



National Institute for Public Health
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Ministry of Health, Welfare and Sport

Air quality assessment 2015 – 2019 for the European measurement obligation in the Netherlands

**Air quality assessment 2015 – 2019 for the
European measurement obligation in the
Netherlands**

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Colophon

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Synopsis

Air quality assessment 2015 – 2019 for the European measurement obligation in the Netherlands

According to European legislation, the Netherlands must have a minimum number of sampling points to assess the nationwide air quality. This obligation is the EU minimum measurement obligation. European Union (EU) Member States must check the minimum sampling points every five years.

Each EU Member State determines the minimum number of sampling points on its own territory based on criteria in the EU directives for air quality. The measured concentrations of air pollutants and the number of inhabitants in predefined air quality areas are used for this purpose. Within these areas, a distinction is made between urban areas (agglomerations) and the remaining areas (zones), which consist of multiple provinces. Whenever the boundaries of these areas change (e.g. because of municipal reorganisations), the minimum number of sampling points need to be reassessed.

National Institute for Public Health and the Environment (RIVM) has assessed the minimum measurement obligation based on measured concentrations obtained between 2015 and 2019. The result shows that the current setup of the monitoring network complies with the minimum number of required sampling points based on EU legislation, except in the agglomeration Den Haag/Leiden. Here, changes in the local environment made a sampling point unsuitable for monitoring air pollutants. A new sampling point has been operational since September 2022, solving the shortcoming.

In line with the previous assessment, there are insufficient suburban sampling points to monitor ozone concentrations. RIVM advises the Dutch Ministry of Infrastructure and Water Management to expand the number of suburban sampling points for ozone where needed.

In some cases, the national legislation, as laid out in the "Regeling beoordeling luchtkwaliteit" (Rbl), requires more sampling points than the minimum required by the EU. This increase is because air quality measurements are not just used for EU legislation, but also for other purposes. For example, these measurements are used to check model calculations and monitor concentrations over extended periods.

The Dutch National Air Quality Monitoring Network (NAQMN) carries out the EU measurement obligation. When necessary, the sampling points operated by the partner monitoring networks of the Public Health Service of Amsterdam (GGD Amsterdam) and the DCMR Environmental Protection Agency are used for this purpose.

Keywords: assessment, air quality, European measurement obligations

Publiekssamenvatting

Beoordeling Nederlandse luchtkwaliteit voor de Europese meetverplichting

De Europese wetgeving verplicht Nederland om een minimaal aantal meetpunten te hebben waarmee het de luchtkwaliteit in het hele land in de gaten kan houden. Dit heet de Europese minimale meetverplichting, die lidstaten elke vijf jaar moeten controleren.

De Europese lidstaten bepalen per land het aantal meetpunten op basis van criteria in de EU-richtlijnen voor luchtkwaliteit. Ze kijken daarbij naar de gemeten concentraties van luchtvervuilende stoffen en het aantal inwoners in verschillende 'luchtkwaliteitsgebieden'. In deze gebieden wordt een onderscheid gemaakt tussen stedelijke gebieden (agglomeraties) en overige gebieden (zones), waaronder meerdere provincies vallen. Door veranderingen hierin, bijvoorbeeld als gemeenten zijn samengevoegd, kan het nodig zijn de meetinspanning aan te passen om aan de meetverplichting te voldoen.

Het Rijksinstituut voor Volksgezondheid en Milieu (RIVM) controleerde de minimale meetinspanning op basis van gemeten concentraties tussen 2015 en 2019. Hieruit blijkt dat Nederland bijna overal aan de minimale meetverplichting voldoet. Alleen in de agglomeratie Den Haag/Leiden was dat niet zo, omdat daar een meetpunt was weggefallen. Dat was niet meer bruikbaar omdat de omgeving van het meetpunt is veranderd. In september 2022 is er een nieuw station geplaatst waardoor deze tekortkoming is opgelost.

Net als de vorige beoordeling blijkt dat er te weinig meetlocaties te zijn om de concentraties ozon in 'voorstedelijke gebieden' voldoende te kunnen bepalen. Het RIVM adviseert het ministerie van Infrastructuur en Waterstaat (I&W) dit aantal uit te breiden.

Op sommige plekken schrijft de nationale wetgeving (Regeling Beoordeling Luchtkwaliteit, ofwel Rbl) voor om met meer meetpunten de luchtkwaliteit te meten dan de Europese wetgeving minimaal voorschrijft. Dit komt omdat luchtkwaliteitsmetingen niet alleen voor de Europese verplichtingen worden uitgevoerd, maar ook voor andere doelen. Bijvoorbeeld om modelberekeningen te kunnen controleren en de gemeten concentraties van bepaalde luchtverontreinigende stoffen over een langere periode te kunnen blijven volgen.

Het Landelijk meetnet Luchtkwaliteit (LML) voert de Europese en nationale meetverplichting uit. Deze wordt waar nodig aangevuld met meetpunten van de partnermeetnetten van de GGD Amsterdam en de DCMR Milieudienst Rijnmond.

Kernwoorden: beoordeling, luchtkwaliteit, Europese meetverplichting

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Summary

Air pollution has been Europe's most significant environmental health risk since the early 1970s. Poor air quality leads to premature deaths, is known for adverse health effects (World Health Organization, 2021), and damages ecosystems through excess nitrogen pollution (Sutton et al., 2015).

To counter these effects, the European Union (EU) has set itself the goal to achieve air quality levels that do not give rise to significant negative impacts on, and risks to human health and the environment. A series of European directives are used as a starting point to control and monitor the concentrations of air pollutants in the European Union. A minimum measurement effort in predefined air quality areas is required for Member States to use measurements of air pollutants to assess the trends in air quality according to the stipulations in these European air quality directives.

In this report, we determine the minimum measurement obligation for the Netherlands when measurements are the only source of information for assessing air quality. For this purpose, measurement data from 2015 – 2019 is used as well as the current European legislation. The results are compared with the previous assessment, based on data from 2009 – 2013 (Mooibroek et al., 2016).

In line with the previous assessment, additional sampling points operated by the Public Health Service of Amsterdam (GGD Amsterdam) and the DCMR Environmental Protection Agency (DCMR) are required to fulfil the minimum measurement effort in the agglomerations Amsterdam/Haarlem and Rotterdam/Dordrecht. At all zones and agglomerations, the minimum number of required sampling points has been met since September 2022 with the installation of a new sampling point in the agglomeration Den Haag/Leiden.

The comparison with the previous assessment also shows that particulate matter and nitrogen dioxide concentration levels continue to decline, leading to a lower mandatory minimum measurement effort in several agglomerations and zones for these pollutants. There is no change for the minimum sampling points for ozone, which already had been attributed to the highest regime and subsequent highest minimum measurement effort. For other pollutants, the previous assessment showed concentration levels below the lower assessment thresholds, and, as such, no minimum measurement effort is required for these pollutants, continuing based on results obtained during 2015 – 2019.

Despite the minimum number of sampling points being met, some agglomerations and zones lack the definition of suburban sampling points for ozone. As such, existing sampling points should be redefined, or additional sampling points should be installed at suburban locations in these areas.

1 Introduction

Air pollution is considered the most significant environmental health risk in Europe since the early 1970s. Poor air quality leads to premature deaths, is known for adverse health effects (World Health Organization, 2021), and damages ecosystems through excess nitrogen pollution (Sutton et al., 2015).

