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

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A R T I C L E I N F O

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Health impact modelling
Mitigation measures

A B S T R A C T

Introduction: Air pollution, particularly NO_2, contributes to poor health, including paediatric asthma. This study estimated the reduction in NO_2 concentrations on annual car-free Sundays in two European cities, Brussels and Paris, which have extensive car-free zones (162 km^2 and 105 km^2). We then conducted health impact modelling of paediatric asthma incidence using a hypothesized expansion of annual car-free Sundays to car-free daily zones.
Problem statement: Exposure to air pollution, particularly NO_2 exposure, contributes to negative health outcomes, including paediatric asthma. Local traffic interventions, such as car-free days, could offer a potential strategy to mitigate these effects.
Methods: We assessed NO_2 concentration reductions using various methods, including (1) direct calculations, (2) direct calculations adjusted for meteorological conditions, (3) random forest modelling, and (4) boosted regression tree modelling. To estimate the reduction in paediatric asthma incidence, we applied existing Exposure Response Functions (ERFs) derived from epidemiological studies. These ERFs were used to quantify the relationship between NO_2 exposure and asthma incidence by linking the estimated reductions in NO_2 concentrations from our models to changes in health outcomes under exposure scenarios similar to the hypothetical case of permanent car-free days.
Results: NO_2 concentrations were significantly lower on car-free Sundays, with reductions ranging from 63 to 83% in selected areas of Brussels and 27–56% in selected areas of Paris. The health impact modelling indicated a reduction in paediatric asthma incidence ranging from 15% [95% CI: 11–19%] in residential areas of Brussels to 34% [95% CI: 25–41%] in heavily trafficked areas

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in Brussels, and from 15% [95% CI: 10–19%] to 19% [95% CI: 13–24%] in Paris for the hypothesized counterfactual scenario of daily car-free zones.

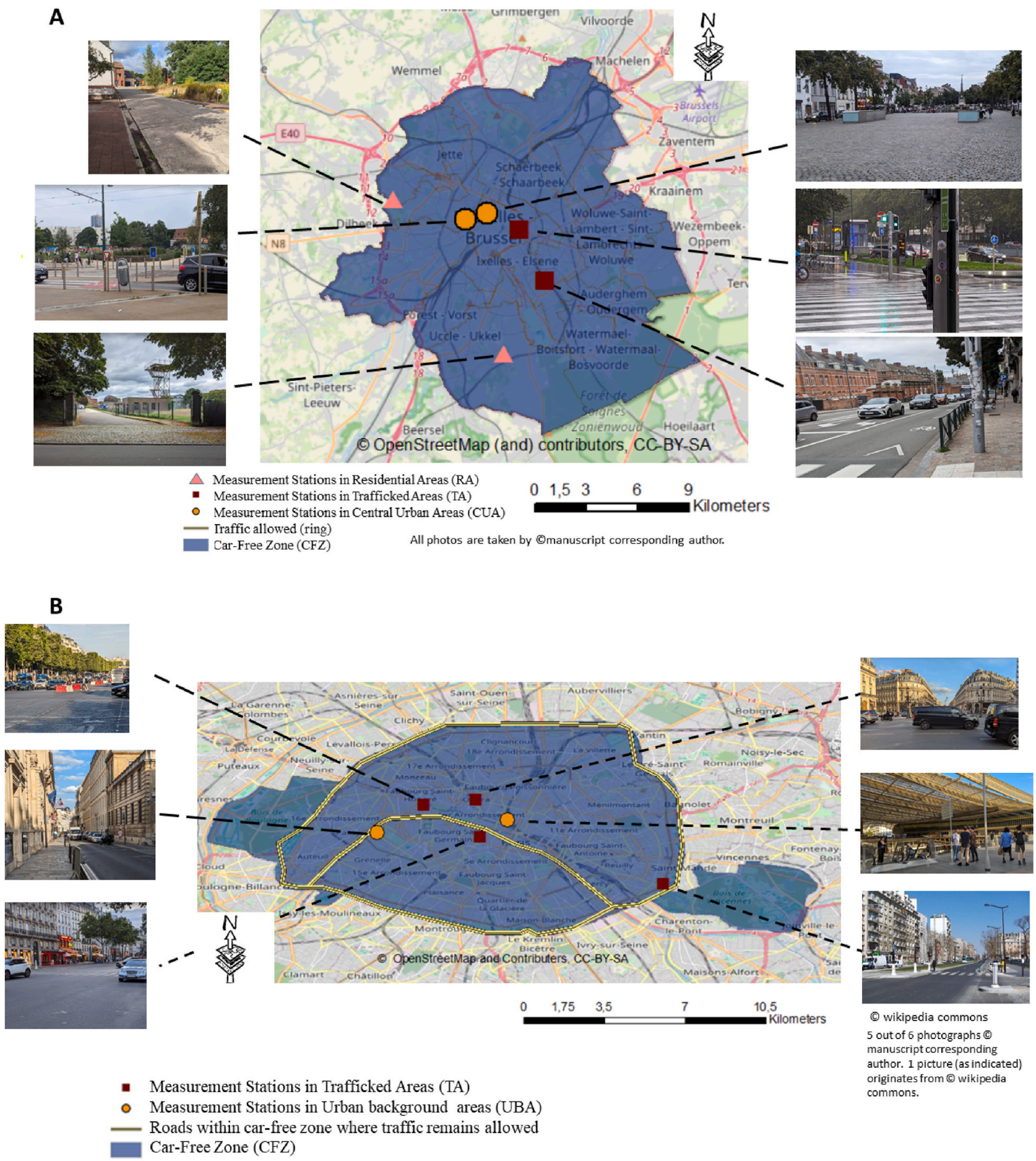


Fig. 1. Extent and characteristics of the car-free areas in Brussels and Paris. Pictures © Manuscript corresponding author (11 pictures) and Wikipedia commons (1 picture). Map constructed in ArcGIS. Background © OpenStreetMaps. Fig. (A) contains Elsene and Arts-Loi measurements as stations in trafficked areas, Sint-Jans-Molenbeek and St-Catherine as central urban stations and Uccle and St-Agatha-Berchem as residential stations in Brussels. Fig. (B) contains Avenue de Champs-Elysée, Rue Bonaparte, Opéra and Soult as stations in trafficked areas and Septième and Les Halles as stations in urban (background) areas in Paris.

