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Supplementary Materials

Vehicular Traffic in Urban Areas: Health Burden and Influence of Sustainable Urban Planning and Mobility

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Supporting Information

SI 1. Review of traffic emissions abatement measures

An extensive review of studies assessing decreases in traffic emissions linked to a specific abatement measure was carried out. This review was conducted in order to select intervention scenarios to be tested by means of a health impact assessments (HIA) model. Thus, the avoided premature mortality resulting from the effect on air quality of the selected traffic emissions abatement measures was modeled. This was based on the known evidence provided by epidemiological studies for the implementation of HIA of air pollution [1–4].

In total, 40 studies were finally selected, which included results based on air quality measurements and modeled scenarios. Studies based on real measurements with ambiguities when associating improvements in air quality with specific measures (due to, e.g., meteorological interferences, no control measurements, etc.) were discarded. A large amount of the studies focus on the following interventions:

a) The creation of low-emissions zones (LEZ): Evidence of the efficiency of LEZs improving air quality is difficult to prove due to the confounding effects of meteorology, natural changes in the vehicle fleet and policy changes at the national, regional and EU levels (e.g., the introduction of zero sulfur automotive fuels). The clearest evidence is from German LEZs which can be applied to both light and heavy-duty vehicles. There is a wide range of reported reductions, between no effect up to 60% [5–12], with values usually in the range 5–15% for PM_x and 5–22% for NO_2.
b) Long-term strategies to foster active transport modes: Increasing cycling effectively requires a network of dedicated cycle lanes with full coverage of a town or city, along with outreach campaigns to address issues related to safety perception. It is worth noting that the decision to cycle is influenced by many factors, including convenience, distance, safety perception, and weather conditions, amongst others. In a study performed in the US, the authors reported a decrease in $PM_{2.5}$ concentrations of 1–2% when replacing short car trips with bicycling [13], while a reduction of 7% in NO_x was reported in Stockholm [14].
c) Spatial planning—redistribution of public space: Understanding how local land use and land cover shapes the intra-urban concentrations of atmospheric pollutants—and thus human health—is a key component in designing healthier cities. Mueller et al. [15] conducted a health impact assessment (HIA) of cycling network expansions in seven European cities and concluded that if European cities achieved a cycling mode share of 24.7%, over 10,000 premature deaths could be avoided annually, associated with changes in air pollution, physical activity, and traffic incidents. Encouraging walking and bicycling requires the actual urban planning to be rethought, decreasing the density of the road network within urban cores. On the other hand, urban vegetation affects air quality through influencing pollutant deposition and dispersion [16,17]. The reduction in vehicle tracers as a result of roadside vegetation has been

shown to reach percentages higher than 20% [18]. It should be mentioned that the amount of green space per person varies significantly within Europe, the lowest provisions being in southern and eastern areas, where an improvement is urgently required. For example, some towns in Spain and Italy have 3 to 4 square meters of green space per person, compared with more than 300 square meters per person in towns in Belgium, Finland, and France (https://data.humdata.org/dataset/green-area-per-capita-square meters-per-capita, accessed on 15 September 2015).

d) The promotion of public transport: Titos et al. [19] found a reduction of 37% in Black Carbon (BC) concentrations which was associated with a reduction in the overlap between bus lines in the downtown area, together with the introduction of brand-new buses with a higher passenger capacity and EURO V motors. Basagaña et al. [20] discovered that air pollution levels increased between 4% and 7% during public transport strikes in Barcelona (Spain), and that this increase reached up to 48% for BC during all-day strikes of the metro system. On the other hand, Bel et al. [21] assessed the effects of the introduction of the Bus Rapid Transit in Mexico City, reporting a reduction in CO concentrations of between 5.5 and 7.2%, NO_x between 4.7 and 6.5%, and PM_{10} between 7.3 and 9.2%. Di et al. [22] concluded that accessibility is an important factor influencing a commuter's decision to take public transport, reducing the use of private cars. The increase in the public transport share mode has been concluded to be directly related to a significant decrease in morbidity [23], partly linked to a decrease in air pollution. Poelman and Dijkstra [24] reported the indicators of access to public transport in European cities, making this information freely available (http://ec.europa.eu/regional_policy/es/information/publications/working-papers/2015/measuring-access-to-public-transport-in-european-cities, accessed on 10 September 2021). They developed a new method of analyzing access to public transport, taking into account the extent of the urban center, the distribution of the population and the exact location of public transport stops and the frequent of departures.

