



ADDITIONAL MATERIALS

Research Report 226

Comparison of Long-Term Air Pollution Exposure from Mobile and Routine Monitoring, Low-Cost Sensors, and Dispersion Models

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Additional Materials 1: Detailed Methods

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Additional Materials 1: Detailed Methods

Comparison of Long-Term Air Pollution Exposure from Mobile and Routine Monitoring, Low-Cost Sensors, and Dispersion Models

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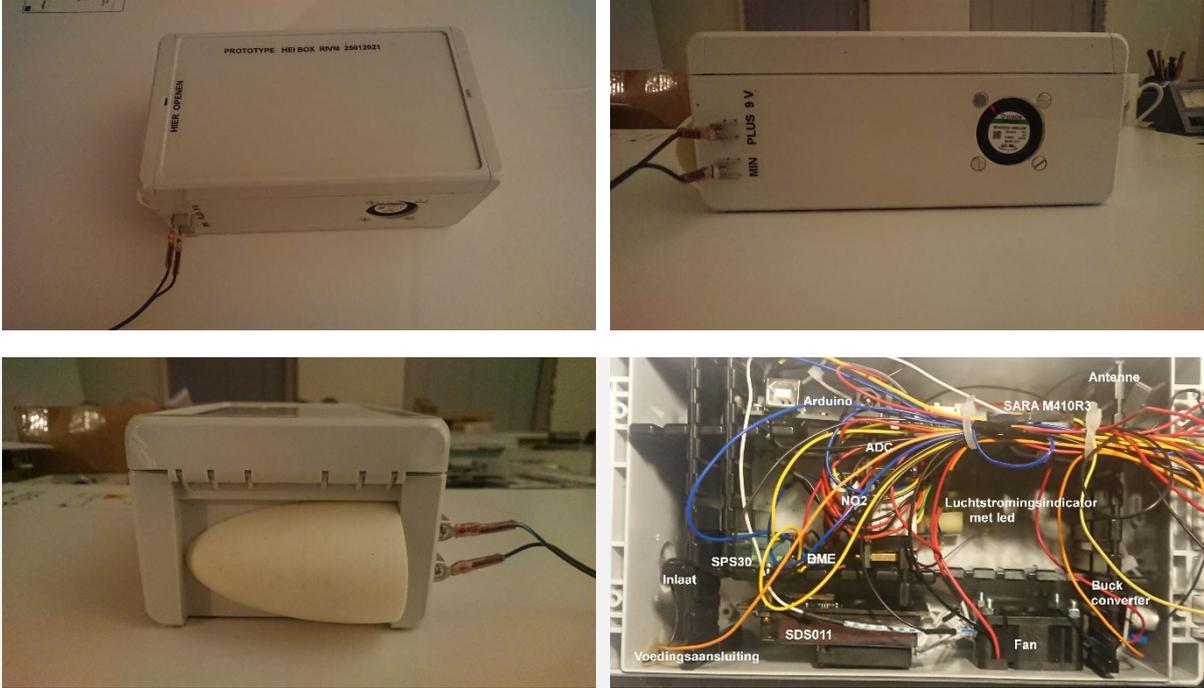
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Section 3.2.1 Low-Cost Sensor Model

Figure S1. Examples of potential sensor location, coupled with modeled background concentration (colors) and modeled road contribution (labels)



Figure S2. The low-cost sensor kit developed by RIVM, containing sensors for PM, NO₂, temperature, humidity and pressure.



Installation Guide Low-Cost Sensors (in English and local language, Dutch)

Installing the Sensor Box

1 Description of sensor box

The sensor box that will be installed in your home contains the SDS011 particulate matter sensor from Nova (*Nova SDS011*), SPS30- particulate matter sensor from Sensirion (*Sensirion SPS30*), the B43F-nitrogen dioxide sensor from Alphasense (*Alphasense B43F*) and the Adafruit BME280 for temperature air humidity and air pressure. The cabinet can be installed fairly easily, using the supplied mounting plate.

2 Description of installation preferences

Choose an **installation** location with free space so that the ambient air flows easily past the cabinet. Some points to pay attention to:

- You must install the box in such a way that the protective cover at the air inlet protects the box against rain; The air inlet and protective cover are located on a short side of the box. If you use the mounting plate, ensure that the protective cover is on the left side (seen from the front) and, therefore, has the opening downwards (see the photos at the bottom of this document).
- The presence of a *power socket* (within ten meters); the sensor box is equipped with a thin connection cable of ten meters (which fits with some care through the crack/draft strip of a closed window or door) and there must therefore also be a socket for the power adapter nearby (note that the connection of the adapter on the 'ten meter cable' must remain dry).
- *installation height* preferably between 1.5 and 2.5 meters, but a location on the first floor of a house is also fine;
- The location must be *representing the living environment* as much as possible;
- Installation preferably on a location around the house with minimal hours of direct sunlight and not in a damp place (for example, between shrubs in the garden).