Conclusion: Implementing car-free Sundays can strongly reduce NO_2 levels and result in lower paediatric asthma incidence if these local traffic intervention measures were to be expanded and implemented permanently.

1. Introduction

Urban and transport planning, and motorised road transport in particular, does affect human health via numerous mechanisms, including air pollution, lack of green and recreational space, low physical activity levels and exposure to elevated noise levels (Mueller et al., 2017). Policy interventions that aim to achieve cleaner mobility and a shift towards more sustainable forms of mobility, such as active travel and public transport, have the potential to reduce the disease burden associated with motorised road transport (Kelly et al., 2021; Nieuwenhuijsen, 2020; Woodcock et al., 2009). More research focusing on the implementation and evaluation of mitigation measures is necessary to provide better policy support to achieve public health improvements (Nieuwenhuijsen, 2020).

Asthma is a chronic respiratory disease that affects millions of people worldwide, with a significant disease burden in both children and adults. Data from the independent health insurance fund in Belgium demonstrate that 12.9% of children between 2 and 18 years are regular users of asthma medication, which can be considered as a proxy for baseline asthma prevalence in children (Belgian independent health insurance fund, 2019 (Vera, n.d). Children using asthmatic medication have a 2.6-fold increased risk of hospital admission and a 1.6-fold increased risk of visiting an emergency department respectively (Belgian independent health insurance fund, 2019 (Vera, n.d). In addition, children affected by asthma have an increased risk of poor health and lower levels of physical activity (Nyenhuis et al., 2022; Papi et al., 2018). Direct economic costs of asthma include medications and hospital treatments while indirect costs include decreased productivity and increased absenteeism from school and work (Bahadori et al., 2009).

Traffic-related air pollution and NO_2, in particular, contribute to the development and severity of asthma in children (Belanger et al., 2013; Khreis et al., 2017). The plausible biological mechanisms include enhanced pulmonary neutrophilic inflammation, as observed in controlled animal and human experiments (Guarnieri and Balmes, 2014). Studies conclude that an average estimate of 22% and 17% of childhood asthma cases in Belgium and France, respectively, could be attributed to NO_2, of which 46% and 58% of attributable cases occurred in the urban centres of these countries (Achakulwisut et al., 2019). Other risk factors for the development of childhood asthma include exposure to typical allergens, such as grass cover, exposure to second-hand smoke and smoking of the mother during pregnancy (Aerts et al., 2020; He et al., 2020; Miyake et al., 2023)

Earlier research has demonstrated that local traffic interventions, such as car-free Sundays, affect air pollution, considerably decreasing concentrations of traffic related pollutants such as Nitrogen Dioxide (NO_2), Black Carbon (BC) and to a lesser extent fine particulate matter ($PM_{2.5}$). It is noteworthy that car-free days improve public health via pathways other than air pollution as well, including reduced noise, increased physical activity and more social interactions (Glazener et al., 2022).

The aim of this study is to evaluate the impact of the existing real-world intervention of annual car-free days, resulting in strong local traffic reductions on NO_2 concentrations and the associated burden. First, we quantify the size of the NO_2 reductions originating from the natural intervention. Second, we extend these findings to a hypothetical scenario, modelling the expansion of car-free days to daily car-free zones. Using this scenario, we estimate the potential reduction in paediatric asthma disease burden linked to NO_2 exposure.

2. Data and methodology

2.1. Study area

Brussels and Paris experience high levels of traffic-related air pollution that varies notably across different areas within these cities. Maps of mean annual NO_2 values (2019) for both cities are shown in appendix 1 Fig. 1. The cities of Brussels and Paris offer a unique opportunity to conduct health impact modelling based on real-world data from car-free Sundays. This is due to two key requirements: availability of reference measurement stations within the car-free zone and a sufficiently large geographic scope. During the annual car-free Sunday, typically held in September, Brussels (162.4 km^2, 100% of the area of Brussels Capital Region) and Paris (105.2 km^2, close to 100% of the area within the inner ring of Paris) have the largest car-free zones in Europe. The car-free zones in Brussels and Paris encompass 1.2 million and 2.2 million people, respectively (population densities: 7558 inhabitants/km^2 and 20169 inhabitants/km^2). Most other cities in Europe either refrain from participating in car-free Sundays or hold car-free Sundays with a very limited geographical extent, making only a couple of streets car free. The magnitude of car-free Sundays in Brussels and Paris allows for a comprehensive evaluation (Fig. 1). Areas within the zone where traffic remains allowed (e.g., ring roads) are also indicated. In areas where traffic is heavily restricted, there are some exceptions for disabled people, public transport, taxis and emergency services. In Brussels, motorised car traffic is restricted from 09:30 to 19:00 on car-free Sundays, while in Paris, it is restricted from 11:00 to 18:00. Reference measurement stations of air pollution are classified into "traffic", "central urban" and "residential" for Brussels and "traffic" and "urban background" for Paris. In appendix 2, maps are shown where both cities are classified in those categories.

2.2. Data collection, processing and analysis

This study's methodology encompasses a comprehensive collection and analysis of air pollution and meteorological data, alongside the use of exposure-response functions reported in existing meta-analysis, to enable the evaluation of the real-world impacts of car-free days in urban settings.