e) Traffic policies: Johansson et al. [25] found that tax reduced total road use by 15% within a charge area in Stockholm, reducing the annual average NO_x concentrations for the streets with the densest traffic by up to 12%, and average PM_{10} concentrations by 7%. Adapt the vehicle velocity to the traffic density have been proved to be an effective environmental policy, reducing NO_x and PM_{10} pollution by 7.7–17.1% and 14.5–17.3%. Conversely, although lower speed limits are associated with lower vehicle emissions, with a well-documented U-shaped relationship being found between traffic emissions and average speed, especially at constant speeds, when vehicle accelerations and decelerations are introduced into the model, the gains from lower emissions due to the reduction in speed are not as great [26].

f) Technological improvements/road management: Currently, there are few electric vehicles, hybrids or gas vehicles in use in the EU. Experience suggests that this is unlikely to change until the cost of these vehicles is at least equivalent to conventionally fueled vehicles, and even then, it will take some time for consumers' acceptance of these technologies to grow. It is only in these countries with a long and consistent incentive program (i.e., Italy: gas; Norway: EVs and HEVs) that have achieved a significant (i.e., greater than around 5%) market share. For example, Soret et al. [27] modeled the effect of changing to a vehicle fleet with 40% of electric vehicles, which would reduce NO_X concentrations by 11–17%.

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Table S1. Review of selected studies analyzing the effectiveness of different abatement measures, aiming to reduce the exposure to traffic emissions.

Measure	Study	City	Parameter	Result (mean reduction)	Real measurement/model	Notes
Low-emission zones, i.e., zones within a city or region where vehicles have to comply with certain emission standards or are obliged to pay a fee	Lutz [9]	Berlin, Germany	EC, PM_{10}, NO_2	14–16%, 3%, 8%	Real measurement	Comparison of concentrations within and outside LEZ. Adjusted for changes in traffic intensity
	Bruckmann et al. [28]	Berlin, Germany	PM_{10}	5–7%	Real measurement	Comparison of annual concentrations from traffic sites before and after LEZ
	Invernizzi et al. [7]	Milan, Italy	PM_{10}, $PM_{2.5}$, PM_1	Not significant, not significant not significant, not significant	Real measurement	Short-term data
	Jensen et al. [8]	Copenhagen, Denmark	Traffic contribution to $PM_{2.5}$, $PM_{2.5}$	12%, 5%	Real measurement	Comparison of data from traffic site before and after LEZ
	Qadir et al. [12]	Munich, Germany	Traffic contribution to $PM_{2.5}$ (organics, EC, OC)	55%	Real measurement	Positive Matrix Factorization of PM2.5, before and after LEZ
	Lutz [29]	Berlin, Germany	Traffic contribution to EC, NO_2	42%, 7–10%	Real measurement	Comparison of data from traffic site before and after LEZ
	Panteliadis et al. [11]	Amsterdam, Netherlands	EC, PM_{10}, NO_2, NO_x	12.9%, not significant, not significant, not significant	Real measurement	Traffic contribution obtained was estimated by subtracting data from urban background site in LEZ
	Morfeld et al. [10]	17 German cities	NO_x, NO_2	Not significant, not significant	Real measurement	Comparison of concentrations within and outside LEZ
	Wolff [30]	German cities with LEZ in 2008	PM_{10}	9%	Real measurement	Comparison of concentration trends in cities with and without LEZ
	Fensterer et al. [31]	Milan, Italy	PM_{10}	13%	Real measurement	Semi-parametric regression model, data for traffic site before and after LEZ