3 Installing the sensor box

- After you have installed your sensor box, connect the power cable to a power source (for example, the socket). As soon as the sensor is supplied with power, an automatic data stream runs, so you don't have to do anything anymore. The data will become visible (the

next day, within 24 hours) on the Samenmeten portal* (<https://samenmeten.rivm.nl/dataPortal/>).

Please note: In all cases, if (all) guidelines for the placement of sensors cannot be met: *a less optimal measurement is better than no measurement!* The most important installation requirement is to avoid placing the box in direct sunlight, as this will quickly destroy the sensors.

If you are in doubt, you can, for example, take a photo of the situation and submit it to Samenmeten@rivm.nl, stating 'HEI project' and the sensor number

*** NB.** *The location of the sensors on the Samen Meten data portal is always an approximation. We show the location in a slightly different place every time the website is refreshed, so that as little as possible can be traced back to a specific address. For more information about this, and about the data portal in general, see <https://www.samenmetenaanluchtkwaliteit.nl/dataportaal>.*

Foto's

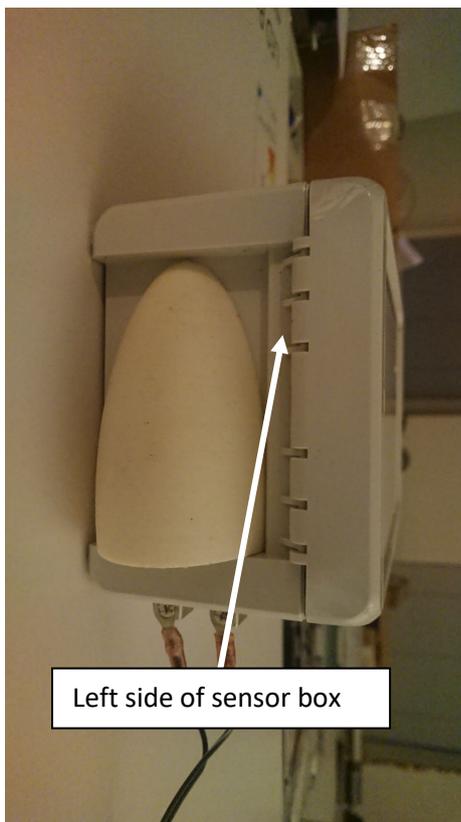


Figure 1 Side view of sensor box with the protective cover with the opening downwards