Hourly air pollution data, measured in micrograms per cubic meter (μg/m^3), were obtained from two primary sources: IRCEL-CELINE (Belgian Interregional Environment Agency) for Brussels, accessible through their website, and Airparif for Paris, available on their open data portal. The data for Brussels span from 2015 to 2022, whereas the Paris data cover the period from 2018 to 2022. The selection of twelve reference measurement stations, six in each city, was guided by specific criteria including their geographical location within the car-free zone, the consistency of data availability with limited gaps (defined as not more than 10% of records missing within a considered calendar year), and their administrative classification (distinguishing between 'traffic' and 'background' stations).

Meteorological data for both cities were sourced from Weatheronline.co.uk. The dataset for Brussels includes daily readings between January 1, 2016, and December 31, 2019, as well as data from car-free days in 2021 and 2022. For Paris, the dataset encompasses daily data from September 1, 2018, to September 30, 2019, and from September 1, 2021, to March 31, 2023. A deliberate decision was made to exclude the year 2020 from the analysis due to the atypical air pollution levels resulting from lockdown restrictions. Additionally, for Paris, data from Sundays with smaller-scale monthly car-free areas introduced from October 1, 2022, were removed from the analysis. This approach allowed for a balance between minimizing financial costs and maximizing the quantity of data retrieved, noting that the models used do not require meteorological data for all years for training purposes.

Exposure-response functions (ERFs) were derived from the relative risks (RRs) associated with ambient NO_2 pollution and paediatric asthma incidence, as reported in meta-analyses by Achakulwisut et al. (2019) and Khreis et al. (2017). These studies were selected based on their inclusion of corrections for confounding factors, such as socio-economic variables, which were part of the quality assessment criteria (Khreis et al., 2017). The age group of interest is children between 1 and 18 years old.

2.3. Derive changes in concentrations

From the six reference measurement stations located in the annual Brussels car-free zone, two stations are located in a "trafficked area", two in a "central urban area" and two in a "residential area". For the Paris region, from the six stations, four are located in "trafficked areas" and two stations in "urban background areas".

The dilution of air pollution can be influenced by a variety of factors, including meteorological conditions such as wind speed and direction. Four different methodologies are used in this study to assess the impact of car-free periods on air quality while attenuating the effect of meteorological parameters. To ensure robust impact estimations, we focused on afternoon NO_2 concentrations, as morning concentrations during car-free Sundays may still be influenced by traffic preceding the event.

2.3.1. Method 1

The first method, 'direct calculations without correction', involved comparing air quality measurements taken on car-free Sundays with regular Sundays. We averaged data over a period of several years to minimize the influence of meteorological variations on the analysis. For Brussels, we considered seven years (2015–2019 and 2021–2022). The average hourly concentrations (13–18 h) on car-free Sundays calculated for the selected "traffic", "central urban" and "residential" measurement stations (point measures) are compared with concentrations on regular Sundays (formula 1).

$$\mathrm{Ratio}_{\mathrm{Raw(Time)}} = \frac{\text{average Concentration CarFreeSunday}(\text{Time})}{\text{average Concentration regularSunday}(\text{Time})} \tag{1}$$

2.3.2. Method 2

The second method uses direct calculations corrected for meteorological conditions, in order to convert to average methodological conditions. We normalised the difference between regular Sundays and car-free Sundays based on the 08:00 a.m. concentrations (before the onset of the car-free day) (formula 2).

$$\mathrm{Ratio}_{\mathrm{Corrected(Time)}} = \frac{\frac{\text{average Concentration CarFreeSunday}(\text{Time})}{\text{average Concentration regularSunday}(\text{Time})}}{\textit{ratio 8 AM concentration}} \tag{2}$$

Where ratio 8 a.m. concentration = 8AM concentration car-free Sunday/average 8AM concentration regular Sunday.

2.3.3. Method 3

The third method uses Random Forest (RF) machine learning models to establish the relationship between historical air quality measurements and other meteorological parameters. During the car-free period, the model predicts the air quality (for Sundays 13–18 h) based on the daily meteorological conditions such as wind speed, minimum temperature, maximum temperature, air pressure and relative humidity and temporal variables (day of the week, month of the year). Details on model parameters and model composition are provided in appendix 3. The difference amongst the predicted concentrations and actual measurements is used as a measure of the impact of the car-free period. Earlier studies such as Grange and Carslaw (2019) applied the random forest machine learning technique successfully to analyse air pollution interventions while removing the impact of meteorological factors.

2.3.4. Method 4

The fourth method is the Boosted Regression Trees (BRF), which is similarly used as RF to measure the impact of the car-free period. RFs and BRTs are both ensemble methods for predicting the target variable, in our case a NO_2 concentration between 13 h and 18 h on Sunday, using multiple decision trees. Details on model parameters and model composition are provided in appendix 3.

In method (3) and (4), the following daily meteorological input data were used: Minimum Temperature (°C), Maximum Temperature (°C), Humidity (%RH), Pressure (hPa) and Wind Speed (m/s, 10 m). For Paris, we also used sunshine hours (Hr/day), but this parameter was not available for Brussels. In addition, the day of the week and month of the year were used as an input variable, considering lower emissions in the weekend and seasonal air pollution variations. In both the RF and the BRT model, 70% of the dataset (regular Sundays) was used to train the data, the other 30% was used for validation purposes. In appendix 3 – technical appendix – more information about the RF and BRT models is available. Appendix 4 includes additional figures and information to understand the relationship between meteorological parameters and air pollution concentrations.

Statistical analyses were carried out using R versions 4.2.3 and 4.3.2 (R Core Team, 2023). The R packages used during the analysis include dplyr (Wickham et al., 2023), ggplot2 (Wickham, 2016), gbm (Ridgeway and Developers, 2024), readxl (Wickham and Bryan, 2023), randomForest (Liaw and Wiener, 2002), lubridate (Grolemund and Wickham, 2011), and tidyverse (Wickham et al., 2019). The full reproducible code is available in the Supplementary Materials (Appendix 6). Some data manipulations and data-analysis were carried out using Microsoft Excel [version 2016] (Microsoft Excel)'.