To counter these effects, the European Union (EU) has set itself the goal to achieve air quality levels that do not give rise to significant negative impacts on, and risks to, human health and the environment. As such, Member States are working closely to improve air quality using a series of EU Directives as the main starting point. These Directives, currently 2004/107/EC, 2008/50/EC, and 2015/1480/EC, provide the current framework to control and monitor the concentrations of air pollutants in the EU.

Using the size of populations and ecosystems exposed to air pollution, the territory of each member state is classified into zones or agglomerations. This classification uses common assessment criteria, reflecting the population density. Zones or agglomerations can be considered aggregated areas with comparable population density and air quality.

Member States can use measurement or modelling results, or a combination of both, to assess the effects of the air quality policies in the defined zones and agglomerations. In terms of the EU Directives, the Netherlands uses measurements as the sole source of information to assess the trends in air quality in each zone and agglomeration. Modelling results are also used, albeit currently in a supporting role.

According to the stipulations in the EU Directives for air quality, a minimum measurement effort in each zone and agglomeration is required for Member States to use measurements of air pollutants to assess the trends in air quality. Hence, these EU Directives contain specific regulations for determining the minimum number of fixed sampling points for each pollutant in each zone or agglomeration. The number of sampling points in these air quality areas is based on the measured (or modelled) concentrations of air pollutants within the specific area and the population density.

In this report, we determine the minimum measurement obligation for the Netherlands when measurements are the only source of information for assessing air quality. For this assessment, measurement results from 2015 – 2019¹ are used, combined with the population density and municipality boundaries established on 1 January 2020 (Centraal Bureau voor de Statistiek, 2023) as starting points.

¹ Due to the COVID-19 measures and the subsequent lockdown periods during 2020 – 2022, there have been decreases in concentration levels of air pollutants, especially in 2020 during the most stringent lockdown. The decrease observed in 2020 and those possibly present in 2021 and 2022, are considered temporary and not representative of the concentrations in "normal" conditions (Velders et al., 2020; Torkmahalleh et al., 2021). Hence, this assessment is performed on measurements conducted during 2015 – 2019, which are more representative of a "business-as-usual" scenario.

Under the EU Directives, the Netherlands is obliged to regularly, meaning at least once every five years, determine the minimum measurement obligation based on prevailing concentrations over five years. As such, this report is the follow-up report of the previously conducted assessment using the period 2009 – 2013 (Mooibroek et al., 2016). Due to the COVID-19 pandemic, the release of the current report has been delayed.

The EU air quality Directives are being revised, and draft versions have shown more stringent (lower) limit values, long-term objectives, and associated lower assessment thresholds. The exact impact of this revision on the minimum number of sampling points in each zone and agglomeration is unknown. However, it is expected that a new assessment based on lower assessment thresholds might lead to an increase in sampling points for some pollutants compared to the assessment reported in this study.

It should be noted that air quality measurements are used not only to fulfil the minimum measurement obligation laid out in the EU Directives, but also for other purposes. These other purposes are, for example, the comparison between measurement and modelling results and following the long-term trend in air pollutant concentrations. As such, more sampling points are required in the Dutch legislation (currently Regeling beoordeling luchtkwaliteit (Rbl)) than sampling points required to fulfil the EU obligation.

2 Provisions and assumptions

In this chapter, the provisions and assumptions needed to perform the air quality assessment are discussed in detail. The EU Directives contain multiple provisions that need to be met to use measurement data to assess air quality. Several of these provisions detail the placement and representativeness of the sampling points. Other provisions deal with the classification of zones and agglomerations in the Member States as areas within which the air quality needs to be assessed. The minimum number of sampling points in a zone or agglomeration is based on prevailing concentrations at appropriate sampling points and the number of residents in these areas over a five-year period.

First, we will discuss the default selection of sampling points from the available networks in the Netherlands. Then, we will look at the changes in zones and agglomerations due to the reorganization of administrative boundaries. In the last section, we will look at the changes in population density for each zone and agglomeration, not only based on the natural population growth but also on population changes due to changes in the administrative boundaries encompassing the air quality areas. In this report, we will also use modelling results for some pollutants to confirm the initial assessment which was solely based on measurements.

2.1 Sampling locations

Air quality measurements in the Netherlands are conducted by several authorities. These include the National Institute for Public Health and the Environment (hereon: RIVM), the Public Health Service of Amsterdam (hereon: GGD Amsterdam), and the DCMR Environmental Protection Agency (hereon: DCMR). While the RIVM operates the nationwide network, the GGD Amsterdam and the DCMR operate additional sampling points within the agglomeration Amsterdam/Haarlem and Rotterdam/Dordrecht, respectively. Within the National Air Quality Monitoring Network (NAQMN) operated by the RIVM, parts of these additional sampling point provisions have been considered during the network design as they are needed to comply with the minimum number of sampling points in these agglomerations. Sampling points operated by the GGD Amsterdam and DCMR are generally more focussed on assessing local air quality impacted by industrial activities. These sampling points might not adhere to all provisions outlined in the EU Directives and are therefore omitted from the assessment. Nevertheless, both these networks also operate sampling points that do adhere to the provisions laid out in the EU Directives, and these are included in the assessment.

In addition to the location and representativeness of sampling points, there are also provisions in the EU Directives that relate to the required measuring methods for each pollutant. In order to use measurement results to compare with limit values or to perform the assessment, these measurements should have been carried out using the reference method or an equivalent method. All measurements regarding compliance with the EU Directives conducted by the RIVM, the GGD Amsterdam and the

DCMR are performed with either the reference method or equivalent methods, depending on the pollutant.

To assess the air quality in the Netherlands, measurements of the NAQMN (RIVM) and partner monitoring networks operated by the DCMR and the GGD Amsterdam are used. The data from the partner monitoring networks are equivalent to the data obtained in the NAQMN and therefore comply with the provisions regarding the measurement methods used.

Simply erecting and operating a sampling point on a suitable location is insufficient to comply with the stipulations in the EU Directive. Compliance requires more effort, specifically regarding data availability at sampling points. The EU Directive 2008/50/EC states that at least 90% of the measurement data at a single sample point must be available to be able to check compliance using the defined limit and target values for each pollutant. With continuous measurements, the data capture is determined as 90% of the available data, excluding the loss of measurements due to calibrations and regular maintenance. It is difficult to estimate an exact amount of time for the additional data loss due to these circumstances. However, 5% additional data loss can be allocated by default for calibrations and regular maintenance. This additional data loss means that the availability for continuous measurements should be effectively set at 85% (EC, 2013). As laid out in the EU Directives, the minimum measurement effort should therefore be seen as the effort when all the required sampling points for the continuous measurements for each pollutant provide at least 85% of measurement data during a full calendar year.

Besides the monitoring networks operated by the DCMR and the GGD Amsterdam, other (regional) monitoring networks are active in the Netherlands. Equivalence with the measurements of the NAQMN has not yet been formally established for these monitoring networks. Therefore, data from these networks are not used for this European assessment of air quality in the Netherlands. Hence, the minimum required measurement effort will be compared with the current measurement effort of the networks operated by the RIVM, the GGD Amsterdam and the DCMR.

2.2 Changes in air quality zones and agglomerations

Since 2000, the Netherlands' territory has been divided into six agglomerations and three zones, following both the municipality and provincial boundaries (Van Breugel and Buijsman, 2000). More information about the initial classification can be found in a short overview in Annex I.

