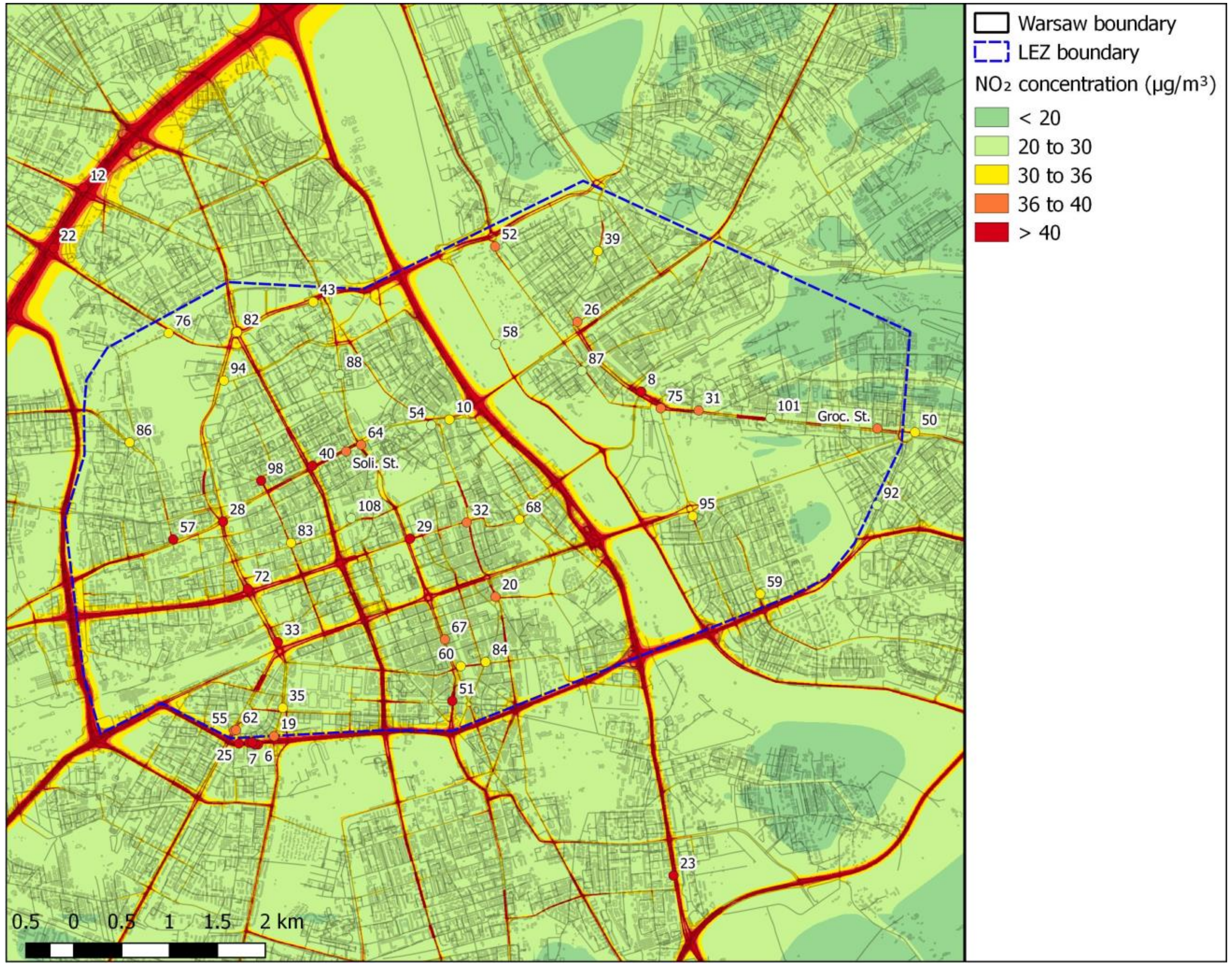
Results summary

- Implementation of the LEZ shows a decrease in NO_2, $PM_{2.5}$ and PM_{10} concentrations at all monitoring locations. The largest decreases are observed at receptors located within the LEZ boundary

NO_2 results

Monitoring site locations: modelled NO_2 concentrations





*Maps shown are 2026 Baseline

Site ID	Location	Latitude (°)	Longitude (°)	Modelled NO_2 concentration (µg/m^3)					
				2019	2026 Baseline	2026 Phase 2	2026 Phase 2 (with TB)	2026 Phase 3	2026 Phase 3 (with TB)
DT_28	LEZ	52.2370	20.9804	64.45	52.37	44.36	43.46	37.84	36.55
DT_29	LEZ	52.2354	21.0090	56.80	46.69	41.01	40.14	35.01	33.73
DT_98	LEZ	52.2408	20.9862	54.42	45.68	41.47	40.66	35.86	34.66
DT_33	LEZ	52.2257	20.9888	53.70	44.57	39.19	38.45	34.14	33.09
DT_8	LEZ	52.2492	21.0443	53.17	44.08	38.48	37.73	32.47	31.39
DT_51	LEZ	52.2202	21.0154	52.87	44.98	40.87	40.24	32.74	31.79
DT_40	LEZ	52.2422	20.9941	52.66	44.27	40.08	39.32	34.59	33.47
DT_72	LEZ	52.2307	20.9842	51.83	42.54	35.70	35.10	30.80	29.99
DT_57	LEZ	52.2353	20.9728	50.29	42.13	37.83	37.15	33.31	32.34
DT_26	LEZ	52.2557	21.0346	46.88	39.54	34.70	34.15	28.89	28.12
DT_32	LEZ	52.2369	21.0177	46.77	39.49	35.29	34.71	29.39	28.53
DT_64	LEZ	52.2442	21.0015	45.96	38.57	34.24	33.62	29.32	28.44
DT_55	LEZ	52.2174	20.9821	45.76	38.91	36.33	35.92	32.92	32.33
DT_62	LEZ	52.2174	20.9824	45.67	38.86	36.23	35.81	32.77	32.16
DT_75	LEZ	52.2476	21.0473	45.63	38.59	34.70	34.09	29.44	28.56
DT_20	LEZ	52.2299	21.0220	45.39	39.34	36.17	35.65	28.87	28.10
DT_31	LEZ	52.2474	21.0531	44.92	37.29	32.41	31.83	28.17	27.37
DT_52	LEZ	52.2628	21.0220	44.79	37.09	32.29	31.77	28.14	27.43
244A Grochowska Street	**LEZ**	**52.2457**	**21.0804**	44.31	36.27	30.40	29.89	26.71	26.05
DT_67	LEZ	52.2259	21.0143	42.42	36.12	32.97	32.44	28.08	27.31
DT_43	LEZ	52.2576	20.9942	42.20	35.49	31.20	30.77	28.09	27.51
DT_39	LEZ	52.2624	21.0377	41.17	35.05	32.14	31.59	28.09	27.31
DT_95	LEZ	52.2375	21.0522	40.89	35.10	31.80	31.29	27.22	26.50
83/89 Solidarności Street	**LEZ**	**52.2436**	**20.9992**	40.78	38.23	34.99	34.42	30.52	29.69
DT_86	LEZ	52.2444	20.9661	40.76	34.83	32.26	31.80	29.46	28.81
DT_60	LEZ	52.2234	21.0167	40.74	34.75	31.86	31.36	27.72	26.99
DT_76	LEZ	52.2547	20.9721	40.65	34.80	32.11	31.66	28.99	28.35
DT_94	LEZ	52.2502	20.9805	40.55	34.17	29.97	29.55	27.13	26.56
DT_10	LEZ	52.2466	21.0150	40.19	34.32	30.58	30.10	26.84	26.19
DT_68	LEZ	52.2372	21.0257	39.67	33.67	29.98	29.52	26.02	25.38
DT_35	LEZ	52.2195	20.9895	39.44	34.10	31.78	31.35	28.61	28.00
DT_83	LEZ	52.2350	20.9908	37.32	32.42	29.94	29.54	26.90	26.33
DT_84	LEZ	52.2238	21.0205	36.67	31.54	29.05	28.63	25.73	25.14
DT_82	LEZ	52.2548	20.9825	35.54	30.73	27.82	27.49	25.65	25.21
DT_59	LEZ	52.2302	21.0625	34.77	30.01	28.48	28.23	25.98	25.64
DT_101	LEZ	52.2467	21.0641	33.67	28.96	26.24	25.89	23.70	23.21
DT_88	LEZ	52.2508	20.9982	33.65	29.49	27.18	26.87	25.05	24.62
DT_54	LEZ	52.2460	21.0122	33.58	29.31	26.71	26.40	23.31	22.88
DT_87	LEZ	52.2511	21.0353	31.81	27.74	25.54	25.23	23.05	22.62
DT_58	LEZ	52.2536	21.0221	31.78	27.46	25.13	24.81	23.08	22.64
DT_108	LEZ	52.2373	21.0000	29.42	26.63	25.21	24.98	23.47	23.16

*DT = diffusion tube. City automatic monitoring sites are shown in bold

Site ID	Location	Latitude (°)	Longitude (°)	Modelled NO_2 concentration (μg/m^3)					
				2019	2026 Baseline	2026 Phase 2	2026 Phase 2 (with TB)	2026 Phase 3	2026 Phase 3 (with TB)
DT_5	Outside	52.2162	20.9851	88.16	70.80	68.17	68.12	66.28	66.22
DT_9	Outside	52.2162	20.9844	84.20	67.77	65.27	65.22	63.43	63.36
DT_25	Outside	52.2162	20.9828	83.21	67.06	64.58	64.52	62.72	62.63
DT_13	Outside	52.2163	20.9849	81.79	66.01	63.59	63.54	61.80	61.73
DT_18	Outside	52.2163	20.9849	81.79	66.01	63.59	63.54	61.80	61.73
DT_7	Outside	52.2161	20.9853	77.80	63.07	60.77	60.73	59.11	59.04
DT_49	Outside	52.2286	21.1403	76.75	59.72	57.32	57.32	55.87	55.87
DT_22	Outside	52.2627	20.9545	64.57	51.21	49.15	49.15	48.13	48.13
DT_12	Outside	52.2683	20.9590	64.56	50.80	48.51	48.51	47.55	47.55
DT_53	Outside	52.1667	21.0313	64.27	49.30	46.79	46.79	45.74	45.74
DT_23	Outside	52.2038	21.0492	55.38	44.68	43.12	43.12	42.24	42.24
DT_117	Outside	52.2261	21.1538	52.60	41.38	39.58	39.58	38.71	38.71
DT_15	Outside	52.1235	21.0180	52.43	41.44	39.73	39.73	38.88	38.88
DT_6	Outside	52.2161	20.9857	50.30	42.03	40.60	40.54	39.44	39.36
DT_19	Outside	52.2169	20.9882	46.21	39.06	37.22	36.97	34.98	34.62
DT_50	Outside	52.2453	21.0862	40.26	34.24	32.90	32.83	31.84	31.75
DT_92	Outside	52.2385	21.0804	24.88	22.60	22.13	22.10	21.73	21.69