	Holman et al. [6]	London (UK), Berlin (Germany), Munich (Germany), Amsterdam (Netherlands), Copenhagen (Denmark)	PM_{10}, EC, NO_x	5–15%, 16%, 4%	Model and real measurement	Review
	Gehrsitz [32]	44 German cities	PM_{10}	1.5–4%	Real measurement	Urban Traffic/Background measurements for 2005-2015, accounting for different LEZ policy phases
	Bruxelles Environment [33]	Brussels, Belgium	NO_2, $PM_{2.5}$	4.7%, 6.4%	Model	Estimation based on vehicles counts and emission factors
	Mudway et al. [34]	London, UK	NO_2, PM_{10}, $PM_{2.5}$	9–15%, not significant, not significant	Real measurement	Linear trends of pollutants for inner and outer London roadside and background sites
	Santos et al. [35]	Lisbon, Portugal	NO_2, PM_{10}, $PM_{2.5}$	13–22%, 22–25%, not significant	Real measurement	Linear trends of pollutants for inner and outer LEZ roadside and background sites
Long-term strategies to foster active transport modes	Grabow et al. [13]	Midwestern US	$PM_{2.5}$	1–2%	Model	Replace short car trips with bicycling (50%)
	Johansson et al. [14]	Stockholm, Sweden	NO_x, BC	7%, 7%	Model	Changing commuting from car to bicycle (209% increase)
Spatial planning—redistribution of public space	Nowak et al. [16]	Ten US cities	$PM_{2.5}$	0.05–0.24%	Model	Removal by trees
	Brantley et al. [18]	Detroit, Michigan, US	BC	7.8–22% (depending on the wind direction)	Real measurement	Roadside vegetation
	Jeanjean et al. [36]	Leicester City, UK	$PM_{2.5}$	9%	Model	Green infrastructure—trees dispersive effect
	Selmi et al. [37]	Strasbourg, France	CO, NO_2, PM_{10}, $PM_{2.5}$, SO_2, O_3	0.03%, 0.5%, 6.6%, 1.5%, 0.5%, not significant	Model	Promote public green spaces (27.80% of the area of the city)

	Rao et al. [38]	Portland-Hillsboro-Vancouver, US	NO_2	8–12%	Model	5% change in Vegetation Management Task Force, high-intensity development, open development and tree canopy
	Rafael et al. [39]	Porto, Portugal	NO_x, PM_{10}	19%, 16%	Model	Implementation of a green urban area (in the center of the study area, by replacing the current buildings)
	Riondato et al. [40]	Dublin, Germany	$PM_{2.5}$	23%	Model	Removal by trees
	Nemitz et al. [41]	Urban areas UK	$PM_{2.5}$	1%	Model	Conversion of half of existing open urban greenspace to forest
	Mueller et al. [15]	Barcelona, Spain	NO_2	19%	Model	Superblock design in the city center
Promotion of public transport	Titos et al. [19]	Granada, Spain	BC, PM_{10}	37%, 33%	Real measurement	Public transportation re-organization (reduced the overlap between bus lines in downtown—50% fewer buses—and introduced brand-new buses with higher passenger capacity and EURO V)
	Basagaña et al. [20]	Barcelona, Spain	NO_2, NO, PM_{10}, $PM_{2.5}$, PM_1, N, BC	4%, 7.5%, 6%, 3.5%, 6%, not significant, 4%	Real measurement	Public transport normal service in comparison with strike days
Traffic policies	Dijkema et al. [42]	Amsterdam, Netherlands	NO_x, PM_{10}, PM_1, Black Smoke	2.4%, 7.4%, 2.8%, 15%	Real measurement	Speed limit intervention on part of the ring highway, adjoined with apartment buildings
	Johansson et al. [25]	Stockholm, Sweden	NO_2, PM_{10}	12%, 7%	Model	Congestion tax
	Bel et al. [43]	Barcelona, Spain	NO_x, PM_{10}	7.7–17.1%, 14.5–17.3%	Real measurement	Variable speed policy (depending on the traffic density)
	Gulia et al. [44]	Delhi city, India	NO_x, $PM_{2.5}$	0.5–1.8%, 0.4–1.9%	Model	Odd–even car scheme
	Bel et al. [21]	Mexico City, Mexico	CO, NO_x, PM_{10}	5.5–7.2%, 4.7–6.5%, 7.3–9.2%	Real measurement	Bus Rapid Transit
Technological improvements/road management	Soret et al. [27]	Barcelona and Madrid, Spain	NO_x	11–17%	Model	40% fleet electrification
	Amato et al. [45]	Barcelona, Spain	PM_{10}, $PM_{2.5-10}$	Not significant, not significant	Real measurement	Reducing road dust emission