Over the years, the boundaries of the three zones and six agglomerations have changed due to municipal reorganisations. The number of municipalities has decreased from 537 in 2000 to 355 in 2020. The last formal change of the air quality areas, as laid out in the national legislation, took place on 21 November 2012 and was implemented on 1 January 2013. The effects of the municipal

reorganisations until 2012 were implemented in the new definitions of the air quality areas (Mooibroek et al., 2016).

After the latest boundary update of the air quality areas, the number of municipalities has decreased from 415 in 2012 (Centraal Bureau voor de Statistiek, 2012) to 355 in 2020 (Centraal Bureau voor de Statistiek, 2020) and has been decreasing further in subsequent years. Most reorganisations until 2020 did not affect the boundaries of the air quality areas, as most reorganisations occurred within an air quality area. Only reorganisations impacting municipalities across air quality areas will influence the boundaries.

These reorganisations occurred in 2015 and 2019, leading to changes in adjacent agglomerations and zones. These changes are:

- in 2015, the municipality Bernisse, initially located in zone Midden, merged with Spijkenisse, a municipality in the agglomeration Rotterdam/Dordrecht. Spijkenisse and Bernisse formed a new municipality named Nissewaard, effectively from 1 January 2015 (Centraal Bureau voor de Statistiek, 2012);
- in 2019, the municipalities Onderbanken and Schinnen, initially located in zone Zuid, merged with Nuth, a municipality in the agglomeration Heerlen/Kerkrade. The merging of these municipalities led to a new municipality named Beekdaelen, effective from 1 January 2019 (Centraal Bureau voor de Statistiek, 2019).

With these reorganisations, the boundaries for the affected zones and agglomerations need to be adjusted in the national legislation, and these changes should be reported to the EU. When reporting to the EU, the air quality areas with adjusted boundaries should be given a unique and new identifier, and it is suggested to change the name of the areas to reflect the changes.

In this report we have chosen to update the agglomeration Rotterdam/Dordrecht by including the newly formed municipality Nissewaard in 2015. This update adds the old municipality Bernisse to the agglomeration, increasing surface area and the number of residents. Similarly, we added the newly formed municipality Beekdaelen in 2019 to the agglomeration Heerlen/Kerkrade, which also lead to an increase in surface area and the number of residents.

It should be noted that both updates, while not official yet, are based on the notion that agglomerations are areas with a similar population density. Therefore, when newly formed municipalities overlap in both a zone and agglomeration, the easiest solution would be to place the whole municipality into the agglomeration. Adding the newly formed municipality to the zone would remove an area of similar population density from the agglomeration, and thus challenge one of the basic principles underlying the agglomeration definition.

All results presented in this report are based on merging the newly formed municipalities into their respective overlapping agglomerations and removal from their respective overlapping zones.

2.2.1 *Upcoming municipalities changes*

Annex II provides a detailed overview of upcoming changes to municipalities and their effect on the boundaries of air quality areas. Until 2023, there is only one change that affects an agglomeration, and this change is the addition of municipality Weesp to the municipality Amsterdam. To update the definition of the agglomeration Amsterdam/Haarlem, the municipality Weesp should be added and subsequently should be removed from zone Midden.

2.3 **Changes in population density**

Besides prevailing concentration levels of pollutants during a five-year period, the assessment also requires information about the population density as supplementary data. In this report we use the number of residents for each municipality as reported on 1 January 2020 (Centraal Bureau voor de Statistiek, 2020).

To determine the number of residents in each zone and agglomeration, we have used the adjusted boundaries as discussed in section 2.2 and calculated the total number of residents within each area. This number is important because based on the prevailing concentrations and the number of residents, the minimum number of sampling points needed in a zone or agglomeration can be determined (see also Annex V of EU Directive 2008/50/EC)

The newly formed boundaries led to a slight increase of residents in the agglomerations Rotterdam/Dordrecht and Heerlen/Kerkrade and a decrease in zones Midden and Zuid. Despite these changes, there has been an increase in the population density for the whole of the Netherlands compared to the latest assessment (Mooibroek et al., 2016). These combined changes have led to changes in the number of residents compared with the assessment from Mooibroek et al. (2016), as can be seen in Table 1.

Table 1 Comparison between the number of residents during the previous assessment (Mooibroek et al., 2016) and the current assessment.

Zone/Agglomeration	Residents 2014 (x 1000)	Residents 2020 (x 1000)	Difference 2020 – 2014 (x 1000)
Amsterdam/Haarlem	1661	1764	103
Utrecht	472	505	33
Den Haag/Leiden	1136	1205	69
Rotterdam/Dordrecht	1303	1362 *	59
Eindhoven	444	456	21
Kerkrade/Heerlen	230	247 *	17
Zone Noord	3258	3315	57
Zone Midden	5020	5193 *	173
Zone Zuid	3306	3341	46
Total sampling points	16830	17388	578

* The number of residents in these zone and agglomerations has also changed due to municipality reorganisations between 2014 – 2020.

Increasing the surface area and subsequent number of residents for the agglomerations Rotterdam/Dordrecht and Heerlen/Kerkrade does not increase the minimum number of sampling points based solely on the

number of residents in these agglomerations. It should be noted that for the agglomeration Utrecht, the number of residents has crossed the threshold of 500.000 residents. However, this does not lead to an increase in the minimum number of sampling locations.

As for the upcoming changes, only the agglomeration Amsterdam/Haarlem is expanded with the municipality Weesp. Based on the number of inhabitants on 1 January 2020, this would mean an addition of 19 738 inhabitants to the agglomeration, and a similar reduction in zone Midden. The addition to agglomeration Amsterdam/Haarlem does not increase the number of sampling points based on the number of inhabitants.

2.4 Comparison with upper and lower assessment thresholds

Upper and lower assessment thresholds are used to classify the pollutant level in each air quality area. These pollutant levels are divided in three different regimes (EU Directive 2008/50/EC; Mooibroek et al., 2016).

- **Regime 1:** the concentrations are above the upper assessment threshold. Measurements are always mandatory in this situation. In this case, if measurements are the only instrument to determine air quality, a minimum number of monitoring stations per zone or agglomeration is required. The minimum number is determined by the number of residents or, in the case of a limit value for the protection of ecosystems, the surface area.
- **Regime 2:** the concentrations are between the upper and lower assessment thresholds. Measurements should be used in this situation, if desired in combination with models.
- **Regime 3:** the concentration is below the lower assessment threshold. Measurements are not required under these circumstances. The air quality may be described with models or based on objective estimations.

Exceedances of upper or lower assessment thresholds are determined per zone/agglomeration and not per individual sampling point, as determined by Mooibroek et al. (2016). This approach means exceedances of a threshold at three different stations in three separate years are considered an exceedance of the assessment threshold within the air quality area.

2.5 Use of modelling results and indicative measurements

In addition to using measurements for assessing air quality in Member States, the EU Directive also offers the possibility to use modelling results or indicative measurements to determine the air quality in certain areas. However, these additional methods must provide sufficient data to assess the air quality. In addition, these methods must, among other things, meet the quality objectives stated in the EU Directive.