Comparison of NO_2 exceedances at monitoring sites by scenario

- The tables below show the number of the 58 monitoring locations in exceedance of the European annual limit value for NO_2 (40 µg/m^3) and with concentrations within 10% of the limit value (36 – 40 µg/m^3) for each of the modelled scenarios
- The 2026 Baseline scenario shows nine locations with exceedances within the LEZ boundary and 23 across the city as a whole
- Implementation of Phase 2 and Phase 3 of the scheme results in seven and 12 fewer locations in exceedance of the NO_2 annual limit value respectively. There are also six fewer locations within 10% of the limit value for Phase 2 and nine for Phase 3
- The implementation of Phase 3 results in no exceedances of the NO_2 limit value within the LEZ boundary and only one location has a concentration above 36 µg/m^3

Scenario	LEZ > 40 µg/m^3	LEZ 36 – 40 µg/m^3	City > 40 µg/m^3	City 36 – 40 µg/m^3
2019	29	4	46	4
2026 Baseline	9	12	23	13
2026 Phase 2	5	6	17	9
2026 Phase 2 (with TB)	4	4	16	7
2026 Phase 3	0	1	11	4
2026 Phase 3 (with TB)	0	1	11	4

Difference from 2026 Baseline	LEZ > 40 µg/m^3	LEZ 36 – 40 µg/m^3	City > 40 µg/m^3	City 36 – 40 µg/m^3
2026 Phase 2	-4	-6	-6	-4
2026 Phase 2 (with TB)	-5	-8	-7	-6
2026 Phase 3	-9	-11	-12	-9
2026 Phase 3 (with TB)	-9	-11	-12	-9

*Total locations = 58

Site ID	Location	Modelled NO_2 concentration ($\mu g/m^3$)						
		2026 Baseline	2026 Phase 2 (with TB)	Phase 2 – Baseline	Phase 2 – Baseline (% of Baseline)	2026 Phase 3 (with TB)	Phase 3 – Baseline	Phase 3 – Baseline (% of Baseline)
DT_28	LEZ	52.37	43.46	-8.91	-17.01%	36.55	-15.82	-30.21%
DT_29	LEZ	46.69	40.14	-6.55	-14.03%	33.73	-12.96	-27.76%
DT_98	LEZ	45.68	40.66	-5.02	-10.99%	34.66	-11.02	-24.12%
DT_33	LEZ	44.57	38.45	-6.12	-13.73%	33.09	-11.48	-25.76%
DT_8	LEZ	44.08	37.73	-6.35	-14.41%	31.39	-12.69	-28.79%
DT_51	LEZ	44.98	40.24	-4.74	-10.54%	31.79	-13.19	-29.32%
DT_40	LEZ	44.27	39.32	-4.95	-11.18%	33.47	-10.80	-24.40%
DT_72	LEZ	42.54	35.10	-7.44	-17.49%	29.99	-12.55	-29.50%
DT_57	LEZ	42.13	37.15	-4.98	-11.82%	32.34	-9.79	-23.24%
DT_26	LEZ	39.54	34.15	-5.39	-13.63%	28.12	-11.42	-28.88%
DT_32	LEZ	39.49	34.71	-4.78	-12.10%	28.53	-10.96	-27.75%
DT_64	LEZ	38.57	33.62	-4.95	-12.83%	28.44	-10.13	-26.26%
DT_55	LEZ	38.91	35.92	-2.99	-7.68%	32.33	-6.58	-16.91%
DT_62	LEZ	38.86	35.81	-3.05	-7.85%	32.16	-6.70	-17.24%
DT_75	LEZ	38.59	34.09	-4.50	-11.66%	28.56	-10.03	-25.99%
DT_20	LEZ	39.34	35.65	-3.69	-9.38%	28.10	-11.24	-28.57%
DT_31	LEZ	37.29	31.83	-5.46	-14.64%	27.37	-9.92	-26.60%
DT_52	LEZ	37.09	31.77	-5.32	-14.34%	27.43	-9.66	-26.04%
244A Grochowska Street	**LEZ**	36.27	29.89	-6.38	-17.59%	26.05	-10.22	-28.18%
DT_67	LEZ	36.12	32.44	-3.68	-10.19%	27.31	-8.81	-24.39%
DT_43	LEZ	35.49	30.77	-4.72	-13.30%	27.51	-7.98	-22.49%
DT_39	LEZ	35.05	31.59	-3.46	-9.87%	27.31	-7.74	-22.08%
DT_95	LEZ	35.10	31.29	-3.81	-10.85%	26.50	-8.60	-24.50%
83/89 Solidarności Street	**LEZ**	38.23	34.42	-3.81	-9.97%	29.69	-8.54	-22.34%
DT_86	LEZ	34.83	31.80	-3.03	-8.70%	28.81	-6.02	-17.28%
DT_60	LEZ	34.75	31.36	-3.39	-9.76%	26.99	-7.76	-22.33%
DT_76	LEZ	34.80	31.66	-3.14	-9.02%	28.35	-6.45	-18.53%
DT_94	LEZ	34.17	29.55	-4.62	-13.52%	26.56	-7.61	-22.27%
DT_10	LEZ	34.32	30.10	-4.22	-12.30%	26.19	-8.13	-23.69%
DT_68	LEZ	33.67	29.52	-4.15	-12.33%	25.38	-8.29	-24.62%
DT_35	LEZ	34.10	31.35	-2.75	-8.06%	28.00	-6.10	-17.89%
DT_83	LEZ	32.42	29.54	-2.88	-8.88%	26.33	-6.09	-18.78%
DT_84	LEZ	31.54	28.63	-2.91	-9.23%	25.14	-6.40	-20.29%
DT_82	LEZ	30.73	27.49	-3.24	-10.54%	25.21	-5.52	-17.96%
DT_59	LEZ	30.01	28.23	-1.78	-5.93%	25.64	-4.37	-14.56%
DT_101	LEZ	28.96	25.89	-3.07	-10.60%	23.21	-5.75	-19.85%
DT_88	LEZ	29.49	26.87	-2.62	-8.88%	24.62	-4.87	-16.51%
DT_54	LEZ	29.31	26.40	-2.91	-9.93%	22.88	-6.43	-21.94%
DT_87	LEZ	27.74	25.23	-2.51	-9.05%	22.62	-5.12	-18.46%
DT_58	LEZ	27.46	24.81	-2.65	-9.65%	22.64	-4.82	-17.55%
DT_108	LEZ	26.63	24.98	-1.65	-6.20%	23.16	-3.47	-13.03%

Site ID	Location	Modelled NO_2 concentration ($\mu g/m^3$)						
		2026 Baseline	2026 Phase 2 (with TB)	Phase 2 – Baseline	Phase 2 – Baseline (% of Baseline)	2026 Phase 3 (with TB)	Phase 3 – Baseline	Phase 3 – Baseline (% of Baseline)
DT_5	Outside	70.80	68.12	-2.68	-3.79%	66.22	-4.58	-6.47%
DT_9	Outside	67.77	65.22	-2.55	-3.76%	63.36	-4.41	-6.51%
DT_25	Outside	67.06	64.52	-2.54	-3.79%	62.63	-4.43	-6.61%
DT_13	Outside	66.01	63.54	-2.47	-3.74%	61.73	-4.28	-6.48%
DT_18	Outside	66.01	63.54	-2.47	-3.74%	61.73	-4.28	-6.48%
DT_7	Outside	63.07	60.73	-2.34	-3.71%	59.04	-4.03	-6.39%
DT_49	Outside	59.72	57.32	-2.40	-4.02%	55.87	-3.85	-6.45%
DT_22	Outside	51.21	49.15	-2.06	-4.02%	48.13	-3.08	-6.01%
DT_12	Outside	50.80	48.51	-2.29	-4.51%	47.55	-3.25	-6.40%
DT_53	Outside	49.30	46.79	-2.51	-5.09%	45.74	-3.56	-7.22%
DT_23	Outside	44.68	43.12	-1.56	-3.49%	42.24	-2.44	-5.46%
DT_117	Outside	41.38	39.58	-1.80	-4.35%	38.71	-2.67	-6.45%
DT_15	Outside	41.44	39.73	-1.71	-4.13%	38.88	-2.56	-6.18%
DT_6	Outside	42.03	40.54	-1.49	-3.55%	39.36	-2.67	-6.35%
DT_19	Outside	39.06	36.97	-2.09	-5.35%	34.62	-4.44	-11.37%
DT_50	Outside	34.24	32.83	-1.41	-4.12%	31.75	-2.49	-7.27%
DT_92	Outside	22.60	22.10	-0.50	-2.21%	21.69	-0.91	-4.03%

$PM_{2.5}$ results

Site ID	Location	Modelled $PM_{2.5}$ concentration (µg/m^3)					
		2019	2026 Baseline	2026 Phase 2	2026 Phase 2 (with TB)	2026 Phase 3	2026 Phase 3 (with TB)
DT_28	LEZ	24.11	23.15	22.29	22.16	22.23	22.01
DT_98	LEZ	22.51	22.11	21.63	21.53	21.61	21.41
DT_40	LEZ	22.43	22.03	21.57	21.47	21.54	21.35
DT_33	LEZ	22.34	21.77	21.22	21.13	21.19	21.02
DT_29	LEZ	22.19	21.60	20.99	20.88	20.96	20.75
DT_72	LEZ	22.16	21.44	20.83	20.76	20.78	20.65
DT_57	LEZ	21.94	21.52	21.09	21.01	21.08	20.91
DT_51	LEZ	21.69	21.26	20.82	20.74	20.71	20.56
83/89 Solidarności Street	**LEZ**	21.39	21.10	20.78	20.70	20.75	20.61
DT_55	LEZ	21.36	21.01	20.75	20.70	20.73	20.63
DT_8	LEZ	21.35	20.79	20.23	20.14	20.18	20.03
DT_62	LEZ	21.31	20.97	20.71	20.66	20.68	20.59
DT_43	LEZ	21.10	20.66	20.27	20.22	20.25	20.15
DT_76	LEZ	20.90	20.64	20.38	20.33	20.36	20.26
DT_86	LEZ	20.82	20.57	20.32	20.27	20.31	20.21
DT_94	LEZ	20.79	20.39	20.04	19.99	20.02	19.93
DT_20	LEZ	20.79	20.51	20.18	20.11	20.08	19.96
DT_32	LEZ	20.77	20.38	19.98	19.91	19.93	19.79
DT_64	LEZ	20.74	20.33	19.92	19.85	19.88	19.75
DT_35	LEZ	20.72	20.50	20.27	20.22	20.25	20.15
DT_26	LEZ	20.66	20.16	19.70	19.64	19.65	19.53
DT_75	LEZ	20.61	20.24	19.85	19.78	19.80	19.68
DT_31	LEZ	20.58	20.12	19.68	19.61	19.65	19.53
244A Grochowska Street	**LEZ**	20.56	19.99	19.51	19.45	19.49	19.37
DT_52	LEZ	20.54	20.06	19.65	19.58	19.61	19.50
DT_67	LEZ	20.42	20.14	19.83	19.76	19.78	19.66
DT_83	LEZ	20.39	20.19	19.96	19.91	19.94	19.86
DT_82	LEZ	20.24	19.96	19.70	19.66	19.69	19.62
DT_60	LEZ	20.23	19.97	19.68	19.62	19.65	19.53
DT_39	LEZ	20.19	19.94	19.65	19.59	19.64	19.51
DT_95	LEZ	20.13	19.86	19.55	19.49	19.50	19.40
DT_10	LEZ	20.02	19.64	19.27	19.22	19.24	19.15
DT_88	LEZ	20.01	19.82	19.62	19.59	19.61	19.55
DT_68	LEZ	19.92	19.65	19.36	19.30	19.32	19.23
DT_84	LEZ	19.67	19.45	19.22	19.17	19.19	19.10
DT_59	LEZ	19.62	19.41	19.27	19.24	19.24	19.19
DT_108	LEZ	19.56	19.44	19.32	19.30	19.31	19.27
DT_101	LEZ	19.36	19.14	18.91	18.87	18.90	18.82
DT_54	LEZ	19.27	19.05	18.84	18.80	18.80	18.74
DT_58	LEZ	19.21	19.02	18.82	18.79	18.81	18.74
DT_87	LEZ	19.14	18.96	18.77	18.74	18.76	18.69