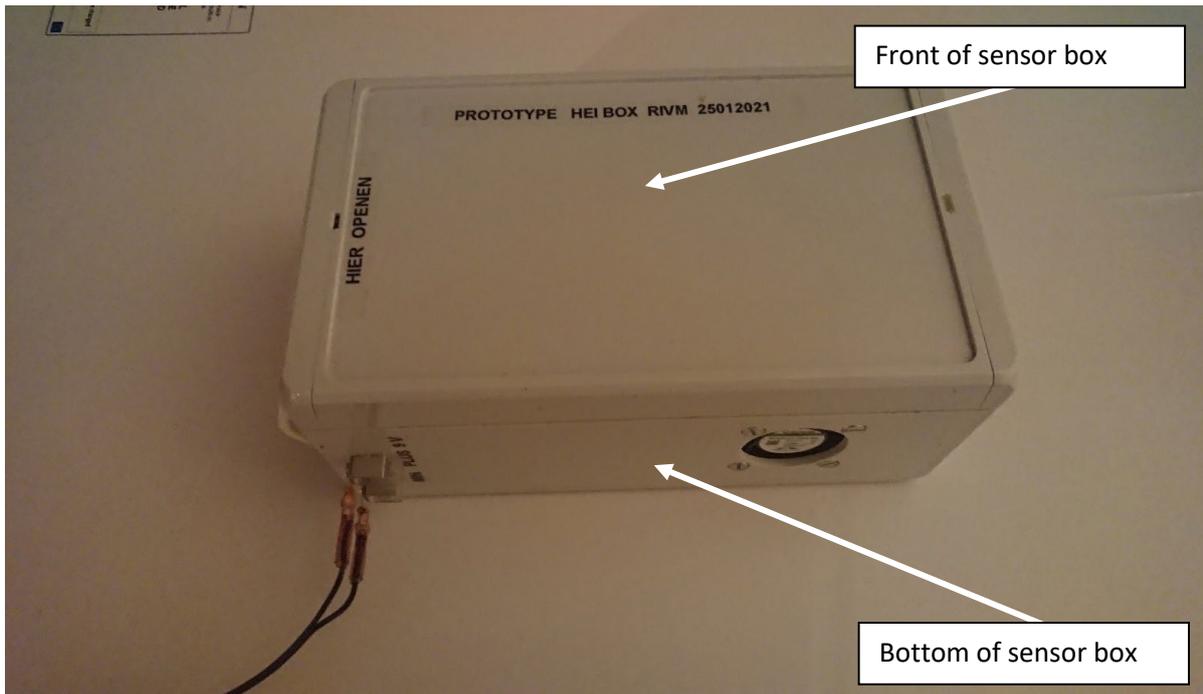


Figure 2 Front view of sensor box

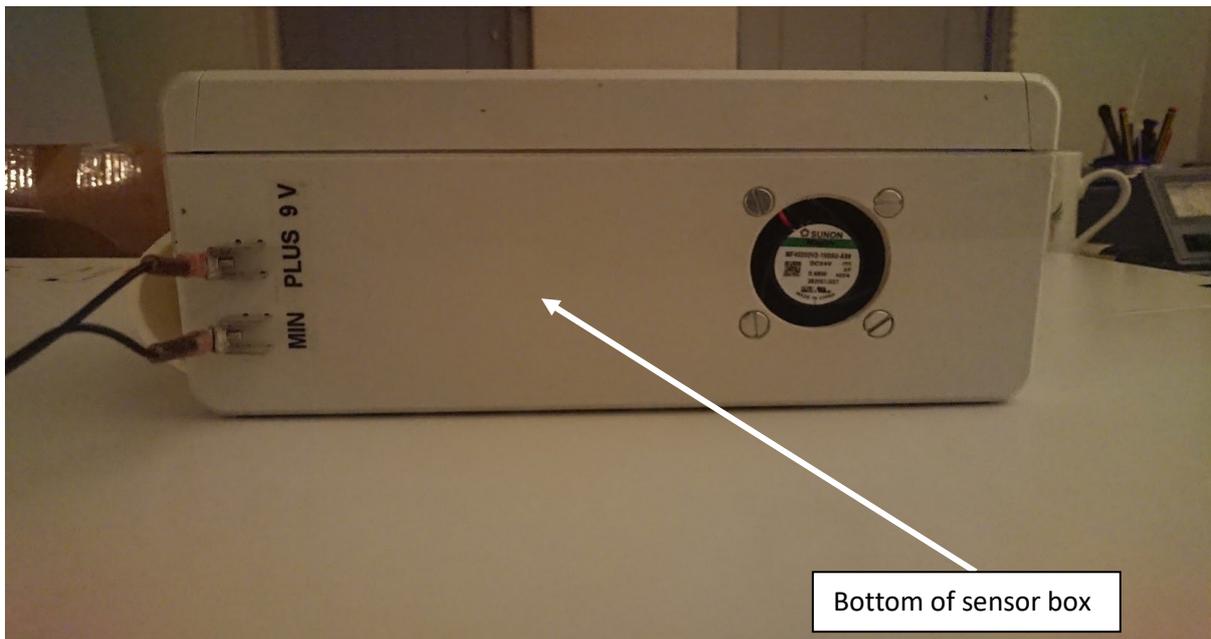


Figure 1 Bottom view of sensor box with fan

Het plaatsen van het sensorkastje

1 Omschrijving sensorkastje

In het sensorkastje dat bij u thuis komt te hangen zijn de SDS011-fijnstofsensoren van Nova (*Nova SDS011*), SPS30-fijnstofsensoren van Sensirion (*Sensirion SPS30*), de B43F-stikstofdioxide sensor van Alphasense (*Alphasense B43F*) en de Adafruit BME280 voor temperatuur, vocht en luchtdruk geïnstalleerd. Het kastje kan redelijk eenvoudig opgehangen of geplaatst worden, met behulp van de bijgeleverde ophangplaat.

2 Omschrijving installatie voorkeuren

Kies een **ophangplek** met vrije ruimte zodat de omgevingslucht gemakkelijk langs het kastje stroomt. Enkele punten om op te letten:

- U dient het kastje zo op te hangen dat de beschermkap bij de luchtinlaat het kastje beschermt tegen inregenen; De luchtinlaat en beschermkap zitten aan een korte zijde van het kastje. Als u gebruik maakt van de ophangplaat, dan zorgt u ervoor dat de beschermkap aan de linkerkant zit (van voren gezien) en dus de opening naar beneden heeft (zie de foto's onderaan dit document).
- De aanwezigheid van een *stopcontact* (binnen tien meter); het sensorkastje voorzien van een dun aansluitsnoer van tien meter (dat past met enige voorzichtigheid door de kier/tochtstrip van een gesloten raam of deur) en er dient dus ook een stopcontact voor de voedingsadapter in de buurt te zijn (let wel dat de aansluiting van de adapter op het 'tienmetersnoer' droog moet blijven).
- *ophanghoogte* bij voorkeur tussen 1,5 en 2,5 meter maar een locatie op de eerste verdieping van een huis is ook prima;
- *De locatie moet zo veel mogelijk representatief* zijn voor de leefomgeving;
- zo **min mogelijk** in de zon of op een vochtige plek (bijvoorbeeld tussen struiken in de tuin).