With the use of modelling results or indicative measurements for the air quality assessment, provided all the necessary conditions mentioned in the EU Directives are met, the total number of sampling points per zone/agglomeration can be reduced by a maximum of 50%. However,

this report only considers the minimum measurement obligations when measurements are the only source of information. Further research is still required to be able to make statements about the possible reduction of sampling locations when modelling results are used for the assessment of air quality, especially regarding the quality objectives associated with modelling results. This report uses modelling results from both Grootchalige Concentraties Nederland (GCN) and Nationale Samenwerkingsprogramma Luchtkwaliteit (NSL) to indicatively compare the assessment results, based on measured values for particulate matter (PM) and nitrogen dioxide (NO₂) concentrations. It should be noted that these modelling results are used without prior assessment regarding the quality objectives laid out in the EU Directive. Additionally, not all assessment thresholds can be assessed using modelling results, limiting their use to the assessment thresholds based on yearly averaged concentrations for NO₂, PM (PM_{2.5} and PM₁₀) and benzene.

2.5.1 *Modelling: Grootchalige Concentraties Nederland*

The model results from the GCN uses the results from a dispersion model (OPS) in combination with calibration using measurements to provide a large-scale picture of air quality in the Netherlands, both for years in the past and the future (Velders et al., 2015, 2016, 2017, 2018; Hoogerbrugge et al., 2019). Using this large-scale picture, the maximum yearly averaged concentrations of PM₁₀ and NO₂ can be derived for each grid cell in each zone and agglomeration. The maximum value for each zone and agglomeration is then compared with the assessment thresholds. Due to the large-scale approach, it should be noted that the maximum concentrations are not necessarily in areas suitable for the assessments for the protection of human health, vegetation, and ecosystems. As such, in some zones and agglomerations, the maximum yearly average might overestimate the concentrations impacting residents, vegetation, and ecosystems.

2.5.2 *Modelling: Nationale Samenwerkingsprogramma Luchtkwaliteit*

The high-resolution model results from the NSL can be used to mitigate the large-scale approach of the GCN (Zanten et al., 2015, 2016; Rutledge-Jonker et al., 2017, 2018; Smet et al., 2019). The NSL is a collaboration between the government, provinces, and municipalities to assess the effect of air quality plans to improve the air quality in the Netherlands. Using the results from exposure model calculations, the number of residents exposed to the upper and lower assessment thresholds for the annual averages of PM₁₀ and NO₂ can be estimated for each individual year in the period for each zone and agglomeration. However, no clear limit value is defined for the number of residents exposed to the upper and lower assessment thresholds. In this report, we use the most stringent limit value that can be derived, allowing no residents to be exposed to concentrations above the upper and lower threshold. Hence, a threshold is exceeded if one or more resident have been exposed to this threshold.

2.5.3 *Indicative measurements*

Since the latest assessment by Mooibroek et al. (2016), there has been a huge increase in citizen science, particularly in the availability of sensor data. Sensor measurements for PM_{2.5}, PM₁₀ and NO₂ are

routinely recorded at the data platform Samenmeten² and shows a larger spatial gradient in sampling locations compared to the official monitoring locations. However, the plausibility, comparability, and equivalence with the reference methods laid out in the EU Directive 2008/50/EC has not been fully established. This is primarily due to, for example, the representativeness of the measurements for a larger area and the large number of different sensors with associated uncertainties reporting results to the data platform. Also, sensor measurements are not guaranteed to adhere to the data coverage criterium. As such, sensor measurements are currently not fit to be used as indicative measurements for use in the assessment regarding the number of sampling locations in air quality areas.

Additionally, monthly concentrations of NO₂ are measured using Palmes tubes, predominantly within the agglomerations Rotterdam/Dordrecht and Amsterdam/Haarlem. Spatial coverage for the rest of the Netherlands is quite dispersed and sampling locations are not robust over the five-year period, as there are many short-term measurement campaigns reporting data. Also, the measurements are predominantly focused on locations directly impacted by sources and are mainly used to study the NO₂ contributions of these sources. As such, these measurements are also not considered as indicative measurements to be used in the assessment regarding the number of sampling locations in air quality areas.

2.6 Considerations for additional sampling points

In addition to the minimum measurement obligation, there are other considerations for performing air quality measurements at additional sampling points. An example of these considerations are the international agreements for measuring air quality in Member States. These agreements and additional considerations are laid down in international treaties such as the co-operative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe (EMEP), the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) and the Global Atmosphere Watch programme (GAW). Measurements in the context of these international treaties are carried out by various institutes in the Netherlands, including the Netherlands Organisation for Applied Scientific Research (TNO), the Royal Netherlands Meteorological Institute (KNMI) and RIVM. Within the NAQMN of the RIVM, both the obligations under the European guidelines and, partly, the obligations under the international treaties are fulfilled. Where possible, the measurements in the context of the European obligation are reused for the international treaties. As a result, participation in these conventions does not automatically mean an increase in the required number of sampling points. Unlike the measurement obligation established by the EU Directives, the obligations arising from the international treaties are currently not implemented in the national legislation.

Besides the participation in international conventions, another consideration for additional sampling points is the use of measurements to calibrate the results of dispersion models (GCN). Additionally,

² For more information see <https://samenmeten.rivm.nl/dataportaal/>

comparative measurements between networks are also carried out in collaboration with various partner monitoring networks at combined sampling points to ensure the comparability of measurements. In the past, RIVM has drawn up several measurement strategies that consider both the minimum obligation and additional considerations (Mooibroek et al., 2016).

This report focusses solely on the required number of sampling points based on the requirements in the EU Directives. As such, other sampling points which are needed to adhere to the participation in international conventions or are needed for the comparison/calibration with dispersion modelling are outside the scope of this report.

However, special attention should be paid to the use of air quality monitoring data for other purposes than adhering to the minimum measurement obligation as laid out by the EU. Declining pollutant concentrations in ambient air and the subsequent decrease in measurement obligations, as well as budget cuts, has led to a decrease in the number of sampling locations for most of the required pollutants in the Netherlands, up to the point of adhering to the bare minimum required for the European obligations. The impact of the reduction in sampling locations on the use of air quality monitoring data for other purposes has not yet been fully established. It should be part of additional research in the near future.

3 Minimum measurement obligation based on the EU Directives

3.1 Particulate matter

The EU Directive 2008/50/EC contains a combined measurement obligation for both PM_{2.5} and PM₁₀. There are three assessment thresholds defined for PM. One threshold for the number of days on which the daily average PM₁₀ concentration may exceed a certain limit value and two thresholds based on the annual average for both PM_{2.5} and PM₁₀.

The most stringent outcome of these three assessments is ultimately responsible for the regime classification in each zone/agglomeration in the Netherlands. More details for the regime classification for each assessment threshold is given in annex III. The upper assessment threshold for the daily averaged concentration is the leading driver for the regime classification of PM. This threshold is still exceeded in several zones and agglomeration, leading to the highest assessment regime. The annual averages for both PM_{2.5} and PM₁₀ are generally between the upper and lower thresholds and PM_{2.5} is in most cases even below the lower assessment threshold.

Table 2 gives an overview of the assessment regime from 2009-2013 (Mooibroek et al., 2016) as well as the current assessment regime. Concentrations of PM have decreased further in recent years, leading to a less stringent regime for the agglomerations Utrecht, Eindhoven, and Heerlen/Kerkrade when observing the measured concentrations. Compared to the previous assessment (Mooibroek et al., 2016), this shift leads to a decrease in the minimum sampling points for these agglomerations. In total, the minimum number of sampling points have decreased from 60 to 57.

Table 2 Overview of the assessment regimes from Mooibroek et al. (2016), the current study, and the minimum number of sampling points based on the current assessment for particulate matter (PM_{2.5} and PM₁₀).