Site ID	Location	Modelled $PM_{2.5}$ concentration ($\mu g/m^3$)					
		2019	2026 Baseline	2026 Phase 2	2026 Phase 2 (with TB)	2026 Phase 3	2026 Phase 3 (with TB)
DT_5	Outside	27.44	25.86	25.54	25.53	25.50	25.48
DT_9	Outside	26.91	25.47	25.18	25.18	25.14	25.13
DT_25	Outside	26.76	25.35	25.07	25.06	25.02	25.01
DT_13	Outside	26.50	25.12	24.85	24.84	24.81	24.79
DT_18	Outside	26.50	25.12	24.85	24.84	24.81	24.79
DT_7	Outside	25.71	24.41	24.14	24.14	24.11	24.09
DT_22	Outside	24.44	23.36	23.18	23.18	23.15	23.15
DT_49	Outside	24.00	22.62	22.38	22.38	22.34	22.34
DT_12	Outside	23.86	22.77	22.59	22.59	22.57	22.57
DT_23	Outside	22.31	21.54	21.40	21.40	21.38	21.38
DT_6	Outside	21.81	21.25	21.12	21.11	21.10	21.08
DT_19	Outside	21.53	21.16	20.97	20.94	20.95	20.89
DT_53	Outside	20.68	19.57	19.39	19.39	19.36	19.36
DT_50	Outside	20.18	19.81	19.69	19.68	19.68	19.66
DT_15	Outside	19.58	18.74	18.60	18.60	18.58	18.58
DT_117	Outside	19.58	18.62	18.46	18.46	18.44	18.44
DT_92	Outside	18.50	18.39	18.36	18.36	18.35	18.35

Comparison of $PM_{2.5}$ exceedances by scenario

- The tables below show the number of 58 specified receptor locations in exceedance of the European annual limit value for $PM_{2.5}$ (20 µg/m^3) and with concentrations within 10% of the limit value (18 – 20 µg/m^3) for each of the modelled scenarios
- The 2026 Baseline scenario shows 26 locations with exceedances within the LEZ boundary and 38 across the city as a whole
- Implementation of Phase 2 and Phase 3 of the scheme results in nine and ten fewer locations in exceedance of the $PM_{2.5}$ annual limit value respectively

Scenario	LEZ > 20 µg/m^3	LEZ 18 – 20 µg/m^3	City > 20 µg/m^3	City 18 – 20 µg/m^3
2019	33	8	48	11
2026 Baseline	26	15	38	20
2026 Phase 2	18	23	30	28
2026 Phase 2 (with TB)	17	24	29	29
2026 Phase 3	18	23	30	28
2026 Phase 3 (with TB)	16	25	28	30

Difference from 2026 Baseline	LEZ > 20 µg/m^3	LEZ 18 – 20 µg/m^3	City > 20 µg/m^3	City 18 – 20 µg/m^3
2026 Phase 2	-8	8	-8	8
2026 Phase 2 (with TB)	-9	9	-9	9
2026 Phase 3	-8	8	-8	8
2026 Phase 3 (with TB)	-10	10	-10	10

*Total locations = 58

Site ID	Location	Modelled $PM_{2.5}$ concentration (µg/m^3)						
		2026 Baseline	2026 Phase 2 (with TB)	Phase 2 – Baseline	Phase 2 – Baseline (% of Baseline)	2026 Phase 3 (with TB)	Phase 3 – Baseline	Phase 3 – Baseline (% of Baseline)
DT_28	LEZ	23.15	22.16	-0.99	-4.28%	22.01	-1.15	-4.95%
DT_98	LEZ	22.11	21.53	-0.58	-2.62%	21.41	-0.70	-3.17%
DT_40	LEZ	22.03	21.47	-0.56	-2.55%	21.35	-0.68	-3.10%
DT_33	LEZ	21.77	21.13	-0.65	-2.96%	21.02	-0.75	-3.45%
DT_29	LEZ	21.60	20.88	-0.73	-3.36%	20.75	-0.85	-3.96%
DT_72	LEZ	21.44	20.76	-0.69	-3.20%	20.65	-0.79	-3.68%
DT_57	LEZ	21.52	21.01	-0.51	-2.38%	20.91	-0.61	-2.83%
DT_51	LEZ	21.26	20.74	-0.52	-2.45%	20.56	-0.70	-3.29%
83/89 Solidarności Street	**LEZ**	21.10	20.70	-0.40	-1.90%	20.61	-0.50	-2.35%
DT_55	LEZ	21.01	20.70	-0.31	-1.47%	20.63	-0.38	-1.80%
DT_8	LEZ	20.79	20.14	-0.65	-3.11%	20.03	-0.77	-3.68%
DT_62	LEZ	20.97	20.66	-0.31	-1.49%	20.59	-0.38	-1.82%
DT_43	LEZ	20.66	20.22	-0.44	-2.11%	20.15	-0.50	-2.43%
DT_76	LEZ	20.64	20.33	-0.32	-1.53%	20.26	-0.38	-1.85%
DT_86	LEZ	20.57	20.27	-0.30	-1.48%	20.21	-0.36	-1.76%
DT_94	LEZ	20.39	19.99	-0.40	-1.97%	19.93	-0.46	-2.25%
DT_20	LEZ	20.51	20.11	-0.39	-1.92%	19.96	-0.55	-2.68%
DT_32	LEZ	20.38	19.91	-0.47	-2.32%	19.79	-0.59	-2.88%
DT_64	LEZ	20.33	19.85	-0.49	-2.41%	19.75	-0.59	-2.90%
DT_35	LEZ	20.50	20.22	-0.28	-1.38%	20.15	-0.35	-1.69%
DT_26	LEZ	20.16	19.64	-0.52	-2.58%	19.53	-0.63	-3.13%
DT_75	LEZ	20.24	19.78	-0.46	-2.27%	19.68	-0.56	-2.78%
DT_31	LEZ	20.12	19.61	-0.51	-2.51%	19.53	-0.59	-2.94%
DT_244	LEZ	19.99	19.45	-0.55	-2.73%	19.37	-0.62	-3.11%
DT_52	LEZ	20.06	19.58	-0.48	-2.38%	19.50	-0.56	-2.79%
DT_67	LEZ	20.14	19.76	-0.38	-1.87%	19.66	-0.48	-2.37%
DT_83	LEZ	20.19	19.91	-0.27	-1.36%	19.86	-0.33	-1.65%
244A Grochowska Street	**LEZ**	19.96	19.66	-0.29	-1.46%	19.62	-0.33	-1.67%
DT_60	LEZ	19.97	19.62	-0.35	-1.74%	19.53	-0.43	-2.16%
DT_39	LEZ	19.94	19.59	-0.35	-1.77%	19.51	-0.44	-2.18%
DT_95	LEZ	19.86	19.49	-0.37	-1.88%	19.40	-0.46	-2.34%
DT_10	LEZ	19.64	19.22	-0.42	-2.12%	19.15	-0.49	-2.48%
DT_88	LEZ	19.82	19.59	-0.23	-1.15%	19.55	-0.27	-1.36%
DT_68	LEZ	19.65	19.30	-0.35	-1.77%	19.23	-0.42	-2.16%
DT_84	LEZ	19.45	19.17	-0.28	-1.45%	19.10	-0.35	-1.78%
DT_59	LEZ	19.41	19.24	-0.17	-0.88%	19.19	-0.22	-1.15%
DT_108	LEZ	19.44	19.30	-0.15	-0.75%	19.27	-0.18	-0.91%
DT_101	LEZ	19.14	18.87	-0.27	-1.41%	18.82	-0.32	-1.67%
DT_54	LEZ	19.05	18.80	-0.25	-1.30%	18.74	-0.31	-1.63%
DT_58	LEZ	19.02	18.79	-0.23	-1.23%	18.74	-0.28	-1.45%
DT_87	LEZ	18.96	18.74	-0.22	-1.17%	18.69	-0.27	-1.42%

Site ID	Location	Modelled $PM_{2.5}$ concentration (μg/m^3)						
		2026 Baseline	2026 Phase 2 (with TB)	Phase 2 – Baseline	Phase 2 – Baseline (% of Baseline)	2026 Phase 3 (with TB)	Phase 3 – Baseline	Phase 3 – Baseline (% of Baseline)
DT_5	Outside	25.86	25.53	-0.32	-1.24%	25.48	-0.37	-1.44%
DT_9	Outside	25.47	25.18	-0.30	-1.18%	25.13	-0.35	-1.37%
DT_25	Outside	25.35	25.06	-0.30	-1.18%	25.01	-0.35	-1.37%
DT_13	Outside	25.12	24.84	-0.29	-1.15%	24.79	-0.33	-1.33%
DT_18	Outside	25.12	24.84	-0.29	-1.15%	24.79	-0.33	-1.33%
DT_7	Outside	24.41	24.14	-0.27	-1.10%	24.09	-0.31	-1.27%
DT_22	Outside	23.36	23.18	-0.18	-0.78%	23.15	-0.21	-0.89%
DT_49	Outside	22.62	22.38	-0.24	-1.06%	22.34	-0.28	-1.24%
DT_12	Outside	22.77	22.59	-0.18	-0.80%	22.57	-0.21	-0.90%
DT_23	Outside	21.54	21.40	-0.13	-0.62%	21.38	-0.15	-0.71%
DT_6	Outside	21.25	21.11	-0.14	-0.66%	21.08	-0.16	-0.77%
DT_19	Outside	21.16	20.94	-0.22	-1.03%	20.89	-0.27	-1.27%
DT_53	Outside	19.57	19.39	-0.18	-0.93%	19.36	-0.21	-1.07%
DT_50	Outside	19.81	19.68	-0.12	-0.62%	19.66	-0.14	-0.73%
DT_15	Outside	18.74	18.60	-0.14	-0.75%	18.58	-0.16	-0.85%
DT_117	Outside	18.62	18.46	-0.16	-0.85%	18.44	-0.18	-0.96%
DT_92	Outside	18.39	18.36	-0.04	-0.20%	18.35	-0.04	-0.24%