3 Het sensorkastje installeren

- Nadat u uw sensorkastje heeft opgehangen, sluit u het aansluitsnoer aan op een voedingsbron (bijvoorbeeld het stopcontact). Zodra de sensor hangt en van stroom voorzien wordt, loopt er een automatische datastroom en hoeft u dus niets meer te doen. De data zal (de volgende dag, binnen 24 uur) zichtbaar worden op het samenmeten-portaal* (<https://samenmeten.rivm.nl/dataportaal/>).

Let wel: In alle gevallen geldt dat, als niet aan (alle) richtlijnen voor de plaatsing van sensoren kan worden voldaan: liever een minder optimale meting dan geen meting! Het meest belangrijke is om het kastje niet in de volle zon te hangen, daarvan gaan de sensoren snel kapot.

Indien u twijfelt, kunt u bijvoorbeeld een foto maken van de situatie en deze voorleggen aan samenmeten@rivm.nl onder vermelding van 'HEI-project' en het sensornummer.

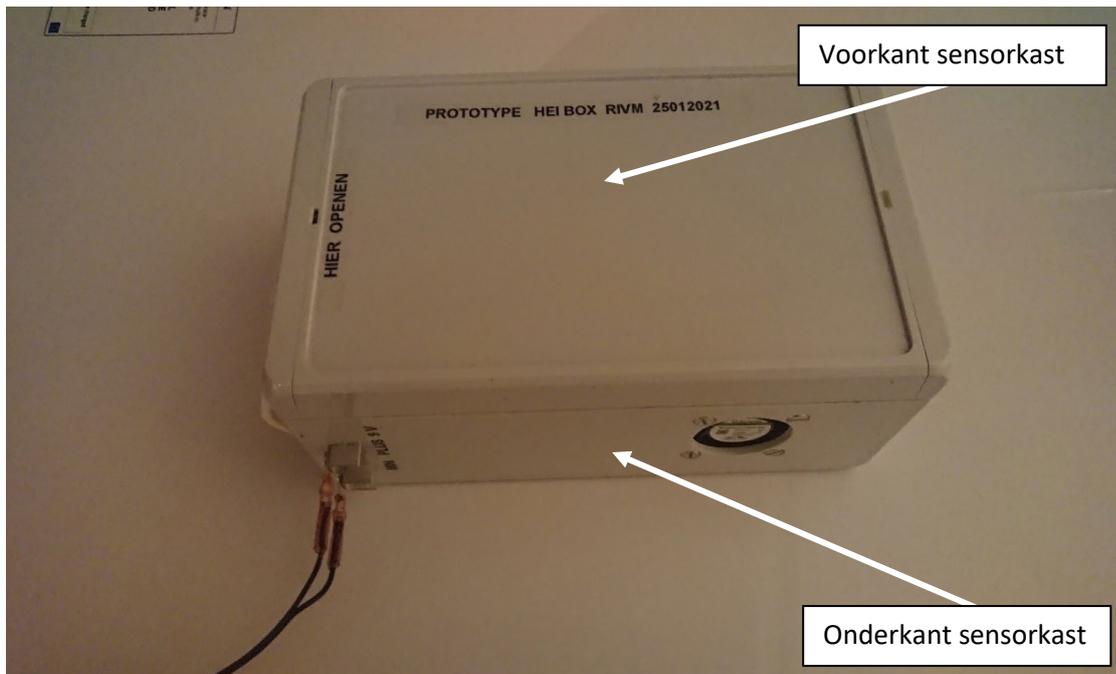
*** NB. De locatie van de sensoren op het Samen Meten dataportaal is altijd een benadering. We laten de locatie bij iedere verversing van de website op een iets andere plek zien, zodat zo min mogelijk herleiding naar een bepaald adres mogelijk is. Voor meer informatie hierover, en over het dataportaal in het algemeen, zie <https://www.samenmetenaanluchtkwaliteit.nl/dataportaal>.**