Zone/Agglomeration	Assessment regime 2009-2013 *	Assessment regime 2015-2019	Minimum sampling points EU
Amsterdam/Haarlem	1	1	7
Utrecht	1	2	2
Den Haag/Leiden	1	1	6
Rotterdam/Dordrecht	1	1	6
Eindhoven	1	2	2
Kerkrade/Heerlen	1	2	1
Zone Noord	1	1	10
Zone Midden	1	1	13
Zone Zuid	1	1	10
Total sampling points			57

* Assessment regimes determined based on Mooibroek et al. (2016).

3.1.1 *Assessment regimes based on modelling results*

Based on the maximum annual concentrations of both PM_{2.5} and PM₁₀ for each zone and agglomeration derived from the GCN results during 2015-2019, no changes for the classified assessment regime are needed. This means that for this assessment, no additional information is obtained from the PM GCN maps from 2015-2019.

The exposure calculations from the NSL for PM₁₀ show that during all five years, residents in all agglomerations and zones have been exposed to concentrations above the lower assessment threshold. Exposure to concentrations above the upper assessment threshold for at least three years only occur in the agglomeration Amsterdam/Haarlem and the zones Midden and Zuid. Based on the measurements, these areas are already classified within the highest regime, so the exposure calculations for PM₁₀ in the NSL do not result in an additional intensification of the regime.

3.1.2 *Additional requirements for PM sampling points*

The minimum sampling points, outlined in table 2, are for the combined measurements of PM_{2.5} and PM₁₀, meaning that one sampling point measuring both PM₁₀ and PM_{2.5} are actually two sampling points. The EU Directive 2008/50/EC provides additional requirements regarding the ratio between the two fractions and requirements for additional PM_{2.5} sampling points in urban areas. In short, these additional requirements are:

- each zone and agglomeration should contain at least one urban background sampling location and one traffic-oriented sampling location, provided this does not increase the number of sampling points (2008/50/EC, Note 1 of Annex V, Section A);
- the total number of urban-background stations and the total number of traffic-oriented stations in a Member State required shall not differ by more than a factor of 2 (2008/50/EC, Note 1 of Annex V, Section A);
- the ratio between the total number of sampling points of PM_{2.5} and PM₁₀ established in a Member State should not differ by more than a factor of 2 (2008/50/EC, Note 2 of Annex V, Section A);
- to assess compliance with the PM_{2.5} exposure reduction target for the protection of human health, one sampling point per million inhabitants summed over agglomerations and additional urban areas in excess of 100 000 inhabitants should be added. These sampling points, located in urban areas, may coincide with the aforementioned sampling points. (2008/50/EC, Annex V, Section B);
- for PM_{2.5}, the chemical composition must be determined in PM_{2.5} at least one sampling location located in a rural environment, which should contain measurements of at least the following components: SO₄²⁻, NO₃⁻, Na⁺, K⁺, NH₄⁺, Cl⁻, CA²⁺, Mg²⁺, EC, OC (2008/50/EC, Annex IV, Part B).

In order to process these requirements, we need to look at the distribution of sampling points in each zone and agglomeration using the networks of the RIVM, the GGD Amsterdam and the DCMR. Table 3 gives an overview of the number of combined sampling points in each

zone/agglomeration, based on the available measurements from these networks.

Table 3 Overview of the number of sampling points required based on this assessment (S. points EU) and the number of operational sampling points per monitoring network (RIVM, GGD Amsterdam and DCMR) for particulate matter (PM; sum PM2.5 and PM10).

Zone/Agglomeration	Number of sampling points in 2019 *			
	S. points EU	RIVM	GGD A'dam	DCMR
Amsterdam/Haarlem	7	1	12	-
Utrecht	2	4	-	-
Den Haag/Leiden	6	4 ^a	-	-
Rotterdam/Dordrecht	6	5	-	15
Eindhoven	2	4	-	-
Kerkrade/Heerlen	1	5	-	-
Zone Noord	10	11	-	-
Zone Midden	13	16	2	1
Zone Zuid	10	11	-	-
Total sampling points	57	61	14	16

* Total number of suitable sampling points for each monitoring network are given.

^a Since September 2022, measurements of both PM2.5 and PM10 have been started at a sampling location in this agglomeration, pushing the number of sampling points from the RIVM to 6 and therefore adhering to the minimum number of sampling locations for PM. Note that the total number of sampling points has not been updated in this table to reflect this change.

From table 3 we can derive that in 2019, the RIVM did not operate enough sampling points in the agglomerations Amsterdam/Haarlem, Den Haag/Leiden and Rotterdam/Dordrecht. To fulfil the minimum sampling points in the agglomerations Amsterdam/Haarlem and Rotterdam/Dordrecht, additional sampling points operated by the GGD Amsterdam and the DCMR, respectively, are required. As for the agglomeration Den Haag/Leiden, the RIVM needs to operate two additional sampling points, i.e. two PM10 measurements or two PM2.5 measurements or one of each, to comply with the minimum number of sampling points for PM. In September 2022, a new sampling location in Den Haag (NL10450; traffic-oriented) has become operational, measuring both PM10 and PM2.5. Therefore, the minimum number of sampling points in this agglomeration has been obtained.

The EU Directive has provisions for the ratio between PM10 and PM2.5 sampling points for the Member States. Thus, to determine the type of sampling points (PM2.5 or PM10), we need to add sampling points from the GGD Amsterdam and DCMR in their respective agglomerations to comply with the minimum number of sampling points, we first need to establish the distribution of PM2.5 and PM10 sampling points operated by the RIVM. In 2019, PM2.5 was measured at 23 sampling locations, and for PM10, 38 sampling locations were used³. The ratio between PM10 and PM2.5 is therefore approximately 1.7, which is comparable to the ratio found in the previous assessment (Mooibroek et al., 2016). This ratio also shows that PM10 measurements are currently still the

³ In this study the PM results from NL10448 (agglomeration Rotterdam/Dordrecht) and NL10543 (agglomeration Amsterdam/Haarlem), as operated by the RIVM, are only used to compare against measurements from respectively the DCMR and GGD Amsterdam at these locations.

dominant PM fraction measured in the Netherlands. This dominance can be explained by the assessment of the three PM thresholds, in which the daily PM₁₀ concentration is the reason most zones and agglomerations are still classified in the most stringent assessment regime. Hence, monitoring of PM₁₀ concentrations is still considered to be important, despite their declining trend over the last decades.

The sum of all sampling points operated by the RIVM in 2019 is 61 PM sampling points (starting from 2023: 63 PM sampling points). This number, without the addition of sampling points from the GGD Amsterdam and the DCMR, exceeds the minimum number of sampling points in the Netherlands. However, as we established earlier, we cannot comply with the minimum number of sampling points in the agglomerations Amsterdam/Haarlem and Rotterdam/Dordrecht. For compliance in these agglomerations, we need to add sampling points from the GGD Amsterdam and the DCMR. Again, we would like to point out that initially there were not enough sample points in the agglomeration Den Haag/Leiden either, but this has been solved for 2023 and forwards with the addition of PM_{2.5} and PM₁₀ measurements at a sample point in this area in September 2022.