PM_{10} results

Site ID	Location	Modelled PM_{10} concentration ($\mu g/m^3$)					
		2019	2026 Baseline	2026 Phase 2	2026 Phase 2 (with TB)	2026 Phase 3	2026 Phase 3 (with TB)
DT_28	LEZ	33.17	32.45	31.63	31.41	31.64	31.22
DT_98	LEZ	31.04	30.86	30.42	30.24	30.45	30.09
DT_40	LEZ	30.93	30.74	30.32	30.14	30.34	29.99
DT_29	LEZ	30.61	30.24	29.66	29.47	29.69	29.31
DT_33	LEZ	30.53	30.13	29.61	29.45	29.62	29.32
DT_72	LEZ	30.04	29.45	28.86	28.73	28.85	28.61
DT_57	LEZ	30.02	29.79	29.39	29.25	29.41	29.13
DT_51	LEZ	29.94	29.69	29.27	29.13	29.21	28.93
83/89 Solidarności Street	**LEZ**	29.25	29.12	28.81	28.69	28.82	28.57
DT_8	LEZ	29.11	28.72	28.19	28.04	28.18	27.90
DT_55	LEZ	29.10	28.89	28.64	28.56	28.65	28.48
DT_62	LEZ	29.03	28.82	28.57	28.48	28.57	28.40
DT_43	LEZ	28.54	28.19	27.82	27.73	27.82	27.65
DT_20	LEZ	28.54	28.39	28.08	27.97	28.02	27.80
DT_76	LEZ	28.43	28.30	28.06	27.96	28.07	27.88
DT_32	LEZ	28.37	28.11	27.72	27.60	27.70	27.46
DT_64	LEZ	28.29	28.04	27.64	27.52	27.64	27.40
DT_86	LEZ	28.28	28.16	27.93	27.84	27.95	27.77
DT_35	LEZ	28.15	28.06	27.84	27.75	27.85	27.67
DT_75	LEZ	28.09	27.87	27.50	27.38	27.49	27.26
DT_94	LEZ	28.05	27.74	27.40	27.32	27.41	27.25
DT_26	LEZ	28.01	27.62	27.18	27.08	27.15	26.95
DT_31	LEZ	27.94	27.61	27.20	27.08	27.20	26.98
DT_67	LEZ	27.91	27.76	27.47	27.36	27.46	27.24
DT_52	LEZ	27.85	27.50	27.10	27.00	27.09	26.90
244A Grochowska Street	**LEZ**	27.78	27.33	26.86	26.76	26.86	26.67
DT_60	LEZ	27.60	27.48	27.21	27.10	27.21	27.00
DT_83	LEZ	27.59	27.48	27.26	27.18	27.26	27.11
DT_39	LEZ	27.54	27.44	27.17	27.06	27.18	26.96
DT_95	LEZ	27.37	27.24	26.94	26.84	26.93	26.73
DT_82	LEZ	27.22	27.01	26.77	26.70	26.77	26.65
DT_10	LEZ	27.06	26.78	26.43	26.34	26.42	26.25
DT_68	LEZ	27.02	26.86	26.58	26.49	26.58	26.40
DT_88	LEZ	26.93	26.81	26.63	26.57	26.64	26.52
DT_84	LEZ	26.66	26.54	26.32	26.24	26.33	26.16
DT_59	LEZ	26.60	26.49	26.35	26.30	26.34	26.24
DT_108	LEZ	26.24	26.18	26.06	26.02	26.06	25.98
DT_101	LEZ	26.12	25.99	25.78	25.71	25.78	25.65
DT_54	LEZ	25.96	25.80	25.60	25.54	25.58	25.47
DT_58	LEZ	25.91	25.80	25.61	25.55	25.63	25.50
DT_87	LEZ	25.79	25.67	25.50	25.44	25.50	25.38

Site ID	Location	Modelled PM_{10} concentration (µg/m^3)					
		2019	2026 Baseline	2026 Phase 2	2026 Phase 2 (with TB)	2026 Phase 3	2026 Phase 3 (with TB)
DT_5	Outside	38.13	36.90	36.55	36.53	36.53	36.50
DT_9	Outside	37.42	36.32	36.00	35.99	35.98	35.95
DT_25	Outside	37.19	36.12	35.80	35.79	35.79	35.75
DT_13	Outside	36.78	35.72	35.41	35.39	35.39	35.36
DT_18	Outside	36.78	35.72	35.41	35.39	35.39	35.36
DT_7	Outside	35.45	34.43	34.14	34.13	34.12	34.10
DT_49	Outside	34.04	33.06	32.77	32.77	32.75	32.75
DT_22	Outside	33.56	32.71	32.50	32.50	32.48	32.48
DT_12	Outside	32.49	31.58	31.38	31.38	31.36	31.36
DT_23	Outside	30.64	30.05	29.90	29.90	29.89	29.89
DT_6	Outside	29.60	29.16	29.02	29.01	29.02	28.99
DT_19	Outside	29.39	29.16	28.98	28.92	28.98	28.87
DT_53	Outside	28.38	27.48	27.27	27.27	27.26	27.26
DT_50	Outside	27.37	27.11	26.99	26.97	26.98	26.95
DT_15	Outside	26.83	26.16	26.00	26.00	25.99	25.99
DT_117	Outside	26.75	25.94	25.76	25.76	25.75	25.75
DT_92	Outside	24.76	24.69	24.65	24.65	24.65	24.64

Site ID	Location	Modelled PM_{10} concentration ($\mu g/m^3$)						
		2026 Baseline	2026 Phase 2 (with TB)	Phase 2 – Baseline	Phase 2 – Baseline (% of Baseline)	2026 Phase 3 (with TB)	Phase 3 – Baseline	Phase 3 – Baseline (% of Baseline)
DT_28	LEZ	32.45	31.41	-1.04	-3.22%	31.22	-1.23	-3.80%
DT_98	LEZ	30.86	30.24	-0.62	-2.01%	30.09	-0.77	-2.50%
DT_40	LEZ	30.74	30.14	-0.60	-1.95%	29.99	-0.75	-2.44%
DT_29	LEZ	30.24	29.47	-0.77	-2.55%	29.31	-0.93	-3.09%
DT_33	LEZ	30.13	29.45	-0.68	-2.26%	29.32	-0.81	-2.70%
DT_72	LEZ	29.45	28.73	-0.72	-2.44%	28.61	-0.84	-2.86%
DT_57	LEZ	29.79	29.25	-0.54	-1.83%	29.13	-0.66	-2.22%
DT_51	LEZ	29.69	29.13	-0.56	-1.88%	28.93	-0.76	-2.56%
83/89 Solidarności Street	**LEZ**	29.12	28.69	-0.43	-1.47%	28.57	-0.54	-1.87%
DT_8	LEZ	28.72	28.04	-0.68	-2.36%	27.90	-0.82	-2.85%
DT_55	LEZ	28.89	28.56	-0.33	-1.15%	28.48	-0.41	-1.43%
DT_62	LEZ	28.82	28.48	-0.34	-1.17%	28.40	-0.42	-1.45%
DT_43	LEZ	28.19	27.73	-0.46	-1.64%	27.65	-0.54	-1.92%
DT_20	LEZ	28.39	27.97	-0.42	-1.48%	27.80	-0.60	-2.10%
DT_76	LEZ	28.30	27.96	-0.34	-1.20%	27.88	-0.42	-1.48%
DT_32	LEZ	28.11	27.60	-0.50	-1.79%	27.46	-0.64	-2.28%
DT_64	LEZ	28.04	27.52	-0.52	-1.85%	27.40	-0.64	-2.28%
DT_86	LEZ	28.16	27.84	-0.33	-1.15%	27.77	-0.39	-1.40%
DT_35	LEZ	28.06	27.75	-0.30	-1.08%	27.67	-0.38	-1.36%
DT_75	LEZ	27.87	27.38	-0.49	-1.74%	27.26	-0.61	-2.18%
DT_94	LEZ	27.74	27.32	-0.42	-1.53%	27.25	-0.49	-1.78%
DT_26	LEZ	27.62	27.08	-0.55	-1.98%	26.95	-0.67	-2.43%
DT_31	LEZ	27.61	27.08	-0.53	-1.93%	26.98	-0.63	-2.30%
DT_67	LEZ	27.76	27.36	-0.40	-1.45%	27.24	-0.52	-1.88%
DT_52	LEZ	27.50	27.00	-0.50	-1.83%	26.90	-0.60	-2.18%
244A Grochowska Street	**LEZ**	27.33	26.76	-0.57	-2.10%	26.67	-0.66	-2.43%
DT_60	LEZ	27.48	27.10	-0.37	-1.36%	27.00	-0.48	-1.73%
DT_83	LEZ	27.48	27.18	-0.29	-1.07%	27.11	-0.37	-1.33%
DT_39	LEZ	27.44	27.06	-0.38	-1.37%	26.96	-0.47	-1.73%
DT_95	LEZ	27.24	26.84	-0.40	-1.46%	26.73	-0.50	-1.85%
DT_82	LEZ	27.01	26.70	-0.31	-1.14%	26.65	-0.36	-1.33%
DT_10	LEZ	26.78	26.34	-0.44	-1.64%	26.25	-0.52	-1.95%
DT_68	LEZ	26.86	26.49	-0.37	-1.38%	26.40	-0.46	-1.72%
DT_88	LEZ	26.81	26.57	-0.24	-0.91%	26.52	-0.29	-1.10%
DT_84	LEZ	26.54	26.24	-0.30	-1.14%	26.16	-0.38	-1.43%
DT_59	LEZ	26.49	26.30	-0.19	-0.70%	26.24	-0.24	-0.92%
DT_108	LEZ	26.18	26.02	-0.16	-0.59%	25.98	-0.19	-0.74%
DT_101	LEZ	25.99	25.71	-0.29	-1.10%	25.65	-0.35	-1.33%
DT_54	LEZ	25.80	25.54	-0.26	-1.01%	25.47	-0.33	-1.30%
DT_58	LEZ	25.80	25.55	-0.25	-0.97%	25.50	-0.30	-1.16%
DT_87	LEZ	25.67	25.44	-0.24	-0.92%	25.38	-0.29	-1.14%