2.4. Health impact modelling: paediatric asthma in the European cities Brussels and Paris

For all twelve measurement stations, six in Brussels and six in Paris, we determined the percentage of paediatric asthma attributable to NO_2 exposure based on the annual averaged NO_2 concentrations for the year 2019.

The meta-analyses of Khreis et al. (2017) synthesised 41 studies qualitatively and pooled 21 studies quantitatively together and obtained a RR of 1.05 per 4 μg/m³ increase in NO_2 (95% CI: [1.04–1.07]). Calculating the Population Attributable Fraction (PAF) corresponds to step four in the health impact evaluation procedure (Fig. 2). To calculate the PAF, the fraction of paediatric asthma incidence attributable to the NO_2, the following formula is used:

$$\mathrm{PAF} = \frac{(\mathrm{RR} - 1)}{\mathrm{RR}} \tag{3}$$

in which RR is the relative risk of the exposure versus non-exposure.

The RR is recalled from the default unit per 4 μg/m³ increase to the relevant exposure unit, using

$$\mathrm{RRexposure} = \exp((\ln(\mathrm{RR4}) / 4)^*(\mathrm{CON})) \tag{4}$$

In which RR4 is the RR for an increase in 4 μg/m³ and CON is the NO_2 concentration from the measurement station. To obtain confidence intervals for the PAF estimates, we applied statistical techniques to the original reported 95% confidence intervals, applying a Monte Carlo Simulation (MCS) with 10 000 simulations. We assume a lognormal distribution of our ERF input data to

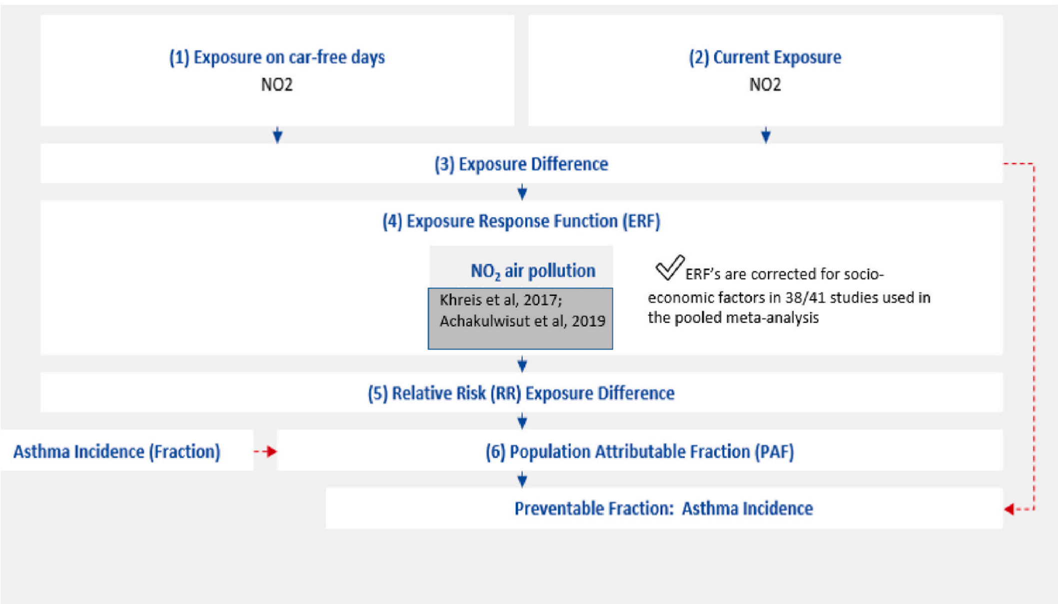


Fig. 2. Procedural steps to conduct a Health impact evaluation, adapted from Mueller et al. (2017).