In the agglomeration Amsterdam/Haarlem, only one sampling point is operated by the RIVM, which measures PM₁₀. To comply with the minimum number of sampling points in this agglomeration, a total of six sampling⁴ points from the GGD Amsterdam are required. Similarly, in the agglomeration Rotterdam/Dordrecht, one additional sampling point operated by the DCMR is required to comply with the minimum number of sampling points. In total, we need seven additional sampling points.

In terms of the ratio between PM_{2.5} and PM₁₀, these seven PM sampling points can be measuring PM_{2.5} only, or a combination of PM_{2.5} and PM₁₀. In all these situations, the ratio between PM_{2.5} and PM₁₀ across the Netherlands will not exceed a factor 2. This is not the case when seven sampling points measuring only PM₁₀ are added, as this will lead to a ratio larger than a factor 2. Therefore, not all seven measurements can consist of only PM₁₀ measurements.

An additional requirement for PM is that the total number of urban background sampling points and the total number of traffic-oriented sampling points for PM cannot differ by more than a factor two. Within the RIVM network, the ratio between urban background and traffic-oriented sampling points for PM combined is 17:20 (in 2023 16:20), meaning that the additional seven sites can be located at urban background, could be traffic oriented, or both. In all three cases, the ratio between urban background and traffic oriented will not exceed a factor 2.

As for the latest requirement, all zones and agglomerations should at least have one urban background and one traffic-oriented sampling point. This means that only in the agglomeration Amsterdam/Haarlem, at least one of the additional sampling points must be situated in an

⁴ Note that in Mooibroek et al. (2016) this number was 5. This lower number is probably caused by the addition of the sampling station NL10543 in 2016, which is used in conjunction with the GGD Amsterdam to compare PM measurements between networks and is therefore omitted in this study.

urban background area. For all other zones and agglomerations, this requirement can be fulfilled using sampling points from the RIVM.

As far as the number of PM sampling points, the additional requirements mentioned above leads to the following list of required additions in order to comply with the minimum number of PM sampling points in these agglomerations.

- **Den Haag/Leiden:** has been fixed with the addition of a PM2.5 and PM10 sampling point at a traffic-oriented location since September 2022.
- **Rotterdam/Dordrecht:** one sampling point (preferably PM2.5, but can be PM10) at rural background, urban background or traffic-oriented location should be used from the DCMR.
- **Amsterdam/Haarlem:** six sampling points (preferably PM2.5, but some can be PM10), with one required at urban background, and five at rural background, urban background or traffic-oriented location, should be used from the GGD Amsterdam.

Based on the sum of residents in agglomerations and additional urban areas, a total of nine PM2.5 sampling points should be in urban areas (Annex IV). The previous assessment required eight PM2.5 sampling points in urban areas, leading to an increase of one additional sampling point (Mooibroek et al., 2016). With the required urban background sampling point in the agglomeration Amsterdam/Haarlem, the total number of urban background sampling points in the Netherlands is ten. This means that the requirement of at least nine urban background sampling locations for PM2.5 is fulfilled.

3.1.3 *Chemical composition of PM2.5*

For all required components, the chemical composition of PM2.5 is measured at one rural background station (NL10644) in the Netherlands. These measurements are in compliance with EU Directive 2008/50/EC, Annex IV.

3.1.4 *Conclusion for PM*

The Netherlands complies to a large extent with the minimum number of sampling points required in each agglomeration or zone as well as to the additional requirements (i.e. ratio PM2.5/PM10, sampling locations and additional composition measurements). For the agglomerations Rotterdam/Dordrecht and Amsterdam/Haarlem, measurements at sampling points operated by the DCMR and GGD Amsterdam are required to meet the minimum number of sampling points in these areas. From the DCMR, any sampling point (either PM2.5 or PM10) at a rural background, urban background, or traffic-oriented location can be used. For the use of the sampling points from the GGD Amsterdam some restrictions apply, as preferably PM2.5 sampling points should be used, and one of the six sampling points should be located in an urban background area.

3.2 **Nitrogen dioxide and nitrogen oxides**

In this section, the measurement obligations for both nitrogen dioxide (NO₂) and nitrogen oxides (NO_x) are combined into a single overview.

For nitrogen dioxide there is one assessment threshold which is based on the annual average and relates to the protection of vegetation and natural ecosystems. In the Netherlands, this assessment threshold can only be applied to one sampling point (NL10934 – Kollumerwaard) due to the additional requirements. The sampling point at Kollumerwaard is the only sampling point representative of a sufficiently large area to meet additional requirements for the assessment of the protection of vegetation and ecosystems. The annual average concentrations of nitrogen oxide at Kollumerwaard are below the lower assessment threshold for nitrogen oxide for all the five years, indicating no requirements for measurements for the protection of vegetation and natural ecosystems. As such, the focus in this section is mainly on nitrogen dioxide.

In the EU Directive 2008/50/EC, there are two different assessment thresholds defined for nitrogen dioxide. These are based on the annual average and the number of hourly concentrations above $140 \mu\text{g}/\text{m}^3$. Both assessment thresholds are related to the protection of human health. The most stringent outcome of the assessments for nitrogen dioxide and nitrogen oxide is ultimately responsible for the regime classification in each zone/agglomeration in the Netherlands. More details for the regime classification for each assessment threshold is given in annex III.

The hourly limit value of nitrogen dioxide for the protection of human health is below the upper assessment threshold in all zones and agglomerations. In some areas, the measurement values are even below the lower assessment threshold for the hourly limit value. For nitrogen dioxide the annual average has the largest impact on the assessment regime, as the upper assessment threshold is exceeded in 5 of the 9 defined zones and agglomerations. Of the remaining four areas, the measurements of all but one area are between the upper and lower assessment thresholds. As can be seen in table 4, only the measurements in zone Noord are below the lower assessment threshold, meaning that for zone Noord there is no obligation to measure the NO_2 concentrations.

Table 4 Overview of the assessment regimes from Mooibroek et al. (2016), the current study and the minimum number of sampling points based on the current assessment for nitrogen dioxide.

Zone/Agglomeration	Assessment regime 2009-2013 *	Assessment regime 2015-2019	Minimum sampling points EU
Amsterdam/Haarlem	1	1	5
Utrecht	1	2	1
Den Haag/Leiden	1	1	4
Rotterdam/Dordrecht	1	1	4
Eindhoven	1	2	1
Kerkrade/Heerlen	1	2	1
Zone Noord	1	3	-
Zone Midden	1	1	9
Zone Zuid	1	1	7
Total sampling points			32

* Assessment regimes determined based on Mooibroek et al. (2016).

When comparing the previous assessment period (Mooibroek et al., 2016) with the current period, we see that the concentration levels of NO₂ continue to decrease, leading to lower regime levels and therefore also a decrease in the number of required sampling points.

3.2.1 *Assessment regimes based on modelling results*

Sampling points ideally should be situated in areas with the highest concentrations related to the protection of human health or vegetation and ecosystems. However, not all these locations are suitable for the placement of a sampling point, for example due to restrictions laid out by local authorities. Therefore, it is possible that within zones and agglomerations the assessment thresholds are exceeded in other locations than the sampling points.

Mooibroek et al. (2016) found the nitrogen dioxide concentrations at sampling points in zone Noord in the period 2009-2013 were no longer above the upper assessment threshold. However, based on modelling results, exceedances of the upper assessment threshold were still found. This led to the classification of the highest regime level for zone Noord in the previous assessment.