Site ID	Location	Modelled PM_{10} concentration (µg/m^3)						
		2026 Baseline	2026 Phase 2 (with TB)	Phase 2 – Baseline	Phase 2 – Baseline (% of Baseline)	2026 Phase 3 (with TB)	Phase 3 – Baseline	Phase 3 – Baseline (% of Baseline)
DT_5	Outside	36.90	36.53	-0.36	-0.98%	36.50	-0.40	-1.07%
DT_9	Outside	36.32	35.99	-0.34	-0.93%	35.95	-0.37	-1.03%
DT_25	Outside	36.12	35.79	-0.34	-0.93%	35.75	-0.37	-1.03%
DT_13	Outside	35.72	35.39	-0.32	-0.91%	35.36	-0.36	-1.00%
DT_18	Outside	35.72	35.39	-0.32	-0.91%	35.36	-0.36	-1.00%
DT_7	Outside	34.43	34.13	-0.30	-0.87%	34.10	-0.33	-0.96%
DT_49	Outside	33.06	32.77	-0.29	-0.87%	32.75	-0.31	-0.94%
DT_22	Outside	32.71	32.50	-0.21	-0.64%	32.48	-0.23	-0.69%
DT_12	Outside	31.58	31.38	-0.20	-0.65%	31.36	-0.22	-0.69%
DT_23	Outside	30.05	29.90	-0.15	-0.51%	29.89	-0.17	-0.55%
DT_6	Outside	29.16	29.01	-0.16	-0.53%	28.99	-0.18	-0.60%
DT_19	Outside	29.16	28.92	-0.24	-0.82%	28.87	-0.29	-1.01%
DT_53	Outside	27.48	27.27	-0.21	-0.76%	27.26	-0.22	-0.81%
DT_50	Outside	27.11	26.97	-0.14	-0.50%	26.95	-0.16	-0.57%
DT_15	Outside	26.16	26.00	-0.16	-0.61%	25.99	-0.17	-0.65%
DT_117	Outside	25.94	25.76	-0.18	-0.68%	25.75	-0.19	-0.72%
DT_92	Outside	24.69	24.65	-0.04	-0.17%	24.64	-0.05	-0.20%

Summary of air quality results

Reduction in pollutant concentrations by scenario

- The table below shows the average reduction in concentrations of NO_2, $PM_{2.5}$ and PM_{10} as a result of implementation of Phase 2 and Phase 3 of the LEZ scheme at the specified receptors. Results are presented for receptors within the LEZ boundary and for the City of Warsaw as a whole
- The largest percentage decrease in concentrations is observed within the LEZ boundary owing to the upgraded fleet and reduction in vehicles on central roads in the city
- The decrease in NO_2 concentrations is more significant than for PM as road transport emissions make up a larger proportion of total NOx emissions than total PM
- The relative decrease in concentrations between Phase 2 and Phase 3 is also larger for NO_2 than PM as the difference between emissions from the Euro standards permitted by both phases is larger for NOx than PM
- These result trends are also reflected in the reduction in emissions of pollutants by scenario, as shown on the next slide

	Average reduction in concentration at receptors (% of 2026 Baseline)					
Pollutant	**NO_2**		**$PM_{2.5}$**		**PM_{10}**	
Scenario	**LEZ**	**City**	**LEZ**	**City**	**LEZ**	**City**
2026 Phase 2	-9.84%	-8.09%	-1.71%	-1.32%	-1.18%	-0.96%
2026 Phase 2 (with TB)	-11.21%	-9.09%	-2.02%	-1.69%	-1.56%	-1.31%
2026 Phase 3	-20.91%	-16.68%	-1.87%	-1.45%	-1.19%	-0.97%
2026 Phase 3 (with TB)	-22.85%	-18.09%	-2.43%	-2.02%	-1.92%	-1.59%

Reduction in emissions of pollutants by scenario

Total emissions on all modelled road links

	Emissions (t/year)					
Pollutant	**NOx**		**$PM_{2.5}$**		**PM_{10}**	
	City	**Difference from baseline (% of 2026 Baseline)**	**City**	**Difference from baseline (% of 2026 Baseline)**	**City**	**Difference from baseline (% of 2026 Baseline)**
2026 Baseline	5179.0		305.5		523.7	
2026 Phase 2	4697.9	-9.3%	289.4	-5.3%	506.3	-3.3%
2026 Phase 2 (with TB)	4672.6	-9.8%	288.1	-5.7%	504.1	-3.8%
2026 Phase 3	4333.4	-16.3%	287.2	-6.0%	505.6	-3.5%
2026 Phase 3 (with TB)	4299.9	-17.0%	284.8	-6.8%	501.2	-4.3%

Total emissions on road links within the LEZ boundary

	Emissions (t/year)					
Pollutant	**NOx**		**$PM_{2.5}$**		**PM_{10}**	
	LEZ	**Difference from baseline (% of 2026 Baseline)**	**LEZ**	**Difference from baseline (% of 2026 Baseline)**	**LEZ**	**Difference from baseline (% of 2026 Baseline)**
2026 Baseline	831.6		47.0		80.9	
2026 Phase 2	622.1	-25.2%	39.2	-16.6%	73.5	-9.2%
2026 Phase 2 (with TB)	596.8	-28.2%	37.9	-19.5%	71.3	-12.0%
2026 Phase 3	429.3	-48.4%	38.5	-18.1%	73.5	-9.2%
2026 Phase 3 (with TB)	395.8	-52.4%	36.1	-23.2%	69.2	-14.6%

Results summary

Summary

- The implementation of both Phase 2 and Phase 3 of the LEZ scheme provide large reductions in NO_2, PM_{10} and $PM_{2.5}$ pollutant concentrations across the City of Warsaw
- The largest decreases in concentrations are observed within the LEZ boundary, which are about double that outside the zone
- The decrease in NO_2 concentrations is more significant than for PM_{10} and $PM_{2.5}$:
  - NO_2 decreases by 11% for phase 2 and 21% for phase 3 within the zone
  - Where as $PM_{2.5}$ only decreases by 2% for phase 2 and 3% for phase 3 within the zone
  - This is due to transport being a larger contributor to NO_2 concentrations than PM concentrations
- The relative decrease in concentrations between Phase 2 and Phase 3 is also larger for NO_2 than PM
  - This is because the relative impact on NOx emissions, from Euro 5 to Euro 6, is greater for than for PM emissions
- At the monitoring locations used in this study, implementation of Phase 2 and Phase 3 of the scheme results in 7 and 12 fewer locations predicted to be in exceedance of the European NO_2 annual limit value in 2026 respectively, and within the zone Phase 3 removes all exceedances at the monitoring locations

Economic and health impact assessment

Introduction

The economic analysis consisted of three types of assessment:

1. Health impact assessment – followed best practice approaches to quantify and monetise the impacts on human health associated with the change in air pollution as a consequence of implementing the LEZ.

2. Cost-Benefit analysis - identified, quantified, monetised and compared the societal impacts associated with the introduction of the Phase 2 and 3 LEZ options.

<u>Impacts assessed:</u>

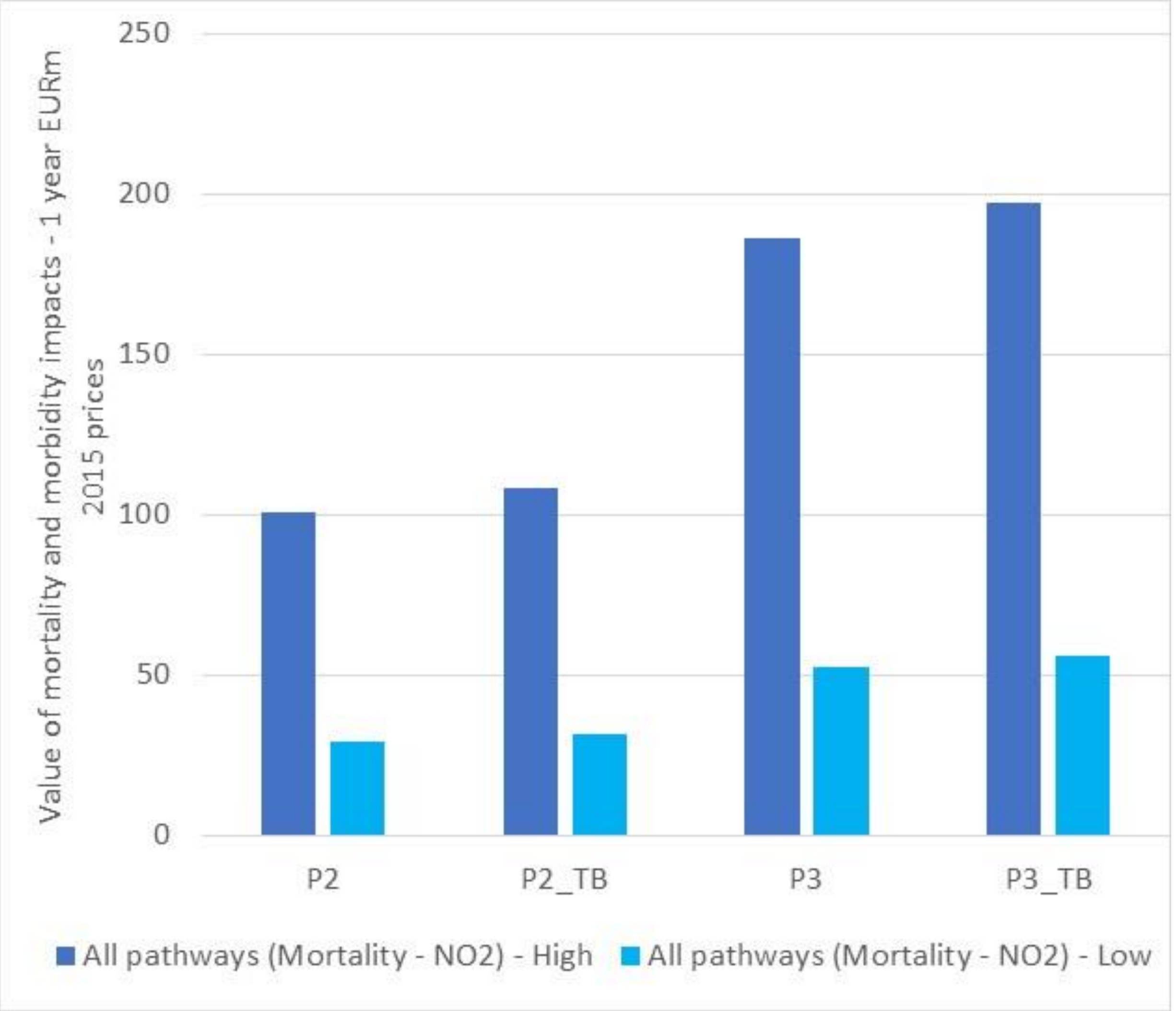
- Health impacts (outputs of Health Impact Assessment)
- Cost of vehicle upgrades to comply with the LEZ
- Changes in fuel and non-fuel vehicle operating costs, and change in GHG emissions, associated with vehicle upgrades
- ‘Welfare’ impacts of trips cancelled due to the LEZ (i.e. the lost value to the individual of the activity foregone / not undertaken)
- Change in travel time from diverted trips due to the LEZ
- Implementation costs.