	Ferrero et al. [46]	Milan, Italy	NO, NO_2	0.4–1.5%, 0.3–0.8%	Model	Replacement (50%) of non-electric vehicles with electric ones
	Harrison et al. [47]	London, UK	$PM_{2.5}$	38%	Real measurement	Implemented diesel particle filters
	Gulia et al. [44]	Delhi city, India	NO_x, $PM_{2.5}$	8.6–33.6% both	Model	Reducing road dust emission
Combination of measures	Izquierdo et al. [48]	Madrid, Spain	NO_x, $PM_{2.5}$	20%, 27%	Model	Central Zero Emissions Zone; regulation of car parking; speed limits; infrastructures reserved for public transport; extension and renewal of the fleet of buses and taxis; efficient urban distribution of goods

Table S2. Review of traffic-related air pollution abatement measures which have proven to be successful in selected European cities. Adapted from: http://fairmode.jrc.ec.europa.eu/measure-catalogue/ (accessed on 5 July 2021).

City	Short description	Classification
Barcelona, Spain	Intensive street cleaning expected to reduce the dust load on roads and therefore resuspension of dust	Other (Traffic planning and management)
Barcelona, Spain	Provision of different modes of transport and optimization of the nodes	Encouragement of shift in transport modes
London, UK	Accelerated uptake of cleaner taxis by introducing an age-based limit	Other (Traffic planning and management)
London, UK	Traffic measure of charging a flat rate to enter central London on weekdays to reduce congestion	Congestion pricing zones (Traffic planning and management)
London, UK	Introduction of cycle superhighways	Slow modes (e.g., expansion of bicycle and pedestrian infrastructure)
London, UK	Reducing unnecessary engine idling of vehicles and school buses in London and the United States	Other (Public information/Education)
London, UK	The website Cleaner Air for London provides up-to-date information on air quality, forecasts, and measures for different groups of users	INTERNET (Public information/Education)
London, UK	Low-emission zone for vans and lorries	Low-emission zones (Traffic planning and management)
London, UK	Best-price tickets accounting the lowest price according to the number of journeys ("Oyster card")	Encouragement of shift in transport modes
London, Birmingham and Manchester, UK	Planting of trees along streets and in other urban locations, particularly in economically deprived areas	Other
Madrid, Spain	Use of compressed natural gas (CNG) buses in the public transport system	Cleaner vehicle transport services
Madrid, Spain	Retrofitting of public transport buses with Diesel particulate filters (DPF)	Retrofitting emission control equipment
Milan, Italy	Area C", the actual implementation of the former "Ecopass" measure, represents the LEZ area within Milan and regulates the access of private vehicles to the central urban zone under the payment of a toll	Congestion pricing zones (Traffic planning and management)
Milan, Italy	Low-emission zone in vehicles during wintertime	Low-emission zones (Traffic planning and management)

Paris, France	Bicycles can be rented for free or at low charge for a limited amount of time throughout the city	Slow modes (e.g., expansion of bicycle and pedestrian infrastructure)
Paris, France	Creation of new transport services based on the sharing of non-polluting vehicles: Autolib (electric vehicles in self-service)	Other (Traffic planning and management)
Paris, France	Extension of a new tramway line (T3) on the ring boulevards around the city of Paris	Land-use planning to ensure sustainable transport facilities
Paris, France	Rebalancing program of public space in Paris, reducing areas attributed to cars and prioritizing slow modes and public transport	Slow modes (e.g., expansion of bicycle and pedestrian infrastructure)
Zürich, Switzerland	Limiting overall NO_x emissions of Zurich airport	Other