Foto's

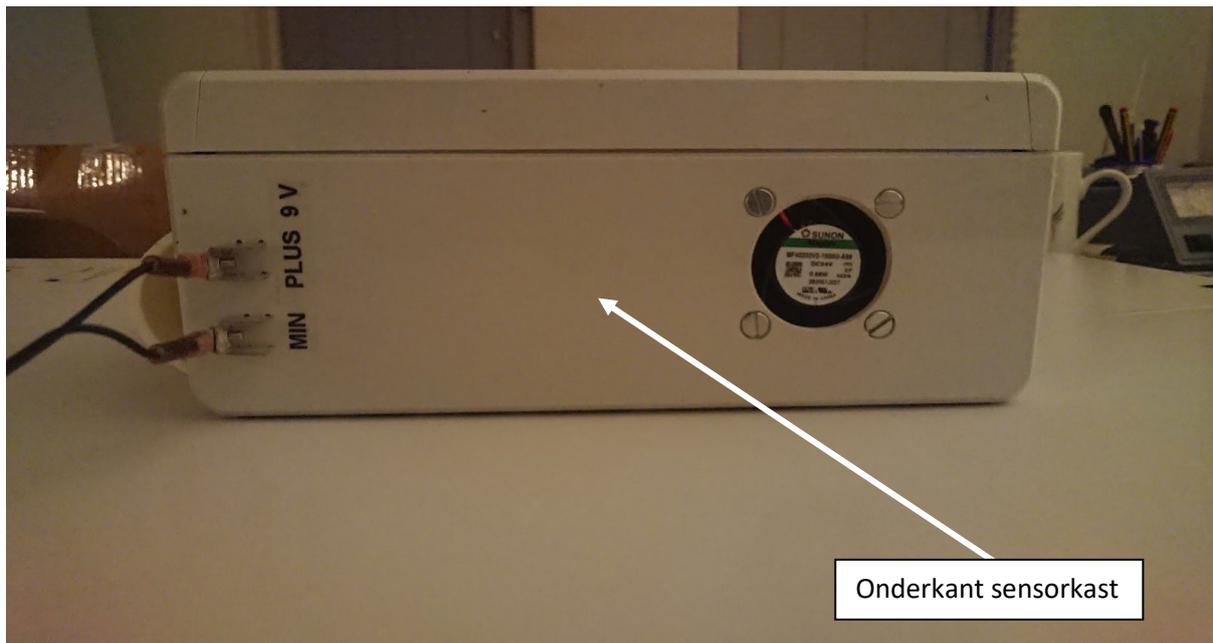


Figuur 1 Zijaanzicht sensorkast met de beschermkap met de opening naar beneden

Linker zijkant sensorkast



Figuur 2 Vooraanzicht sensorkast met de onderkant onderaan



Figuur 2 Onderaanzicht sensorkast met de ventilator

Section 3.2.2 Google Airview Monitoring

Figure S3 **Pollutants measured in Google Airview monitoring**

Device	Pollutants	Operating
GPS	Location	Google Ji-BOx
EPC	Ultrafine Particles	Google Ji-BOx
AE33	Black Carbon	Google Ji-BOx
DRX DustTrack	PM2,5	Manual
LiCOR	CO2	Google Ji-BOx
MiniDisc	Ultrafine Particles	Manual
2BTech	NOx	Google Ji-BOx
Aerodyne	NO2	Google Ji-BOx



Section 3.3 New External Validation Data Campaign

Quality Assurance and Control Protocol for Newly Collected External Validation Data

Quality Assurance

Standard operating procedures (SOPs) for all measurement devices have been included in the QA plan. The SOPs as used in the ESCAPE study for PM, NO_x, reflection and weighing were used for the measurements with the Harvard impactor and Ogawa badge. The SOP for the MiniDisc from the Exposomics study was used for the UFP measurements. The SOP for the MA200 has been newly developed.

Quality Control

Reference site for temporal variation

The measurement campaign took place over the course of 20 months. To account for temporal variation of the measurements within this period, a reference site was established at an emission-low farm near the IRAS offices. This site was the equivalent of a regional background site to avoid the influence of local sources. It was equipped with one of the measurement kits with all instruments for the entire duration of the measurement campaign. Weekly integrated measurements were taken following the schedule of the field measurements. For BC and UFP, real-time measurements were performed.

Device comparisons

Comparisons of all MiniDisc and MA200 devices were performed between every 3 to 5 measurement weeks in the laboratory to ensure proper functionality and assess consistency of the equipment. During these measurements, the aim was to achieve sufficient variability in offered pollutant concentrations. The duration of these measurements was a minimum of 10 hours. The measurements were compared on minute and hourly averages.

Comparisons with reference monitors

Co-location of the Harvard impactor and Ogawa badge was performed every 3 to 5 measurement weeks for the duration of one week to compare measurements from these devices with those from reference monitors from the RIVM national routine monitoring network. The RIVM reference site that was used is Cabauw, a regional background site where hourly concentrations of NO₂ and PM_{2.5} are measured. The Ogawa badge was also co-located with an RIVM traffic site in Utrecht (Constant Erzeijstraat) to additionally compare high concentrations of NO₂. UFP is not routinely measured in the RIVM national monitoring network.

Duplicate and blank measurements

Duplicate and blank measurements of 1-week duration were performed alongside the sample measurements with the Harvard impactor and Ogawa badge in the field at the temporal reference site. The procedures for sample and blank measurements are further described in the SOPs, available upon request of the author.