A review of the modelling results for both GCN and NSL for the 2015-2019 period led to a different regime assessment, not only for zone Noord but some agglomerations as well. As with PM, we are looking at the maximum annual averages from a grid cell located in the zone or agglomeration for each year. For zone Noord, this means that two of the five years have maximum values above the lower assessment level (i.e., 2015 and 2016), one year is below this level (2019) and for two other years, these values are on the lower assessment threshold after rounding to whole numbers (i.e. 2017 and 2018 are rounded to 26). Purely based on mathematical comparisons, the lower assessment threshold is only exceeded for two years in the five-year period and as such, the lowest assessment regime applies. However, since the modelling results clearly show that for two additional years the maximum value in zone Noord is on or around the lower assessment threshold, we suggest putting zone Noord in regime 2 based on GCN modelling results. In the previous assessment (Mooibroek et al., 2016), zone Noord was maintained in regime 1, although it was noted that the trend in measurements suggested that zone Noord might have to be put into regime 2 soon. While the result from this assessment suggests regime 3, we strongly advise to put zone Noord in regime 2 until a new assessment is performed.

Based on the measurements, agglomerations Utrecht and Eindhoven are put in regime 2, whereas the GCN results show exceedances of the upper assessment thresholds in all five years. Therefore, we advise to keep both agglomerations in regime 1 until a new assessment is performed.

An interesting feature that can be observed from this exercise is that the maximum annual averages in agglomeration Heerlen/Kerkrade, which are based on GCN, are well below the lower assessment threshold. However, actual measurements in this agglomeration are above this threshold in four of the five years during 2015 - 2019. Therefore, based

on the modelled concentrations, there is no measurement obligation in the agglomeration Heerlen/Kerkrade, whereas the measurement results indicate a regime 2 classification for this agglomeration. Based on these results, we advise to put this agglomeration in regime 2.

When looking at the results of the NSL exposure calculations over the five-year period, all zones and agglomerations, except agglomeration Heerlen/Kerkrade, show residents being exposed to annual average NO₂ concentrations above the upper assessment threshold. It should be noted that for the agglomeration Heerlen/Kerkrade, four out of the five years are above this threshold. In this assessment, we don't allow residents to be exposed to concentrations above the upper threshold. For the agglomerations of Eindhoven, Heerlen/Kerkrade and Utrecht, and zone Noord, this would mean that, based on the exposure calculations in the NSL, these areas should all remain classified as regime 1. However, the number of residents exposed to NO₂ concentrations above the upper assessment threshold continuously declines every year, with zone Noord and agglomeration Heerlen/Kerkrade showing an exposure of less than 50 residents for the five-year period. The number of exposed residents in the agglomerations Eindhoven and Utrecht to concentrations above the upper assessment level, while still being on the decline, is approximately a factor 10 higher. These outcomes suggest that agglomerations Utrecht and Eindhoven should remain in the most stringent regime, whereas zone Noord and agglomeration Heerlen/Kerkrade might be put in regime 2 instead.

Overall, the outcome from the GCN and NSL modelling results agree and suggest putting zone Noord and agglomeration Heerlen/Kerkrade into regime 2, while maintaining the stringent regime for agglomerations Utrecht and Eindhoven, despite measurement concentrations being between the lower and upper assessment threshold.

Table 5 Overview of the assessment regime for nitrogen dioxide based on measurements (Meas.) and the maximum modelled values for the 2015 – 2019 based on GCN and NSL calculations.

Zone/Agglomeration	Assessment regime based on		
	Meas.	GCN	NSL
Amsterdam/Haarlem	1	1	1
Utrecht	2	1	1
Den Haag/Leiden	1	1	1
Rotterdam/Dordrecht	1	1	1
Eindhoven	2	1	1
Kerkrade/Heerlen	2	3	2
Zone Noord	3	2	2
Zone Midden	1	1	1
Zone Zuid	1	1	1

The information shown in table 5 is used to determine the final assessment regimes for each zone and agglomeration. For each area, the most stringent regime, ranging from 1 to 3, is kept and used as the final regime as shown in table 6.

Table 6 Overview of the proposed assessment regime for nitrogen dioxide (NO₂) based on measurement and modelling results and the minimum number of sampling points needed.

Zone/Agglomeration	Assessment regime 2015-2019 incl. modelling	Minimum sampling points EU
Amsterdam/Haarlem	1	5
Utrecht	1	2
Den Haag/Leiden	1	4
Rotterdam/Dordrecht	1	4
Eindhoven	1	2
Kerkrade/Heerlen	2	1
Zone Noord	2	3
Zone Midden	1	9
Zone Zuid	1	7
Total sampling points		37

When comparing the assessment in this study against the previous assessment (Mooibroek et al., 2016), the minimum requirement of nitrogen dioxide sampling points can be decreased with 4 sampling stations (zone Noord) to 37 sampling stations. However, we still must consider the additional requirements and the link with ozone. These factors are discussed in the following sections.

3.2.2

Additional requirements for NO₂ sampling points

The European directive refers to a link between the minimum number of sampling points for ozone and sampling points for nitrogen dioxide. This link is further discussed in the assessment of the ozone concentrations, but a short overview will be given in this section.

The EU Directive 2008/50/EC includes an additional requirement that at least one sampling point for urban background levels and one traffic-oriented station must be set up per zone/agglomeration, provided this does not increase the total number of sampling points.

Based on the number of residents and the measured concentrations, there is a minimum measurement obligation of one sampling point in agglomeration Kerkrade/Heerlen. In order to be able to meet the requirement of having one sampling location for urban background levels and one traffic-oriented sampling point in each agglomeration, an additional sampling location must be added. As mentioned earlier, the total number of sampling points in a zone or agglomeration should not increase due to this requirement. As such, no additional sampling point in the agglomeration Kerkrade/Heerlen is needed and the one sampling point in this agglomeration can be either situated in an urban background or traffic-oriented location.

As for the sampling points in other zones and agglomerations, at least one sample point at an urban background location and one sample point at a traffic-oriented location should exist.

3.2.2.1 Linked with ozone

Sampling points for nitrogen dioxide are in the EU Directive 2008/50/EC linked with sampling points for ozone. Member States are required to measure nitrogen dioxide at a minimum of 50% of the required ozone sampling points. Hence, the minimum requirements for the number of nitrogen dioxide in a zone or agglomeration is not only dependent on the concentration levels of nitrogen dioxide, but also on the number of ozone sampling points.

Table 7 gives an overview on how many of the nitrogen dioxide sampling points measurements of ozone are required. Hence, the number of sampling points required in the EU, as shown in table 7, should be read as: *for the agglomeration Amsterdam/Haarlem, a minimum of five sampling points of nitrogen dioxide is needed, on which on three sampling points measurements of ozone should also be performed.*

Table 7 Overview of the number of sampling points required based on this assessment for nitrogen dioxide (NO₂).

(S. points EU; the number in brackets denote the number of sampling points that should include ozone measurements) including additional requirements and the number of operational sampling points per monitoring network (RIVM, GGD Amsterdam and DCMR)

Zone/Agglomeration	Number of sampling points in 2019 *			
	S. points EU	RIVM	GGD A'dam	DCMR
Amsterdam/Haarlem	5 (2)	1	15	-
Utrecht	2 (1)	3	-	-
Den Haag/Leiden	4 (2)	3 ^a	-	-
Rotterdam/Dordrecht	4 (2)	3	-	9
Eindhoven	2 (1)	3	-	-
Kerkrade/Heerlen	1 (1)	3	-	-
Zone Noord	3 (3)	8	-	-
Zone Midden	9 (3)	10	-	1
Zone Zuid	7 (3)	9	-	-
Total sampling points	37	43	15	10

* Total number of suitable sampling points for each monitoring network are given.