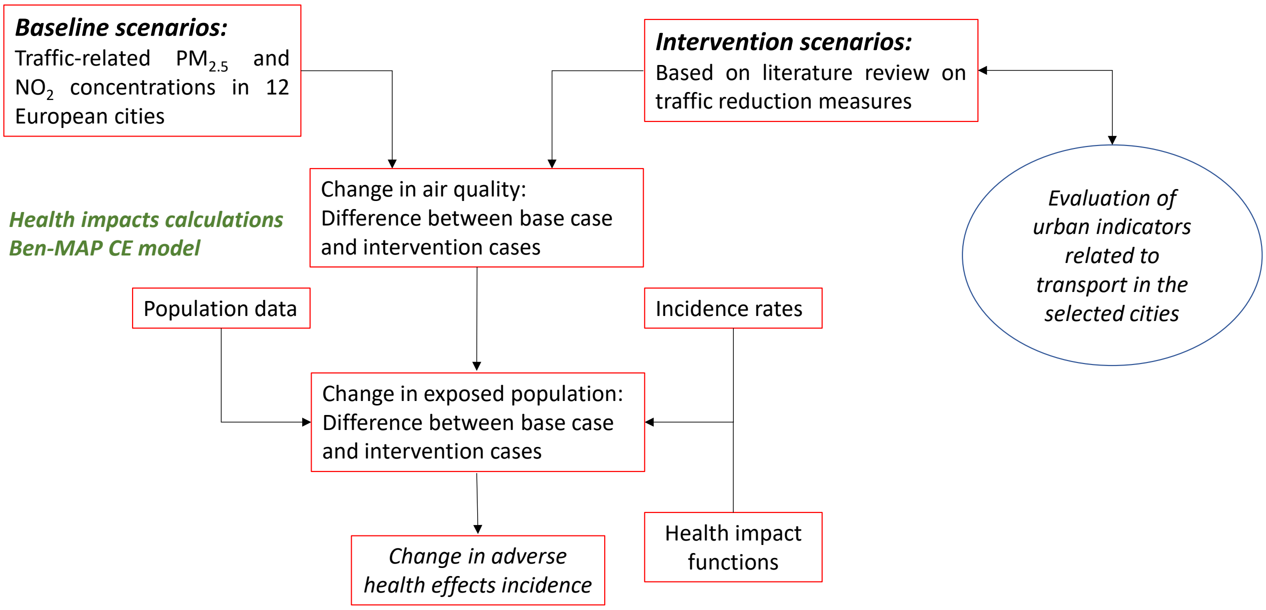

Figure S1. Methodology steps and the input data files required to run BenMAP-CE.