Device-specific QC

Device-specific quality control measures are detailed in the corresponding SOP. This section provides an overview of these measures.

Ogawa badge

- Four laboratory blanks are taken from each lot of 40 coated filters that are analyzed simultaneously with the samples.
- Before each analysis run, a full calibration is conducted in triplicate.
- Field duplicate and blank measurements alongside sample measurements.

Harvard impactor

- Calibration of rotameters by comparison with a soap film meter
- Quality control procedures for weighing and reflectance measurement are described in the corresponding SOPs, including temperature and humidity control, control filters.
- Field duplicate and blank measurements of PM_{2.5} alongside sample measurements.

MiniDisc

- Zero-calibration before each measurement period.
- Device comparisons between every 3-5 measurement weeks.

MA200

- Zero-calibration before each measurement period.
- Device comparisons between every 3-5 measurement weeks.

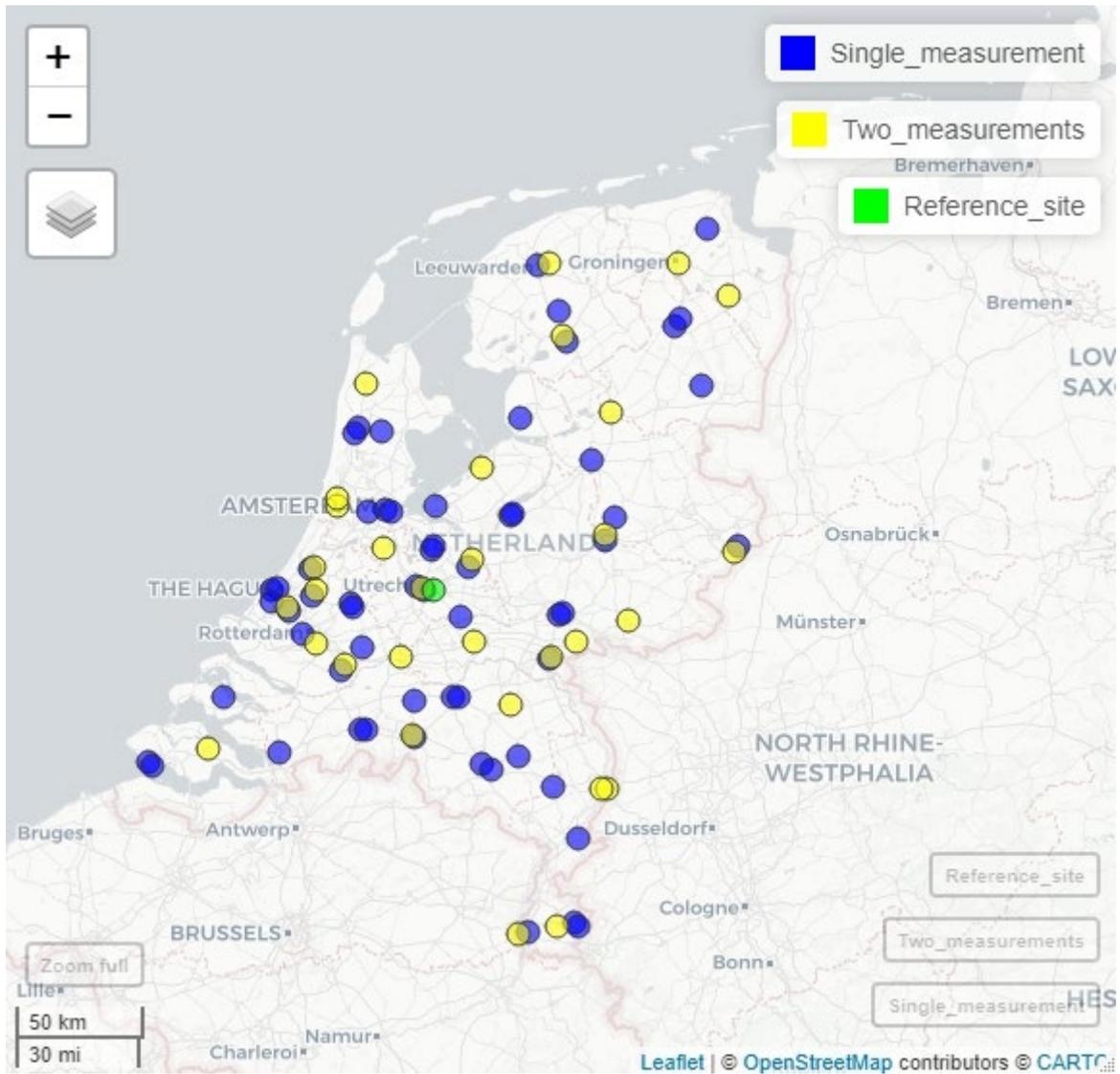


Figure S4 Monitoring locations of the new external validation campaign

Section 3.4 Epidemiological Studies

Table S1 Outcome definition for adult cohorts (following ELAPSE)