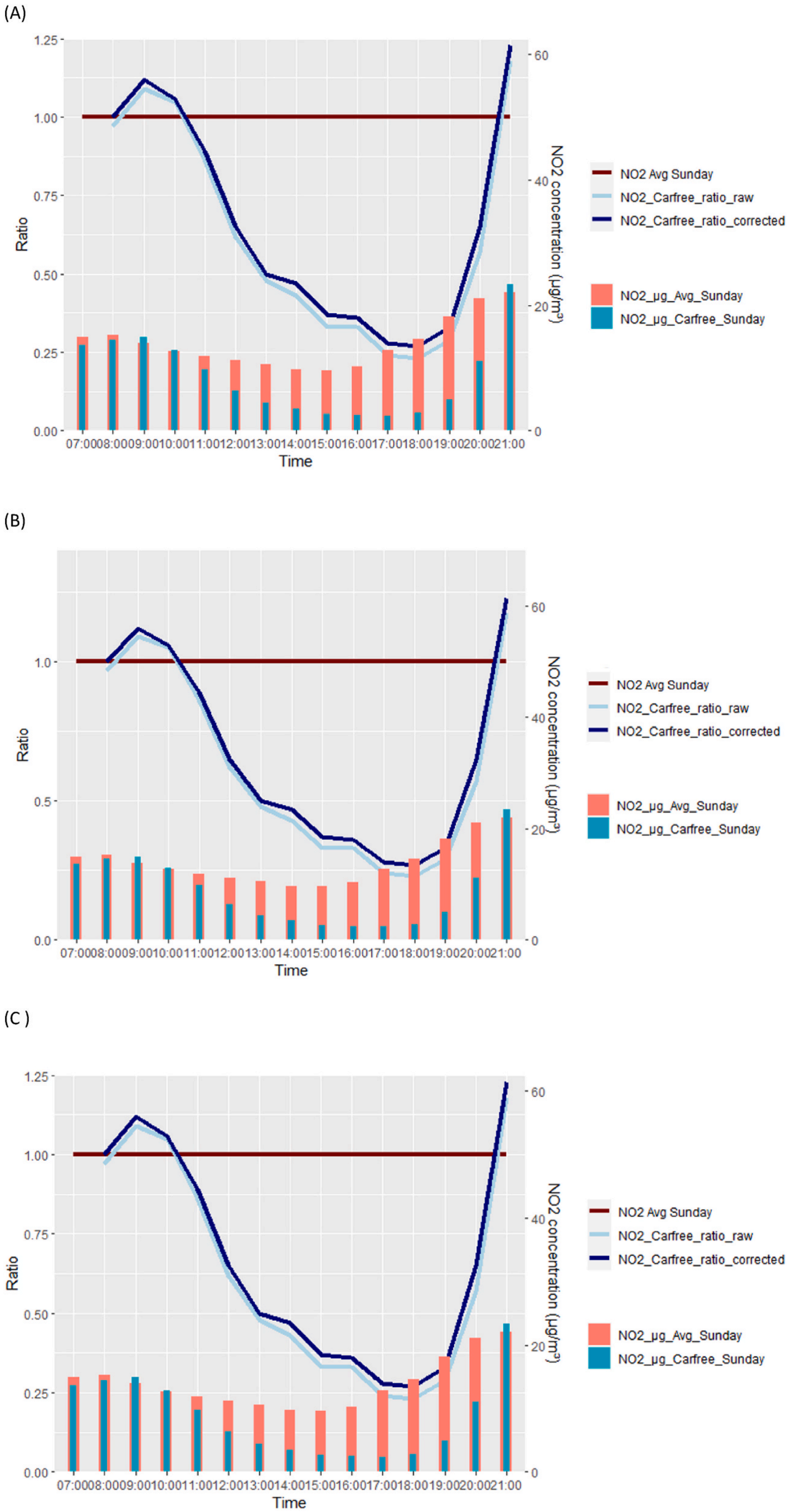


Fig. 3. Direct calculations for the ratio of NO_2 concentrations between regular Sundays and car-free Sunday's hour-by-hour (2015–2022) using method (1) and method (2). (A) = Residential Areas in Brussels (B) Trafficked Areas in Brussels and (C) Central Urban areas in Brussels.

conduct the MCS.

Confounding factors such as socio-economic factors are considered in the establishment of the ERF based on the pooled studies, as this was a criterium for inclusion (Khreis et al., 2017)

The PAF calculation can also be utilised as a starting point to calculate the mitigation potential of traffic measures on health outcomes: the difference between the PAF in baseline scenario (regular days) and counterfactual scenario (car-free days) corresponds to the Preventable Fraction (PF), the percentage of paediatric asthma cases that can be prevented by implying the local traffic mitigation measures every day of the year. Rather than examining the health impact of a single car-free Sunday per year, our analysis considers the counterfactual hypothetical scenario in which traffic in Brussels and Paris is permanently reduced to the levels of car-free Sundays. From the percentage reduction in NO_2 on car-free days, taken from reduction calculation method 3 'random forests', the average exposure on car-free days can be calculated and used as an input for (1) in Fig. 2. The current exposure (2) corresponds to the mean annual NO_2 exposure recorded in the selected measurement stations during the years 2015–2022 for Brussels and 2018–2022 for Paris. The exposure difference (3) between (1) 'exposure on car-free days' and (2) 'current exposure (regular Sundays)' is used to calculate the RR of the Exposure Difference (5) based on the ERF and RRs reported in (4), and invoking again formula 3 and formula 4. The derivation of the counterfactual scenario diverges by assessing the difference between observed (car-free days) and model-simulated NO_2 concentrations (regular days) under hypothetical daily car-free scenarios, termed Exposure Difference (3). This approach yields a PF (Preventable Fraction) Estimate via Step 4, contrasting with the PAF calculation. The methodology incorporates a Monte Carlo analysis with 10 000 simulations to mitigate uncertainty in these estimations.

Statistical analyses were carried out using R versions 4.2.3 and 4.3.2 (R Core Team, 2023). The R packages used during the analysis include dplyr (Wickham et al., 2023), ggplot2 (Wickham, 2016) and readxl (Wickham and Bryan, 2023). The full reproducible code is available in the Supplementary Materials (appendix 7). More details on the data collection, processing and analysis are available in appendix 8. A full list of abbreviations is available in appendix 9.

3. Results

3.1. *Derive changes in concentrations: reductions in NO_2 concentrations on car-free days*

3.1.1. *Case-studies for Brussels and Paris*

Fig. 3 illustrates that using methods 1 and 2, the NO_2 concentrations at measurement stations within the car-free area on car-free Sundays in Brussels deviate substantially from the concentrations on regular Sundays. Concentrations between 13:00 and 18:00, when the car-free Sunday reaches its maximal effect, reached average reductions of 69%, 72% and 66% (13–18 h) in trafficked, central urban, and residential areas, respectively. These reductions range between 50% and 80% in individual hours (Fig. 3 and Table 2)

The three classifications of regions demonstrate a consistent and similar pattern. The disparity between the direct calculations without correction and the corrected approach is limited. Car count data for different locations with similar characteristics show similar reductions of 60–80% in residential, trafficked and central urban areas in the number of cars (Appendix 5, appendix Fig. 9). At the same time, the number of active road users (cyclists and pedestrians) are increased in central urban and trafficked areas on car-free Sundays compared to regular Sundays (appendix 5, appendix Fig. 9).

Using the direct calculation method (method 1 and method 2) for the Paris region, strong NO_2 concentration reductions of 30–60% are observed (Fig. 5). Table 1 summarizes the results of the RF and BRT methods (method 3 and method 4). These machine learning approaches show substantial deviations between the expected or predicted NO_2 concentrations on car-free Sundays, including after accounting for meteorological parameters. While the actual observed NO_2 values in Brussels central urban stations are on average around 6 μg/m³ on regular Sundays between 13 and 18 h, the expected value is estimated as 26 μg/m³ (95% 22–29, RF) and 31 μg/m³ (95% CI 25–33, BRT), which corresponds to a 73–82% lower actual value. For residential and trafficked areas, the RF-BRT models find reductions of respectively 73–83% and 79–83% in the actual values. For Paris, we find 25–49% reductions in trafficked areas and

Table 1

Observed actual NO_2 values on car-free Sundays (μg/m³) versus the values that would have been expected based on meteorological conditions on those days (2015–2022). The last column, % reduction, shows the range of %reduction for both machine learning methods, including the 95% confidence intervals.