3. Distributional analysis of business impacts

- Cost-benefit analysis (as presented in the slides above) is valuable to compare and contrast the aggregate impacts of the proposed LEZ. However, this may overlook important dynamics and risks which may affect specific groups in Warsaw.
- This analysis qualitatively assesses the specific impacts on businesses and the potential risks posed by the LEZ and costs of compliance
- This explored in further detail: What types of business will be impacted, how will they react and what will be the impact.

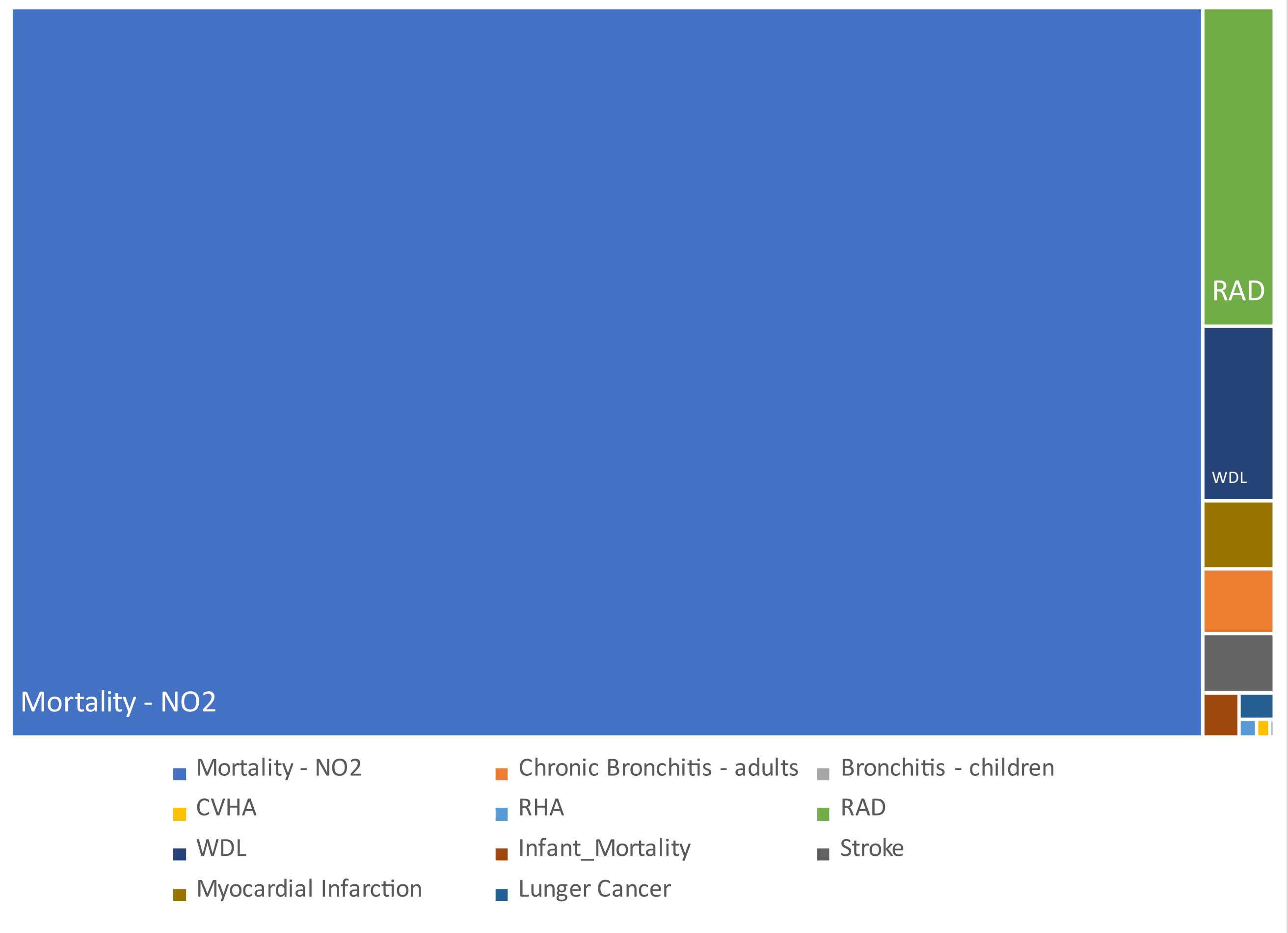
Health impact assessment (HIA) – overall monetised impacts

- HIA captures a range of different health impact pathways, including both mortality and morbidity effect
- To assess the impacts, we have closely followed the methodology and assumptions used in assessments in the EU – as applied by the EC and EEA
  - Results include monetisation of mortality effects associated with chronic exposure to NO_2 only (to avoid double counting of mortality effects which can also be calculated from a change in $PM_{2.5}$)
- The chart shows the total, monetised economic benefit of one year of air pollution impacts delivered by the proposed LEZ
  - Shows relative (or difference) impact compared to the baseline
  - Shows Phase 2 and 3, without and with (_TB) modelled changes in traffic
- The low/high sensitivities (dark/light blue bars) represents reflects uncertainty in the approach to monetising mortality effects (again following the example of the EU-approach)
- ***The air pollution benefit on human health could range from EUR 31m – 108m per annum for Phase 2 (with TB), and from EUR 56m – 197m pa for Phase 3 (with TB)***
- This benefit captures savings in healthcare costs, avoidance of lost productivity (e.g. people being unable to attend work due to ill health), and avoidance of lost 'utility' (i.e. the value that people place on their own good health and wellbeing)



Health impact assessment (HIA) – impacts per year split by pathways

- Chart below shows contribution of different health impact pathways to overall monetised effect (shows Phase 3_TB, low sensitivity estimate)
- Most important pathway bar far is reduction of mortality associated with chronic exposure
  - Other key pathways include reduction in restricted activity days (RADs) and work loss days (WDL)



- HIA also produces 'non-monetised' health impacts of change in air pollution associated with the LEZ, as set out below (these are the impacts which add up to the total monetised effect)
- Note: these should not be viewed as actual effects that would be observed in the real-world. In practice, the reduction in air pollution would manifest in different ways – e.g. reduction in incidence and prevalence of disease, but also a change in severity of cases. The underlying HIA methodologies do not allow prediction of effects with high certainty
  - Instead, it produces 'attributable' (or equivalent) effects which can be considered broadly representative of the overall effect of a change in air pollution, for use in economic appraisal

PHASE 2_TB	PHASE 3_TB
29 fewer deaths per annum	54 fewer deaths per annum
303 life-years saved	555 life-years saved
4 fewer new cases of chronic bronchitis in adults	4 fewer new cases of chronic bronchitis in adults
11 fewer bronchitis episodes in children	13 fewer bronchitis episodes in children
5 less hospital admissions each year for respiratory or cardio-vascular complaints	6 less hospital admissions each year for respiratory or cardio-vascular complaints
8,900 fewer restricted activity days	10,600 fewer restricted activity days
4,100 fewer work days lost	4,900 fewer work days lost
2 less new stroke cases	3 less new stroke cases
Reduction in 7 myocardial infarctions	Reduction in 9 myocardial infarctions
2 fewer new cases of lung cancer	2 fewer new cases of lung cancer

Cost-benefit analysis - overview

- Cost-benefit analysis was deployed to demonstrate the value-for money (VFM) of Phase 2 and 3 of the proposed LEZ, and compare and contrast between the Phases
- To undertake the CBA, we have deployed Ricardo's Clean Air Zone Economic Assessment model: this has been tried, tested and matured through our economic assessment of multiple Clean Air Zone proposals in the UK.
- Simply, the model identifies and assesses a range of impacts associated with the different behavioural responses to a city-level access restriction scheme.
- Both Phases are assessed against a defined 'do nothing' baseline.
- The analysis produces:
  - Net Present Value (NPV) – sum of all monetised costs and benefits, displaying whether the LEZ will deliver an overall benefit (positive NPV) or cost (negative NPV) to society
  - Benefit-cost ratio (BCR) – ratio of monetised benefits to costs, signalling the 'return per zloty invested'
- There is uncertainty around the CBA results and the accuracy of the analysis is inherently driven by the data available. There is also uncertainty around the assessment methods used to monetise the impacts.
  - To explore this uncertainty we have undertaken sensitivity analysis around the central results. This has identified and flex the most uncertain assumptions and parameters in the assessment.

General assumptions:

- All impacts are presented in 2023 prices. Data inflated to 2023 prices based on World Bank indicator GDP Deflators
- Split of vehicles by Euro standard adopts same source as used for the air quality modelling
- Poland-specific fuel prices taken from stat.gov.pl
- Carbon prices taken from DG MOVE Handbook on external costs of transport
- All impacts discounted to 2023, using a social discount rate of 3% (in line with the European Commission's Better Regulation Toolbox)

Cost benefit analysis – vehicle upgrade costs

Description: captures costs for proportion of vehicle owners that choose to upgrade from a non-complaint to a compliant vehicle in response to the LEZ. Given the underlying vehicle fleet improves over time, this is modelled as 'bringing forward' upgrades that would otherwise occur a number of years in the future – i.e. the baseline catching up with the LEZ scenario

Approach

1. Fleet of unique vehicles accessing the proposed LEZ identified from Polish government data for city of Warsaw (https://bdl.stat.gov.pl/)
2. Proportion of non-compliant vehicles identified by applying assumptions around split by Euro standard (in line with air quality modelling)
3. Behavioural assumptions on proportion of non-compliant vehicles upgrading as a result of the LEZ (Buy new, buy used, fuel switch) applied
4. Poland specific vehicle price data estimated based on Ricardo internal data and statista.com
5. Scenario costs are net of baseline costs – LEZ brings forward vehicle upgrades that would have occurred in the future (and are hence discounted relative to LEZ scenario costs which occur sooner). Upgrades are assumed to be brought forward 2 years based on Polish data (https://motofakty.pl)

Results: Costs of vehicle upgrades brought forward due to LEZ

- **P2:** 752.9m zloty
- **P3:** 1.1b zloty

Additionally, lost residual value of scrapped non-compliant vehicles estimated based on age of non-compliant vehicles:

- **P2**: 14.9m zloty **P3**: 48.2m zloty

Table: Estimated number of vehicles purchased in response to the LEZ

Purchased vehicles		Phase 2		Phase 3	
		Buy New	Buy Used	Buy New	Buy Used
Car	Petrol	768	14,954	4,158	42,341
	Diesel	7,720	30,881	14,204	56,815
HGV	Petrol	2,489	2,676	4,158	4,470
	Diesel	22,433	24,116	26,028	27,980
Bus	Diesel	-	-	220	661
Taxi	Petrol	23	447	124	1,265
	Diesel	231	922	424	1,697
LGV	Petrol	1	3,142	6	6,948
	Diesel	2,242	8,967	4,938	19,752

Cost benefit analysis – fuel and non-fuel opex (upgraded vehicles)

Change in fuel and non-fuel operating costs

1. Same assumptions on unique vehicles fleet and behavioural assumptions to yield numbers of upgraded vehicles
2. Combine vehicles upgrade with assumed vkm travelled per vehicle per year (Source: Ricardo economic model)
3. Change in fuel efficiency and annual operating costs of purchased vehicles vs. replaced non-compliant vehicles calculated based on assumed average mileage of different vehicle types (Source: Ricardo economic model)

Captures fuel and non-fuel opex impacts over period until baseline ‘catches-up’ with the LEZ scenario in terms of fleet mix.