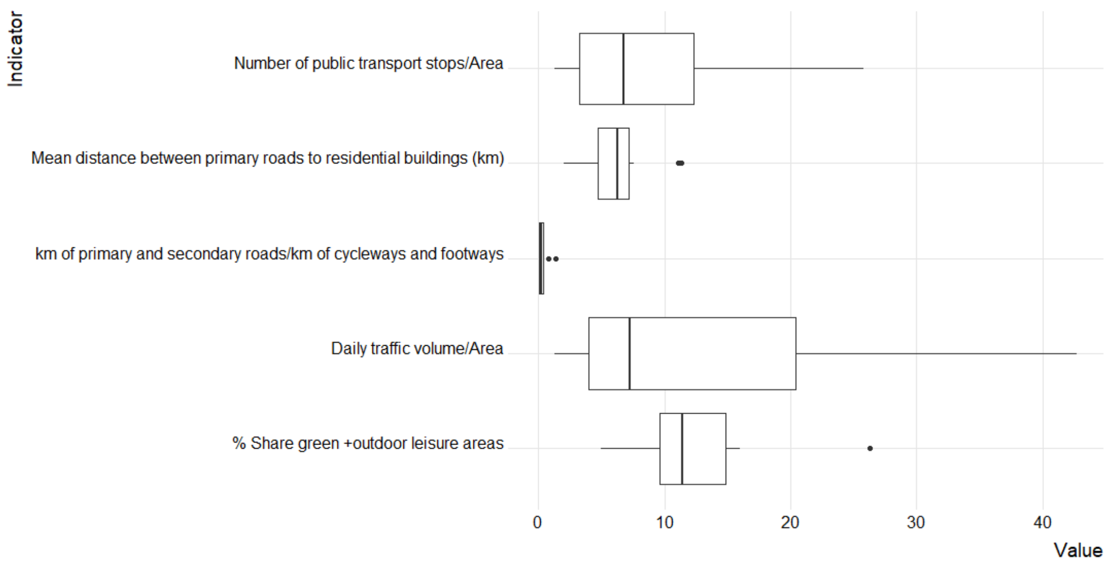

Figure S2. Boxplot of the distribution of different indicators in the selected cities considered relevant from an air quality perspective.

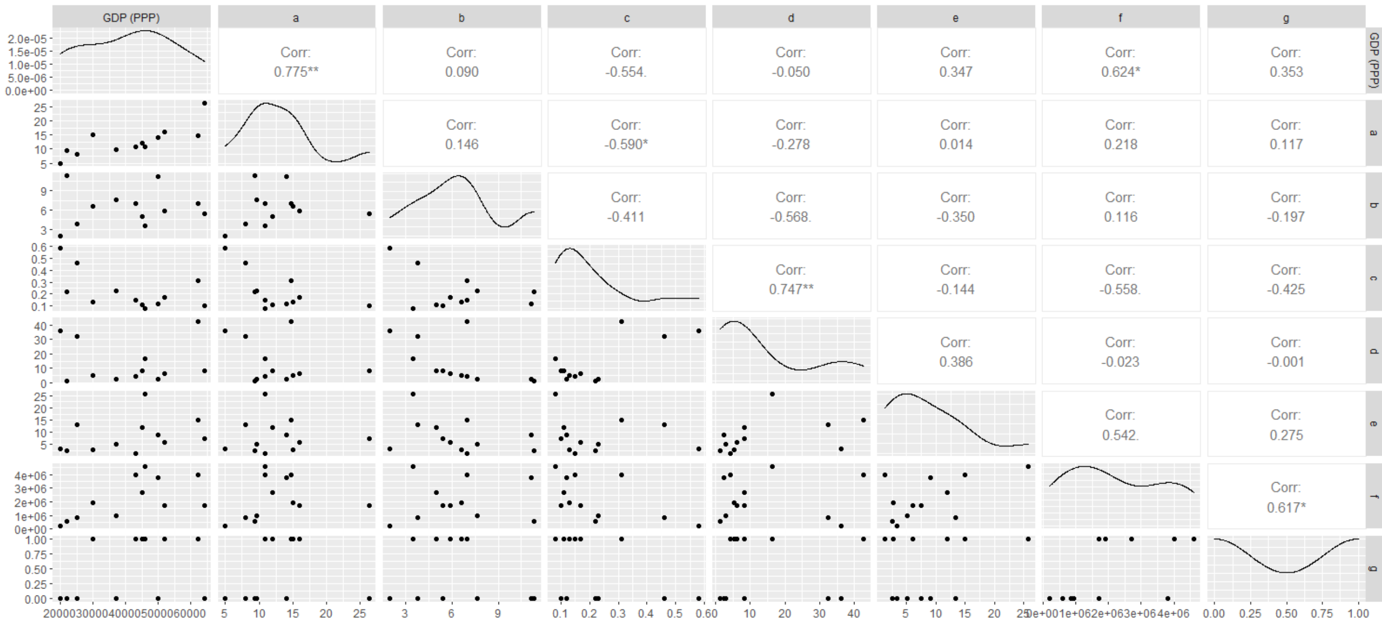

Figure S3. Correlogram of GDP (PPP) in the cities under study against selected city indicators. Correlation coefficients represent Pearson's correlation coefficients (r). (**a**) Share urban green areas (%); (**b**) Distance primary roads to residential buildings; (**c**) Road type Ratio; (**d**) Daily traffic volume/Area; (**e**) Public transport stops/Area; (**f**) Distribution of public transport stops Index; (g) Implementation of Low Emission Zone (0 = no)