Cause	ICD-9 codes	ICD-10 codes
Mortality		
Natural cause	001-779	A00-R99
Cardiovascular	400 – 440	I10 – I70 ¹
Respiratory	460 – 519	J00 – J99
Lung cancer	162.2-162.9	C34.0 to C34.9
Incidence		
Coronary events	410, 411, 427.5 (hospital) and 410-414, 427.5 (mortality)	I20.0, I21, I22, I23, I46 (hospital) and I20-I25, I46 (mortality)
Cerebrovascular events	431, 433.x1, 434, 436 (hospital) and 431-436 (mortality)	I61, I63, I64 (hospital) and I61-I64 (mortality)

Section 4.1 Exposure Model Development

Table S2 Spatial predictor variables with units, a priori defined directions of effect for supervised stepwise model and buffer sizes in the mobile data set.

Predictor variable	Abbreviation	Units	Direction of effect	Buffer
Industry area	INDUS_	m²	+	100
				300
				500
				1000
				5000
Port area	PORT_	m²	+	100
				300
				500
				1000
				5000
Airport area	AIR	m²	+	5000
Natural and forested areas	NATUR_	m²	-	100
				300
				500
				1000
				5000
Urban Green area	URBG_	m²	-	100
				300
				500
				1000
				5000
Agricultural land area	AGRI_	m²	-	100
				300
				500
				1000
				5000
Population density	POP_	n	+	100
				300
				500
				1000
				5000
Household density	HHOLD_	n	+	100
				300
				500
				1000
				5000
Traffic intensity on nearest road	TRAFNEAR	Veh.day⁻¹	+	
Traffic intensity on nearest major road	TRAFMAJOR	Veh.day⁻¹	+	
Heavy-duty traffic intensity on nearest road	HTRAFNEAR	Veh.day⁻¹	+	
Heavy-duty traffic intensity on nearest major road	HTRAFMAJOR	Veh.day⁻¹	+	

				50
				100
Road length of all roads	RDL_	m	+	300
				500
				1000
				50
				100
Road length of all major roads	MRDL_	m	+	300
				500
				1000
				50
Traffic intensity on all roads				100
(sum of (traffic intensity * length of all segments))	TLOA_	Veh.day⁻¹m	+	300
				500
				1000
				50
Traffic intensity on all major roads				100
(sum of (traffic intensity* length of all segments))	TMLOA_	Veh.day⁻¹m	+	300
				500
				1000
				50
Heavy-duty traffic intensity on all roads				100
(sum of (heavy-duty traffic intensity* length of all segments))	HLOA_	Veh.day⁻¹m	+	300
				500
				1000
				50
Heavy-duty traffic intensity on major roads				100
(sum of (heavy-duty traffic intensity*length of all segments))	HMLOA_	Veh.day⁻¹m	+	300
				500
				1000
				100
Highway	HIGH_	m	+	300
				500
				1000
				100
Restaurants	REST_	n	+	500
				1000
				5000
				100
Traffic Lights	TL_	n	+	500
				1000
				100
Bus Stops	BS_	n	+	500
				1000
X Coordinate	POINT_X		-	
Y Coordinate	POINT_Y		-	
Map produced by Kriging	Kriging Map	particles/cm ³		

Section 4.3 Epidemiological Analysis

Table S3 Population characteristics Duels cohort (Bouma, 2023)

Covariate		
<i>Individual covariates</i>	Category	N (%) or mean (sd)
Age		54.3 (15.0)
Sex	Male	5227876 (48.7)
	Female	5507858 (51.3)
Marital status	Married	6554479 (61.1)
	Widowed	852964 (7.9)
	Divorced	1174803 (10.9)
	Single	2153488 (20.1)
Region of origin	Dutch	8732131 (81.3)
	Western	1055828 (9.8)
	Other non-Western	319633 (3.0)
	Suriname	200271 (1.9)
	Turkey	197419 (1.8)
	Morocco	163338 (1.5)
	Antilles Netherlands	67114 (0.6)
Standardized household income	<1%	141753 (1.3)
	1-5%	192802 (1.8)
	5-10%	347895 (3.2)
	10-25%	1306536 (12.2)
	25-50%	2610783 (24.3)
	50-75%	2920752 (27.2)
	75-90%	1894331 (17.6)
	90-95%	657075 (6.1)
	95-99%	532320 (5.0)
	>99%	131487 (1.2)
<i>Area-level covariates</i>	Neighborhood (mean (sd))	Region (mean (sd))
Percentage non-western immigrants	10.9 (13.5)	11.5 (7.5)
Social assistance (per 1000 inhabitants)	43.1 (44.1)	30.5 (2.5)
Unemployment (per 1000 inhabitants)	26.4 (9.6)	26.6 (3.6)
Mean income per income recipient (*€ 1000)	30.7 (6.9)	46.6 (16.5)
Percentage low education	32.0 (10.3)	31.9 (3.1)
<i>Mortality outcomes^a</i>	N	
Natural cause mortality	945,615	
Cardiovascular mortality	244,977	
Respiratory disease mortality	84,734	
Lung cancer mortality	71,622	

^a ICD-10 codes: natural cause mortality: A00-R99, cardiovascular mortality: I10-I70, respiratory disease mortality: J00-J99, lung cancer mortality: C34.