	Actual observed values (NO_2) on the car-free Sundays	Random Forest (RF) prediction using meteorological conditions, NO_2 [95% CI]	Boosted Regression Tree (BRT) predictions using meteorological conditions, NO_2 [95% CI]	% Reduction in NO_2 car-free Sunday compared to regular Sunday (13–18 h)
Brussels Traffic Stations	11 μg/m³	59 [55–64] μg/m³	56 [51–60] μg/m³	79–83%
Brussels central urban stations	6 μg/m³	26 [22–29] μg/m³	31 [25–33] μg/m³	73–82%
Brussels residential stations	3 μg/m³	15 [12–18] μg/m³	14 [11–17] μg/m³	73–83%
Paris Traffic Stations	24 μg/m³	38 [32–44] μg/m³	43 [37–49] μg/m³	25–49%
Paris Urban Stations	11 μg/m³	20 [16–25] μg/m³	24 [19–28] μg/m³	31–61%

Table 2
Comparison of reduction in NO_2 concentrations in the European cities Brussels and Paris on car-free Sundays (13–18 h) versus regular Sundays (13–18 h), for different types of locations, using four different methods to calculate the reduction percentages.

	% Reduction, method 1: direct calculation without correction	% Reduction, method 2: direct calculation, corrected	% Reduction, method 3: Random Forest (RF)	% Reduction; method 4: Boosted Regression Trees (BRT)
Brussels Traffic Stations	69% [64–74%]	71% [66–77%]	81% [80–83%]	80% [78–82%]
Brussels central urban stations	72% [67–77%]	77% [72–82%]	77% [73–79%]	81% [76–82%]
Brussels residential stations	66% [61–71%]	63% [58–68%]	80% [75–83%]	79% [73–82%]
Paris Traffic Stations	27% [25–29%]	37% [34–40%]	41% [38–45%]	40% [36–44%]
Paris Urban Stations	51% [47–55%]	48% [44–52%]	48% [42–54%]	51% [48–56%]

31–61% reductions in urban (background) areas. Those observations are consistent with the direct calculation methods in Figs. 3 and 4.

The results delivered by the four different calculation methods delivered very consistent results (Table 2). The maximum difference in % 'reduction' of NO_2 concentrations on car-free Sundays and regular Sundays between the calculation methods does not exceed 20 percentage points in any case, including when the uncertainty related to the RF and BRT model predictions is considered.

3.2. *Health impact modelling: case-study on paediatric asthma in two European cities*

3.2.1. *Quantification of the fraction of asthma incidence associated with current NO2 concentrations*

40% [95% CI: 31–49%] and 39% [95% CI: 30–48%] of paediatric asthma incidence can be explained by exposure to traffic-related NO_2 air pollution in busy trafficked areas in Brussels and Paris, respectively. In urban areas in those cities, 30% [95% CI: 23–37%] and 29% [95% CI: 21–35%] of paediatric asthma incidence can be explained by exposure to traffic-related NO_2, while this is 18% [95% CI: 13–23%] in more remote residential areas in Brussels (Table 3).

3.2.2. *Reduction in paediatric asthma incidence*

The mitigation potential of local traffic interventions on paediatric asthma incidence in the European cities of Brussels and Paris are calculated. Given the consistency between the four different calculation methods, regardless the method deployed in this section the result would be very similar. We used the outputs from the RF model as this was deployed for both Brussels and Paris, as this method is reported and validated in other scientific studies before (Grange and Carslaw, 2019).

A mean minimum estimate of 15% [95% CI: 11–19%] of paediatric asthma cases could be avoided across all regions in Brussels and Paris by local traffic interventions, such as the hypothesized scenario with expansion of annual car-free Sundays to car-free daily zones. This even increases to 34% [95% CI: 25–41%] for busy trafficked areas in Brussels (Fig. 5).

4. Discussion

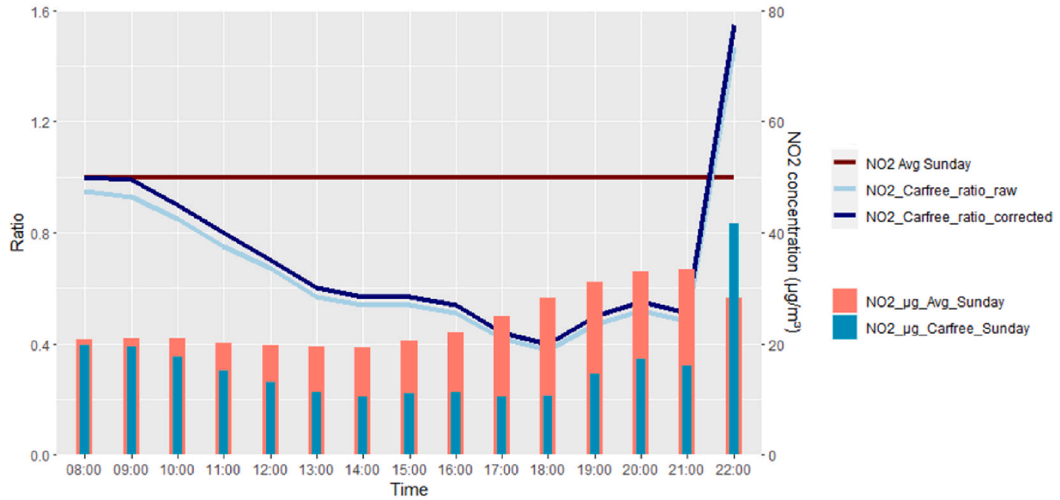
Brussels and Paris are known to have the largest car-free zone in Europe during the annual car-free Sunday. This natural intervention provided an opportunity to understand what reductions in NO_2 concentrations could be achieved and then to conduct a hypothetical scenario where the observed intervention was expanded to daily. Regardless of the feasibility of this scenario, the calculation demonstrates the potential effect that can be achieved by local traffic interventions.