Results

- Change in fuel and non-fuel operating costs in P2 and P3 scenarios relative to baseline:

(million zloty)	Fuel	Non-fuel
Phase 2	-1,258	-240
Phase 3	-2,121	-297

Cost benefit analysis – impact of cancelled and re-routed trips

Welfare loss of cancelled trips

1. Number of annual non-compliant trips to LEZ estimated from local transport model provided by the city and fleet projections
2. Apply behavioural assumptions to estimate proportion that cancel
3. Estimated value of lost utility of cancelled trips based on value of the fine and perception of probability of being charged

Change in travel time

1. Non-compliant vehicle-km travelled estimated from transport model and fleet projections
2. Apply behavioural assumptions to estimate proportion of vkm that divert
3. Calculated travel time assuming average speed of 30 kmh
4. Estimated value of increase in travel time based assuming 10% increase travel time for those that divert and data on average wages in Poland

Captures welfare and change in travel time impacts over period until baseline 'catches-up' with the LEZ scenario in terms of fleet mix.

Results

(million zloty)	Welfare of cancelled trips	Change in travel time of diverted trips
Phase 2	28.94	49.99
Phase 3	59.45	102.04

Cost benefit analysis – change in GHG emissions

Greenhouse gas emissions

1. Estimated change in fuel use converted to GHG emissions using emission factors
2. Valued using current carbon price data

Captures GHG impacts over period until baseline ‘catches-up’ with the LEZ scenario in terms of fleet mix.

	Phase 2	Phase 3
Change in GHG emissions (ktCO_2e)	-453.3	-756.3
Value (million zloty)	200.5	334.6

- For comparison, we can compare the estimated change in GHG emissions to the total GHG emissions associated with the trips identified in our LEZ modelling in the baseline (note this focuses on trips, fuel consumption and GHG emissions within a defined geographical and vehicle scope, which may differ to estimates of GHG emissions associated with road transport from other sources).
- Based on these estimates Phase 2 and 3 would respectively deliver a reduction of 4% and 6% of GHG emissions associated with road transport in Warsaw.

Implementation costs

- Estimated costs of implementation of new sticker system and annual operating costs provided by City:
- 10m zloty up-front setup costs and 400,000 ongoing annual costs

Cost benefit analysis – overall results

Results

- Both scenarios highly positive benefit:cost ratio/Net present value – i.e. for both Phase 2 and 3, the benefits of implementing the LEZ outweigh the costs
- This net benefit for both Phases is driven largely by improvements in fuel efficiency of newer vehicles and the benefits for human health of reduction in air pollution (Largest benefits), which outweigh the cost of vehicle upgrades (Largest cost)
- Phase 2 and 3 are estimated to deliver a net benefit to society valued at 1.6bn and 2.9bn zloty respectively
  - For context, this represents 6% and 12% respectively in comparison to the city's annual budget (25bn zloty)
- Phase 3 is estimated to deliver a higher Benefit-cost Ratio (BCR).
  - In other words, the additional benefit of progressing to more stringent restrictions on Euro standards appears to outweigh the costs of doing so.

Results (Million zloty)	Phase 2	Phase 3
Health impacts	792.91	1,434.13
Vehicle upgrades	-752.91	-1,086.95
Residual value of scrapped vehicles	-14.94	-48.24
Change in fuel use	1,258.41	2,120.56
Change in non-fuel vehicle operating costs	240.39	296.82
Welfare impacts of cancelled trips	-28.94	-59.45
Change in travel time	-49.99	-102.04
GHG Emissions	200.55	334.64
Implementation costs	-10.79	-10.79
Benefit:Cost ratio	**2.91**	**3.20**
Net present value:	**1,634.69**	**2,878.69**

Note: green text signifies a benefit, red text signifies a cost

Cost benefit analysis – sensitivity analysis

- As noted, there is uncertainty around the CBA results, driven by uncertainty around underlying data and assessment methods used.
- To explore this uncertainty we have undertaken sensitivity analysis around the central results. This has identified and flex the most uncertain assumptions and parameters in the assessment. Specifically we have tested:
  - The assumed length of average vehicle ownership (assumed to be 2-years in central analysis, increased to 5 –years)
  - Number of unique vehicles travelling into the LEZ each year (tested 20% reduction and increase around central assumptions)
  - Valuation of health impacts (adopting the low-high range around the monetisation of mortality effects, following the EU approach)
- Key conclusion: ***under all sensitivity tests, the key results and conclusions from the analysis remain stable***. Namely that both Phases are seen to deliver a positive NPV, and the BCR of Phase 3 is higher than that of Phase 2.
  - Hence these conclusion are robust to these key uncertainties in the underlying data and methods
- Increasing the assumption on years that vehicle upgrades are brought forward leads to a small increase in BCR for both Phases and a very significant increase in NPV
- The results are not very sensitive to a 20% change in fleet size with a small effect on BCR and NPV
- Using low and high estimates of the value of health impacts from air pollution benefits leads to a significant impact on results, however utilising low estimates still results in very positive BCR for both phases (2.4 and 2.59 respectively)

<table>
<tr><th></th><th></th><th></th><th>Phase 2</th><th>Phase 3</th></tr>
<tr><td colspan="2" rowspan="2">Central results</td><td>Benefit:Cost ratio</td><td>2.79</td><td>3.08</td></tr>
<tr><td>Net present value (m zloty)</td><td>1,536</td><td>2,714</td></tr>
<tr><td rowspan="10">Sensitivity test</td><td rowspan="2">5 years of life remaining</td><td>Benefit:Cost ratio</td><td>2.96</td><td>3.29</td></tr>
<tr><td>Net present value (m zloty)</td><td>3,947</td><td>6,971</td></tr>
<tr><td rowspan="2">20% reduced fleet size</td><td>Benefit:Cost ratio</td><td>2.92</td><td>3.22</td></tr>
<tr><td>Net present value (m zloty)</td><td>1,585</td><td>2,739</td></tr>
<tr><td rowspan="2">20% increased fleet size</td><td>Benefit:Cost ratio</td><td>2.89</td><td>3.19</td></tr>
<tr><td>Net present value (m zloty)</td><td>1,685</td><td>3,018</td></tr>
<tr><td rowspan="2">Health impacts low</td><td>Benefit:Cost ratio</td><td>2.4</td><td>2.59</td></tr>
<tr><td>Net present value (m zloty)</td><td>1,197</td><td>2,077</td></tr>
<tr><td rowspan="2">Health impacts high</td><td>Benefit:Cost ratio</td><td>3.42</td><td>3.82</td></tr>
<tr><td>Net present value (m zloty)</td><td>2,072</td><td>3,681</td></tr>
</table>

Cost benefit analysis – caveats and limitations

The robustness of the analysis is inherently driven by the data available and methods adopted. When drawing conclusions from the results, it is important to keep in mind:

- There was a lack of Warsaw-specific, or even Poland-specific, data for certain metrics (e.g. fuel efficiency of vehicles). In such cases international data sets were applied and considered for their relevance
- The analysis is based on several key assumptions:
  - The baseline fleet projection and euro standard split in 2026
  - Assumed behavioural responses to LEZ, i.e. what proportion choose to upgrade their vehicle, cancel trip, etc.
  - The estimated number of ‘unique’ vehicles which access the LEZ over the course of a year
  - Vehicle ownership patterns (i.e. how much upgrades are brought forward by).
- The health benefits of reduced air pollution are likely undervalued – the approaches adopted do not capture all detrimental health effects that have been associated with exposure to air pollution, and it adopts a conservative approach to considering overlaps between effects of different pollutants and the valuation of impacts.
- The analysis tested separately the shift from ‘no LEZ to Phase 2’, and from ‘no LEZ to Phase 3’. This is different to how the scheme is intended to work, and the impacts of shifting from ‘Phase 2 to Phase 3’ could be different in practice

Distributional analysis – Focus on impacts on businesses

Introduction

- Cost-benefit analysis (as presented in the slides above) is valuable to compare and contrast the aggregate impacts of the proposed LEZ. However, this may overlook important dynamics and risks which may affect specific groups in Warsaw. For example, cost-benefit analysis quantifies the overall compliance costs, but does not consider where these fall and whether these are affordable for those affected
- We have also conducted a 'distributional analysis' to consider in further detail who will be impacted by the proposed LEZ, how, how significantly, and how they will respond
- This analysis has focused specifically on the impacts on businesses. Note: it was not in scope to consider effects on households. Given that cars will be captured in the LEZ restrictions, there may also be important risks and demographic to consider for these groups (e.g., if older vehicles are predominantly owned by lower-income households, they may face a greater share of the costs of complying with the LEZ.

Data sources – two channels of stakeholder engagement

- To gather more specific information to support the assessment of potential impacts on and risks for businesses, information was gathered through two stakeholder engagement activities:
- An ***online survey*** collected responses from over 100 respondents. This gathered data on the characteristics of businesses operating in the LEZ and how they might be potentially impacted
- On April 19 2023, a ***workshop*** was held at the Smolna Entrepreneurship Center to investigate reactions of businesses to the proposed LEZ. 10 different companies belonging to different sectors participated, providing their opinions on the proposed LEZ.
    - Participants were asked to engage in discussions on the LEZ and to fill out worksheets to assess their reaction to the LEZ and to understand how it would impact their business in Warsaw.