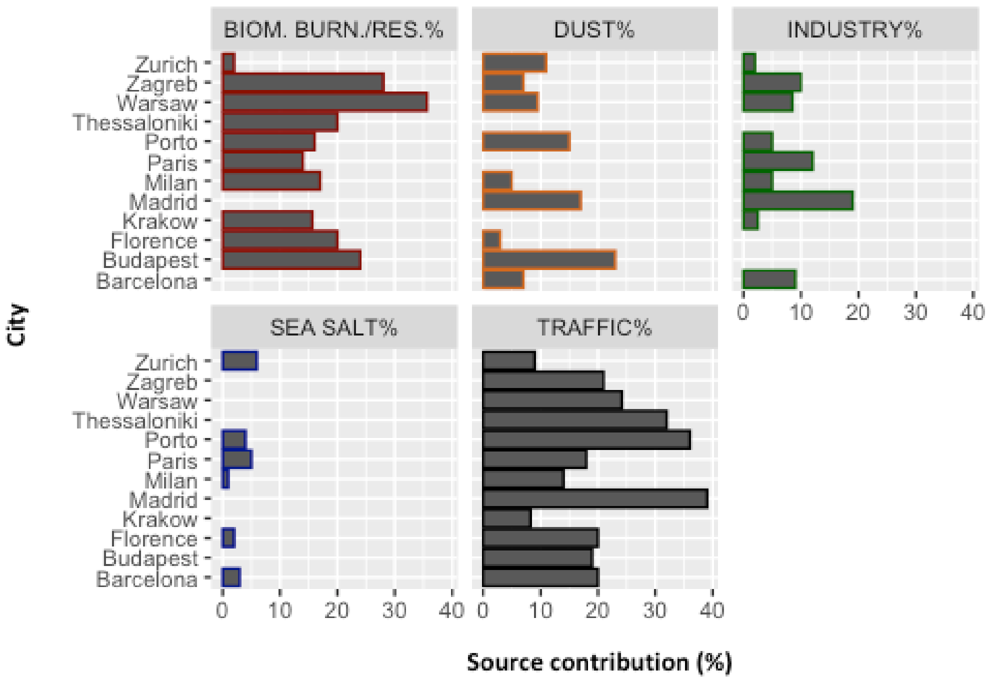

Figure S4. $PM_{2.5}$ source contributions reported in the literature for the selected cities.