Our findings demonstrate that local traffic interventions, exemplified by car-free Sundays, effectively reduce NO_2 concentrations. In fact, the reductions achieved during these events could bring NO_2 levels below the WHO recommended threshold of 10 $\mu g/m^3$, including in currently heavily polluted urban areas with high traffic volume. This information is important for policymakers. It indicates the potential for significant improvements in air quality and subsequent health outcomes. These interventions generate health and wellbeing improvements and as well economic benefits by reducing medication sales, hospital treatments, school absenteeism, and doctor visits, which are covered by social security and therefore taxpayers.

Our analysis demonstrates that permanently reducing NO_2 concentrations at levels similar to those observed on car-free Sundays could prevent more than 1 in 10 asthma cases in all urban areas, up to 3 in 10 cases in the most trafficked areas. The mitigation potential for Brussels was found to exceed that of Paris. This could be due to the presence of a few very busy ring-roads around Paris and one highway through Paris, which are not closed for traffic on car-free days. In addition, a few more exceptions are allowed in the Paris region to drive your car on a car-free Sunday, potentially reducing the amount of traffic to a lesser extent. In addition, the Paris car-free area has a smaller geographical extent (105 vs 162 km^2).

While transitioning to electric cars could also reduce the burden of NO_2-related asthma, adopting a multidisciplinary approach and considering "One Health" perspective, reducing overall traffic volume proves to be the more favourable intervention. This approach generates greater public health benefits not only for asthma but also for other diseases such as cardiovascular diseases and diabetes, which are linked to various factors including NO_2, particulate matter, green space availability, noise, and levels of physical activity influenced by urban mobility policies (Mueller et al., 2017; Woodcock et al., 2011). It has also been demonstrated that while car-use is

(A)



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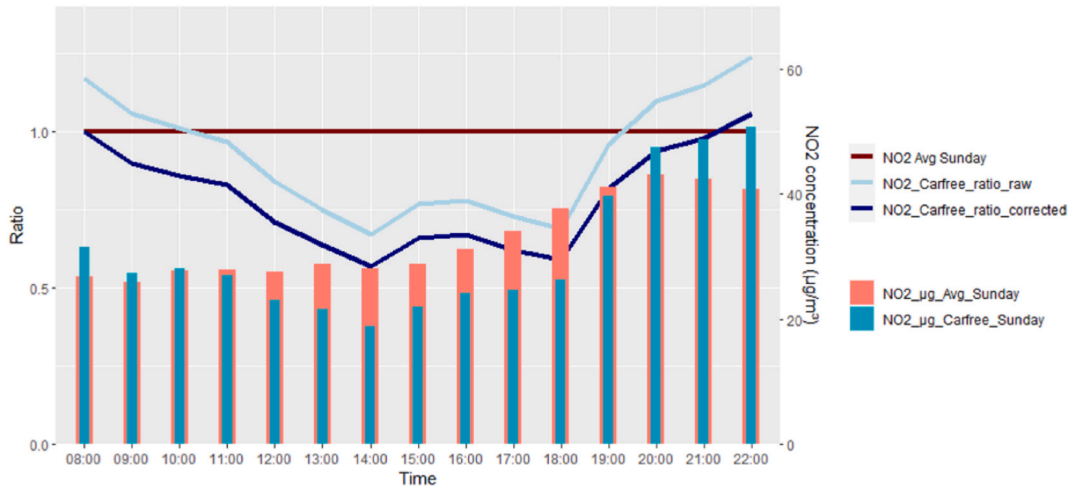

Fig. 4. Direct calculations for the ratio of NO_2 concentrations between regular Sundays and car-free Sundays. (A) = Urban (background) areas in Paris and (B) Trafficked Areas in Paris (2018–2022).

strongly decreased on car-free Sundays, physical activity in the form of cycling and walking is substantially increased in central urban areas and usually car-trafficked areas in Brussels (Telraam, 2024), also benefiting human health.

Comparing our findings with existing literature (Glazener et al., 2022), we find that most studies included in the review report a reduction in NOx and NO_2 concentrations when car use is decreased, although the results for $PM_{2.5}$ are more varied. Several important factors should be considered in this regard. First, our study focuses specifically on Brussels and Paris, which have the largest car-free zones in Europe during annual car-free days. Cities where car-free events only involve the closure of a few streets while traffic remains allowed elsewhere will experience smaller reductions in pollution compared with cities that have events with a larger geographical extent, as noted in Glazener et al.'s review (Glazener et al., 2022). Second, the sources of air pollutants can vary geographically. While traffic is a major contributor to NO_2 concentrations in Europe, other regions may have smaller fractions of NO_2 originating from vehicles. For example, our study has observed reductions of over 70% in NO_2 concentrations through local traffic interventions, while a study in areas around Lima, Peru, suggests that less than one-third of NOx is attributed to vehicle traffic (Michalski et al., 2022). Third, not all previous studies did correct for meteorological conditions when evaluating concentration differences between regular days and car-free days, while this is an important aspect as meteorological parameters influence the dilution of pollution.