Distributional analysis – Focus on impacts on businesses

Overview of effects

- Businesses could be affected either: directly (i.e. where they own and operate non-compliant vehicles which travel into the LEZ), indirectly (e.g. where they do not operate non-complaint vehicles, but rely on suppliers or customers who do) or both.
- Businesses both inside and outside the proposed LEZ could be affected (although those inside the LEZ are more likely to face greater effects, e.g. as all trips will need to be compliant)
- The LEZ could effect businesses across a wide-range of sectors, including: taxi drivers and operators, bus and coach operators, logistics, refuse and waste collection and operations, etc
- The size of impact on businesses and the affordability risks this imposes will depend on a number of variables, including: vehicle ownership; number, type and age of vehicle; frequency of trips into the LEZ; size of overall operations and ability to pass-through any costs to customers.
    - In addition, a key driver of costs will be the behavioural response of firms to the LEZ, i.e. whether they choose to upgrade vehicles or otherwise
- Smaller firms are more likely to face greater affordability risks due to a number of factors, including: they do not have large fleets which can be redistributed, they are likely to have smaller cash reserves to fund upgrades, they have smaller operations over which costs can be spread and may also find it more difficult to access capital or may face higher borrowing charges.
- Not all effects on businesses will be negative: e.g. those operating cleaner fleets or modes of travel may see an increase in demand for their services.
- Not all businesses and business trips will be affected: not all trips will enter the LEZ, and only a proportion will be non-compliant (see table on the right)

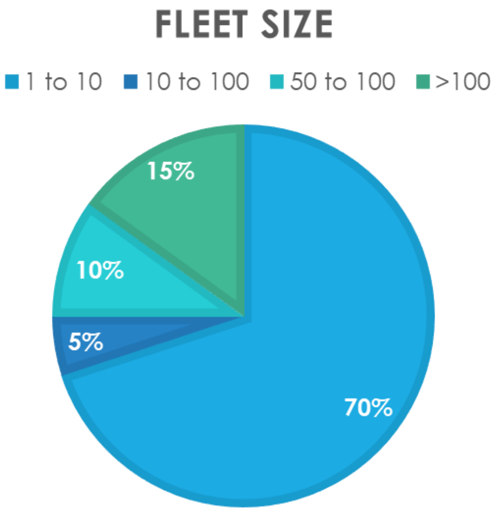
Proportion of all vkm which are non-compliant in 2026

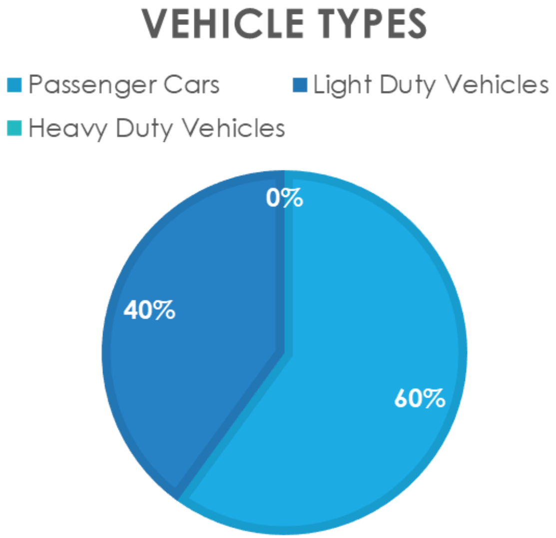
		P2_TB	P3_TB
Car	Petrol	1%	5%
Car	Diesel	21%	39%
LGV	Petrol	0%	0%
LGV	Diesel	16%	36%
rHGV	Diesel	42%	49%
aHGV	Diesel	42%	49%
Bus	Diesel	0%	32%
Coach	Diesel	0%	32%

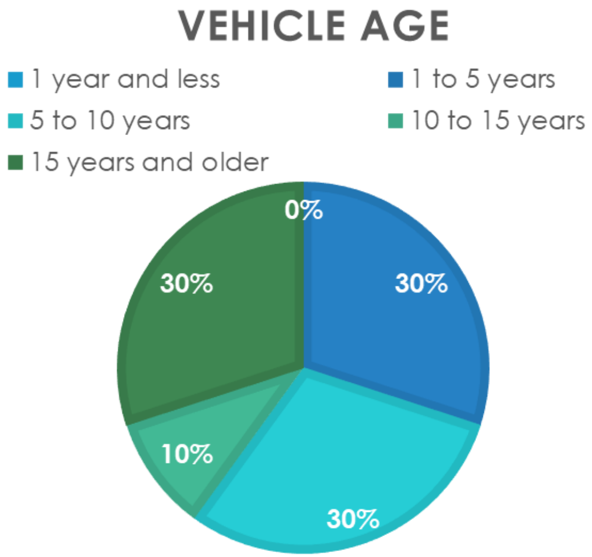
Business impacts – profile of online survey respondents

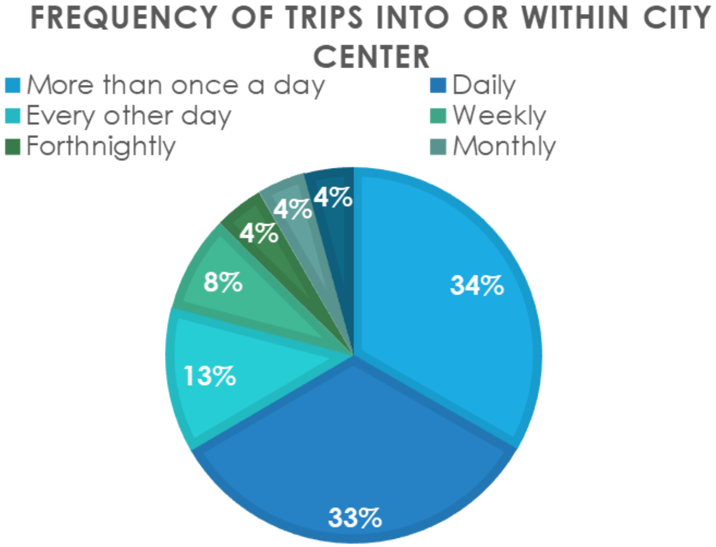
Stakeholder survey

- Most companies surveyed were micro companies with less than 10 employees
- The survey captured businesses from the whole city
- Close to half of respondents have their location in either Śródmieście, Ochota, or Praga Południe
- Most businesses reported their clients being located in Śródmieście and Mokotów
- 80% of respondents reported having a vehicle fleet
- The most common response was amongst: small fleet operators, deploying cars and other light duty vehicles, accessing the proposed LEZ either daily or more than once a day.







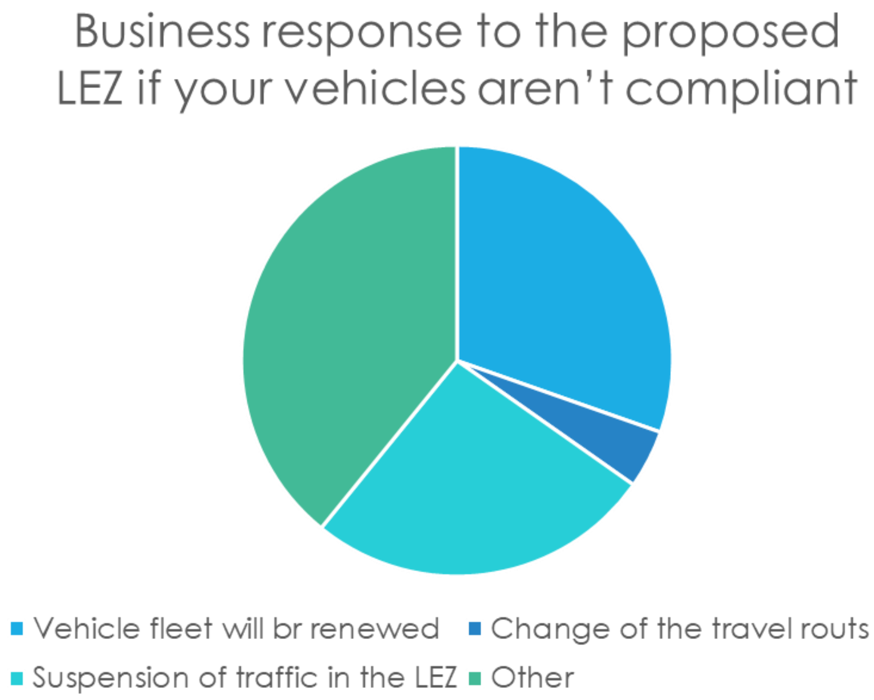


Business impacts – online survey views on impact and response

- The survey responses provide insight into how businesses may ***respond*** to the introduction of the LEZ:
  - A significant proportion suggested they would ‘upgrade’: *A third of surveyed businesses will renew their vehicle fleet.* For these respondents, affordability and impacts on business operations are perhaps more manageable
  - But a significant proportion of respondents also suggested the effects could be more severe, somewhat interrupting business operations: *Around 30% suggested they would suspend traffic altogether in the LEZ.*

- Businesses reported that in most cases they would not be able to ***pass through costs*** of compliance with the LEZ to their respective costumers. The inability to do so poses a greater risk for affected businesses

- With regards to the ***support measures*** for helping businesses comply with the LEZ, several suggestions were made, including:
  - a financial subsidy for the purchase of new vehicles (e.g. 50% of the vehicle value - preferred support measure for majority of respondents).
  - subsidy for alternative means of transport,
  - improvements of the public transport network,
  - vehicle upgrades/retrofits, and
  - derogations for businesses on vehicles being compliant was also proposed as a potential support measure.



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Business impacts – workshop views on impact and response

Workshop

- During the workshop, the opinions of ten people were collected, including entrepreneurs, representatives of business groups, including taxi drivers and food producers, and the City Hall.
- All participants agreed on the need to improve air quality in Warsaw and that a low emissions zone could be helpful, although it will in many cases involve the need of part of the car fleet replacement.
- Participants were concerned with impacts on their customers who may become unable to access the LEZ due to owning a non-compliant vehicle (although it was noted lack of parking in the centre is a greater obstacle for small businesses).
  - Participants also noted that a strong effect of the LEZ would a change in supply conditions.
- Participants indicated that they would respond in various different ways to the LEZ, albeit upgrading their vehicle fleet or changing transport mode was a more likely ***response***, with changing routes or cancelling trips being less likely
- Participants emphasized the need for a holistic approach to change. They suggested several ideas for ***support measures*** to aid compliance and minimise risks for businesses, these included:
  - Improvements to public transport have been pointed out as a key need for mitigating disruptions to customers and businesses in the LEZ, as well as the potential for park and ride schemes (which increase parking spaces outside the zone).
  - Investments in cycling schemes and infrastructure to maximize the potential of cycling were also proposed.
  - Taxi drivers have suggested increasing the maximum charging rate, hoping to help address the high cost of replacement of vehicles that many taxi drivers will face.

Summary and implication for the LEZ options

Potential implications for the design of the LEZ

Air quality assessment

- The LEZ is very effective at reducing exceedances of the European NO_2 annual limit value, with phase 3 (the Euro 6 standard for diesel) removing all exceedances at monitoing locations within the zone itself.
- The LEZ does reduce PM concentrations but the impact is much less significant than for NO_2, since transport exhaust emissions are a smaller contributor to PM than they are to NO_x. Other policies such as direct vehicle reductions and restrictions on the use of solid fuel burning for domestic combustion would likely be more effective.
- The difference between Phase 2 and Phase 3 is more significant for NO_2 than $PM_{2.5}$, with the move from Phase 2 to Phase 3 doubling the reduction in NO_2 concentrations

Economics assessment

- For both Phase 2 and Phase 3 the benefits outweigh the costs of introducing the LEZ (i.e. result in a positive benefit:cost ratio(BCR)/Net present value)
- Phase 3 has a higher BCR than Phase 2 (3.2 vs 2.91) and significantly higher net present value than Phase 2 (2. 9b zloty vs. 1.6b zloty)
- The results are driven largely by improvements in fuel efficiency of newer vehicles and health impacts (Largest benefits) and cost of vehicle upgrades (Largest cost)
- Businesses are most likely to upgrade their vehicle fleet or look to change travel mode in response to the LEZ.
- There are concerns around impacts on customers and reduced traffic to the LEZ.
- Improvements to public transport and cycling infrastructure were suggested as potential mitigation measures, as well as exemptions or subsidies for upgrading vehicles for businesses.