Table S4 Population characteristics PIAMA cohort of the population for the asthma analysis, ages 1 – 20 years (a) and the lung function analysis (b)

a. Characteristics of participants included in the asthma analysis

Characteristics	n/N (%)
Female	1780/3687 (48.3)
Maternal asthma and/or hay fever	881/3652 (24.1)
Paternal asthma and/or hay fever	911/3658 (24.9)
Dutch nationality	3190/3521 (90.6)
High maternal education	1298/3678 (35.3)
High paternal education	1458/3637 (40.1)
Breastfeeding (≥ 12 weeks)	1627/3463 (47.0)
Older siblings	1860/3678 (50.6)
Daycare center attendance ^a	2040/3538 (57.7)
Mother smoked during pregnancy	626/3652 (17.1)
Smoking at child's home ^b	
Early life ^c	912/3686 (24.7)
Age 20 years	186/2127 (8.7)
Active smoking at least once a week ^d	
Age 14 years	119/2431 (4.9)
Age 20 years	426/2127 (20.0)
Use of natural gas for cooking	
Early life ^c	3028/3674 (82.4)
Age 20 years	1564/2127 (73.5)
Mold/damp spots in participant's home	
Early life ^c	300/3643 (8.2)
Age 20 years	242/2127 (11.4)
Furry pets in participant's home	
Early life ^c	1720/3677 (46.8)
Age 20 years	877/2127 (41.2)

^a During second year of life.

^b Defined as parental smoking until and including age 17 years and any smoking at age 20 years.

^c During first year of life.

^d At age ≥ 14 years.

b. Characteristics of participants included in the lung function analysis (N=625)

Characteristic	
Boys, n (%)	292 (46.7)
Age [years], mean \pm std	16.4 \pm 0.2
Weight [kg], mean \pm std	64.2 \pm 10.1
Height [cm], mean \pm std	175.6 \pm 8.9
Parental atopy	
Atopic mother, n (%)	195 (31.2)
Atopic father, n (%)	210 (33.6)
Presence of pets at age 16, n (%)	363 (58.1)
Presence of molds at age 16, n (%)	62 (9.9)
Breastfeeding more than 12 weeks, n (%)	343 (54.9)
Gas cooking at age 16, n (%)	491 (78.6)
Maternal smoking during pregnancy, n (%)	83 (13.3)
Indoor tobacco smoke exposure at age 16, n (%)	42 (6.7)
Parental education, n (%)	
Low	50 (8.0)
Intermediate	187 (29.9)
High	388 (62.1)
Dutch nationality, n (%)	606 (97.0)
Respiratory infections at age 16 ^a , n (%)	263 (42.1)
Lung function	
FEV ₁ [L], mean \pm std	3.94 \pm 0.72
FVC [L], mean \pm std	4.70 \pm 0.87

^a Respiratory infections in the 3 weeks before lung function measurement.

Table S5 Population characteristics EPIC-NL cohort, N=33,270 (population most adjusted model 3)

variable	category	N	%
sex	Female	25150	75,6
mar_stat	Single	5407	16,3
mar_stat	Married/living with partner	23483	70,6
mar_stat	Separated	2569	7,7
mar_stat	Widowed	1811	5,4
bmi_cat	Underweight	280	0,8
bmi_cat	Normal weight	15815	47,5
bmi_cat	Overweight	12846	38,6
bmi_cat	Obese	4329	13
employed	No	13077	39,3
employed	Yes	20193	60,7
smoking	Current	9703	29,2
smoking	Ex	10117	30,4
smoking	Never	13450	40,4
edulev	Low	5363	16,1
edulev	Medium	25885	77,8
edulev	High	2022	6,1
occstatus	Employed/self-employed	20193	60,7
occstatus	Unemployed	6003	18
occstatus	Retired	7074	21,3
		mean	sd
age_b	Year	49,7	11,8
smoke_dur	Year	14,3	15
smoke_cig	# cigarettes	8,3	10,1
fruit	g/day	261,9	167,9
meat	g/day	88,9	50,6
Alcohol	g/day	10,8	15,3
totveg	g/day	137,8	54,2