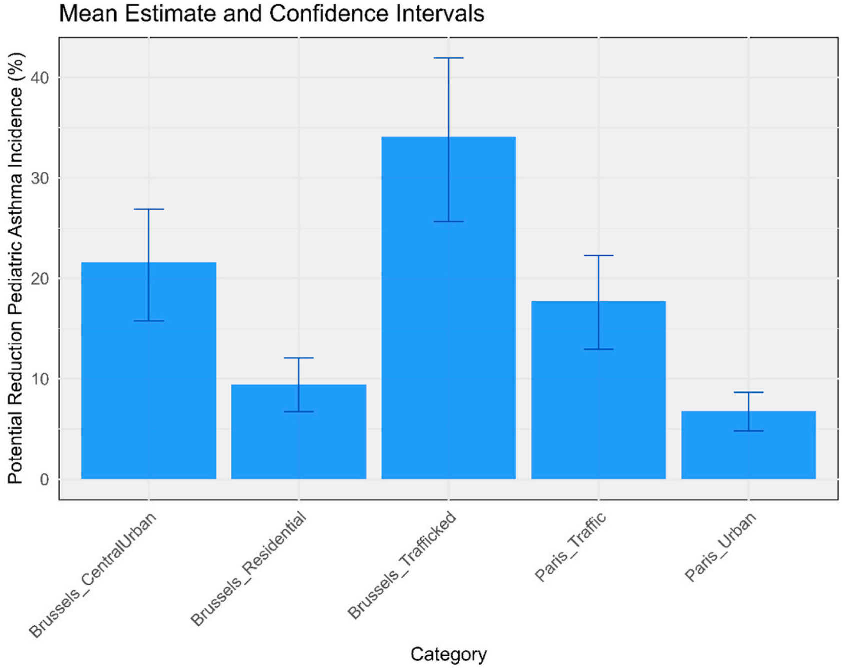

Fig. 5. Percentage of paediatric asthma incidence that could be avoided by local interventions in traffic volume in different areas of Brussels and Paris.

Table 3
Annual mean concentrations (2019) averaged over the different categories of reference measurement stations in Brussels and Paris + Population Attributable Fraction (PAF) location for paediatric asthma for these locations.

	Annual Mean Concentration (μg/m³) (Year: 2019)	Population Attributable Fraction (PAF) of Paediatric Asthma to NO_2
Trafficked Areas Brussels	42.4	40.3% [30.6%–48.8%]
Central Urban Areas Brussels	29.7	30.4% [22.7%–37.2%]
Residential Areas Brussels	16.6	18.3% [13.3%–23.0%]
Trafficked Areas Paris	41.0	39.4% [29.9%–47.7%]
Urban Background Areas Paris	27.8	28.7% [21.4%–35.5%]

The review of Glazener et al. (2022) also contained the notion that car-free days require intensive planning and that smartly designed car-free days can be used as a tool for health impact evaluation. For this to happen, there is need to increase the number of car-free days in sufficiently large geographical regions. In addition, the presence of a measurement network of air pollution monitors is required, as modelled air pollution concentrations mostly contain static emission data and will therefore only very partially capture the effects of car-free days, making them an unreliable tool for such analysis. Large-scale areas, with the presence of sufficient air pollution measurement stations, and ideally traffic measurement counts, are the best combination to conduct large-scale intervention studies investigating the potential health benefits of local traffic interventions.

Our study has some limitations. First, few cities in the world have car-free Sundays of a sufficient geographical extent to have measurable effects on regional air pollution. The second limitation is that car-free days are always organised on Sundays, when there is less traffic and as a consequence air pollutant concentrations are lower. Potentially, if car-free days were organised on weekdays, the reduction percentage could be more pronounced because of the higher weekday traffic. Furthermore, NO_2 air pollution from neighbouring areas outside car-free zones, such as the city rings of Brussels and Paris, and more remote busy trafficked roads also contribute to NO_2 concentrations. Since traffic is not restricted in these surrounding areas, our study captures only the mitigation potential of local traffic interventions on paediatric asthma incidence. The total potential of mobility interventions is more substantial.

It is a considerable benefit of our study emphasizing the merit of analysing real-world interventions over hypothetical scenarios, providing concrete evidence of how these interventions improve urban air quality and public health. By analysing the concrete effects of these local traffic interventions, our research not only provides solid evidence of the potential health benefits from reduced vehicle emissions, but also bridges the gap between theoretical models and actionable outcomes. This methodological choice enhances the validity of our findings and offers urban planners and policy-makers valuable insights into the effectiveness of such measures. The inclusion of an actual intervention underlines the feasibility and advantages of implementing traffic reduction strategies, making a persuasive argument for the broader adoption of similar initiatives in urban settings worldwide.

5. Conclusion

Local traffic interventions in European cities effectively reduce nitrogen dioxide (NO_2) concentrations. This conclusion is strongly supported by multiple independent methods that consistently yield similar results. Quantitatively, cities like Brussels demonstrate a substantial reduction of 63–83% in pollution levels solely through local traffic interventions, with further potential gains from regional and long-range traffic management. Our case study on paediatric asthma shows that local traffic interventions in cities such as Brussels and Paris could prevent at least 1 in 10 asthma cases citywide, with prevention rates reaching approximately 30% in heavily trafficked areas. Our health impact modelling in this study was based on expanding the natural intervention of annual car-free Sundays to a hypothetical scenario where the observed intervention was expanded to daily. This approach can be replicated to assess the impact of traffic interventions on other pollutants, including $PM_{2.5}$, as well as on other diseases such as diabetes and cardiovascular conditions. Going forward, we recommend additional interventional studies to further assess the health impact of local and regional traffic interventions. This can be achieved through initiatives such as carefully planned large-scale car-free days, while ensuring the presence of a monitoring network to measure air pollution levels accurately.

CRediT authorship contribution statement

Bram Vandeninden: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Eva M. De Clercq:** Writing – review & editing, Visualization, Supervision, Data curation. **Brecht Devleesschauwer:** Writing – review & editing, Validation, Project administration, Funding acquisition. **Martina Otavova:** Writing – review & editing. **Bruno Masquelier:** Writing – review & editing. **Frans Fierens:** Writing – review & editing, Validation, Conceptualization. **Christel Faes:** Writing – review & editing, Supervision, Methodology. **Catherine Bouland:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jth.2024.101953.

Data availability

Air Pollution Measurement Data: Publicly Available (open data); Meteo Data: Purchased, no license to distribute, anyone can purchase (weatheronline.co.uk); Code available in supplementary materials.

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