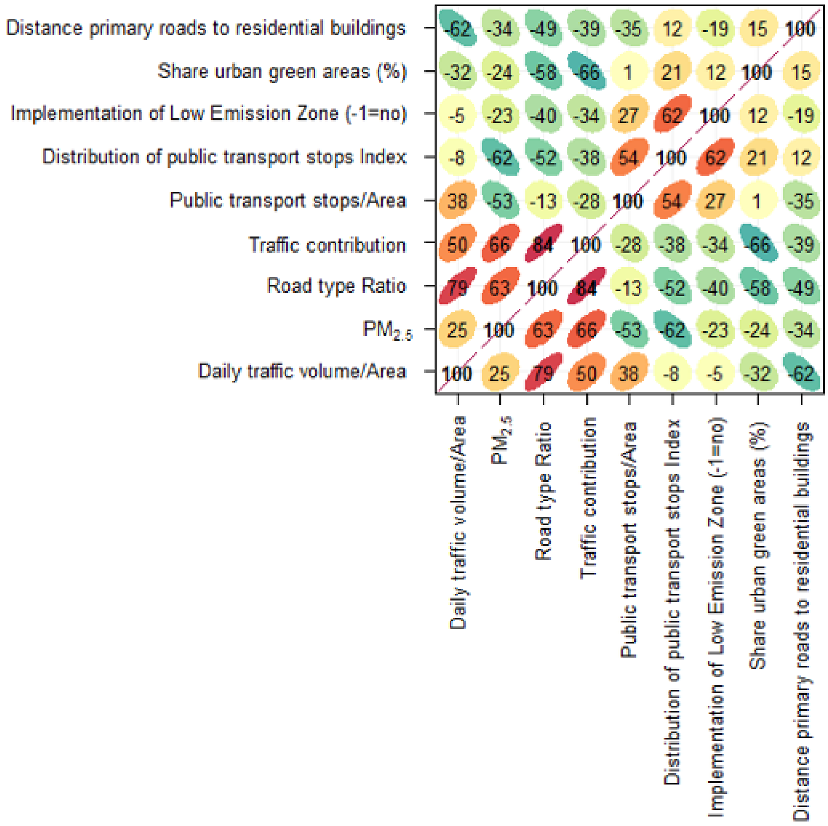

Figure S5. Correlation matrix including selected city indicators and $PM_{2.5}$ traffic contribution and $PM_{2.5}$ concentrations in µgm^{-3}.

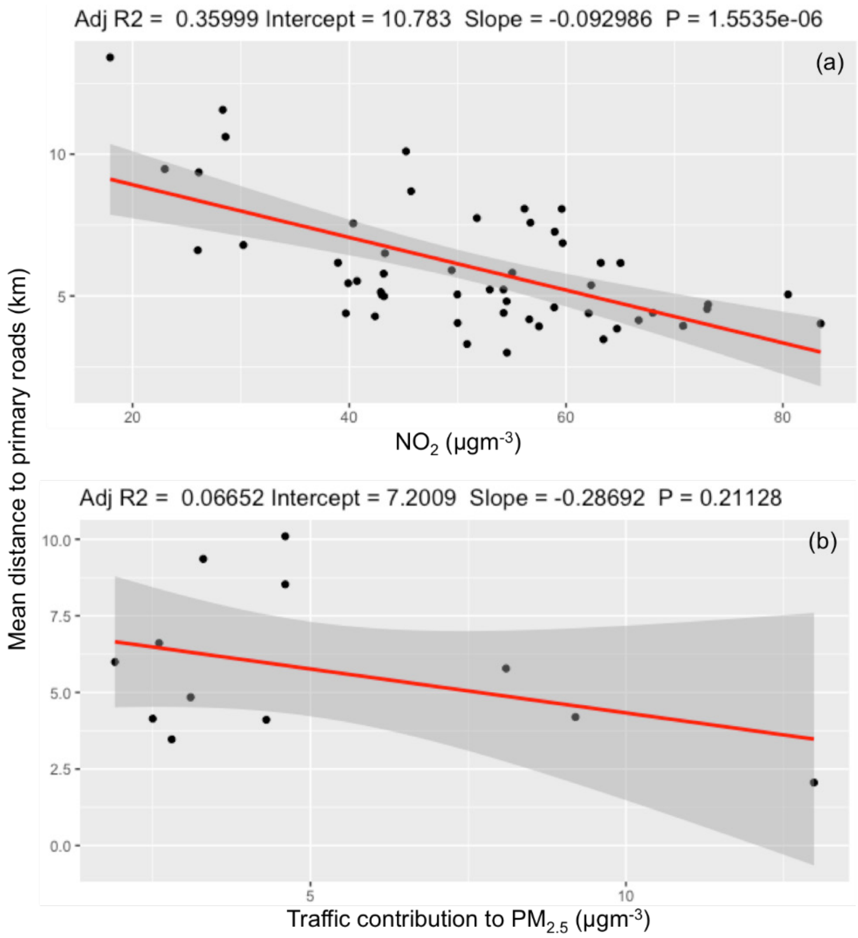

Figure S6. Linear regression between mean NO_2 (**a**) and $PM_{2.5}$ traffic contributions (**b**) in µgm^{-3} against mean distance to primary roads of the different measurement points.

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