^a Since September 2022, measurements of NO, NO₂ and NO_x have been started at a sampling location in this agglomeration, pushing the number of sampling points from the RIVM to four and therefore adhering to the minimum number of sampling locations for NO₂. Note that the total number of sampling points has not been updated in this table to reflect this change.

Although the assessment using data from 2015 – 2019 shows that the number of sampling points in the agglomeration Den Haag/Leiden does not fulfil the minimum obligated number of sampling points, it should be noted that starting from September 2022, a sampling point in this agglomeration measuring NO, NO₂ and NO_x is operational. As such, this deficiency has been resolved.

For the agglomerations Amsterdam/Haarlem, four sampling points from the GGD Amsterdam need to be used to comply with the minimum number of sampling points. Since the RIVM sampling point is a traffic-oriented site, at least one of the four sampling points from the GGD Amsterdam should be situated at an urban background location.

Additionally, ozone must also be measured at one of the sampling points from the GGD Amsterdam.

Only one additional sampling point is needed from the DCMR in the agglomeration Rotterdam/Dordrecht, without additional requirements regarding location and ozone measurements. These requirements are covered by the sampling points operated by the RIVM in this agglomeration.

3.2.3 *Conclusion for NO₂ and NO_x*

As of September 2022, the Netherlands complies to a large extent to the minimum number of sampling points required in each agglomeration or zone, and to the additional requirements for nitrogen dioxide.

For the agglomerations Rotterdam/Dordrecht and Amsterdam/Haarlem, measurements at sampling points operated by respectively the DCMR and GGD Amsterdam are required to meet the minimum number of required sampling points in these areas. From the DCMR, any of the available non-industrial sampling points can be used. For the use of the sampling points from the GGD Amsterdam, some restrictions apply, as one of the four sampling points should be located in an urban background area. Additionally, one of the four sampling points should have ozone measurements.

3.3 **Ozone**

Compared to other pollutants discussed in the EU Directives 2004/107/EC and 2008/50/EC, ozone does not have assessment thresholds defined but instead uses long-term objectives. The difference between assessment thresholds and long-term objectives is that thresholds can be exceeded in three of the five years. However, long-term objectives must be met on all years in the defined period.

Suppose the long-term objectives have not yet been achieved in a zone or agglomeration in the past five years. In that case, Member States can determine the minimum number of ozone stations based on the population density.

There are two long-term objectives for ozone. The first objective is related to protecting human health. It uses the maximum daily eight-hour mean within a calendar year. The second objective is to protect vegetation, using the AOT40 for May to June in a calendar year.

During 2015 – 2019, the long-term ozone objective for the protection of human health is exceeded in all five years in all zones and agglomerations. This is also the case for the long-term objective for the protection of vegetation in most zones and agglomerations. Only in the agglomerations Amsterdam/Haarlem and Utrecht, this objective is exceeded on four of the five years. This outcome puts ozone in the most stringent regime, leading to the minimum number of sampling points outlined in table 8.

Table 8 Overview of the exceedances of the long-term objectives from Mooibroek et al. (2016), the current study and the minimum number of 6 sampling points based on the current assessment for ozone.

Zone/Agglomeration	Above LTO 2009-2013 *	Above LTO 2015-2019	Minimum sampling points EU
Amsterdam/Haarlem	+	+	3
Utrecht	+	+	2
Den Haag/Leiden	+	+	3
Rotterdam/Dordrecht	+	+	3
Eindhoven	+	+	1
Kerkrade/Heerlen	+	+	1
Zone Noord	+	+	6
Zone Midden	+	+	6
Zone Zuid	+	+	6
Total sampling points			31

* Assessment regimes determined based on Mooibroek et al. (2016).

Compared with the previous assessment by Mooibroek et al. (2016), the minimum number of sampling points has increased by one. Due to a population increase in the agglomeration Utrecht, the number of residents has crossed a threshold which leads to the addition of one sampling point for ozone.

For the agglomeration Heerlen/Kerkrade, the number of residents is below the threshold for requiring a minimum number of sampling points for ozone. However, since measurements are the only source of information, at least one sampling point should be present by default.

3.3.1

Additional requirements for ozone sampling points

In the EU Directive 2008/50/EC, ozone has some additional provisions. For example, the Directive prescribes that Member States must set up at least one station in all zones or agglomerations, where the highest population exposure occurs. In addition, in all agglomerations, at least 50% of the stations must be in a suburban area. Also, Member States must measure nitrogen dioxide at a minimum of 50% of the required ozone sampling points.

Table 9 Minimum number of sampling point for ozone measurements, including additional provisions regarding the number of sampling points in a suburban area and the number of sampling points with combined measurements for nitrogen dioxide.

Zone/Agglomeration	Number of sampling points		
	S. points EU	Suburban	Nitrogen dioxide
Amsterdam/Haarlem	3	2	2
Utrecht	2	1	1
Den Haag/Leiden	3	2	2
Rotterdam/Dordrecht	3	2	2
Eindhoven	1	1	1
Kerkrade/Heerlen	1	1	1
Zone Noord	6	1	3
Zone Midden	6	1	3
Zone Zuid	6	1	3
Total sampling points	31	12	18

In table 9, an overview of the additional requirements is presented, with respect to the number of suburban locations and combined measurements of nitrogen dioxide. This table should be read as follows: "in the agglomeration Amsterdam/Haarlem, a minimum of three sampling points for ozone are required. Of these sampling points, two should be in a suburban area and two should have combined measurements with nitrogen dioxide".

As can be seen from table 10, in the agglomeration Amsterdam/Haarlem we would need to use two ozone sampling points from the GGD Amsterdam, for which at least one sampling point also measures nitrogen dioxide (see also section 3.2.3).

Table 10 Overview of the number of sampling points required based on this assessment (S. points EU) and the number of operational sampling points per monitoring network (RIVM, GGD Amsterdam and DCMR for ozone (O₃))

Zone/Agglomeration	Number of sampling points *			
	S. points EU	RIVM	GGD A'dam	DCMR
Amsterdam/Haarlem	3	1	3	-
Utrecht	2	3	-	-
Den Haag/Leiden	3	2 ^a	-	-
Rotterdam/Dordrecht	3	3	-	5
Eindhoven	1	2	-	-
Kerkrade/Heerlen	1	2	-	-
Zone Noord	6	7	-	-
Zone Midden	6	9	-	-
Zone Zuid	6	7	-	-
Total sampling points	31	36	3	5

* Total number of suitable sampling points for each monitoring network are given.

^a Since September 2022 measurements of O₃ have been started at a sampling location in this agglomeration, pushing the number of sampling points from the RIVM to 4 and therefore adhering to the minimum number of sampling locations for NO₂. Note that the total number of sampling points has not been updated in this table to reflect this change.

3.3.1.1 Number of suburban locations

As of January 2013, the ozone sampling points shown in table 11 have been defined as suburban locations in the Netherlands.

Table 11 Ozone sampling points at suburban locations in the Netherlands

Zone/Agglomerations	Suburban locations
Amsterdam/Haarlem	NL49003 Amsterdam-Nieuwendammerdijk NL49701 Zaandam-Wagenschootpad
Utrecht	NL10643 Utrecht-Griftpark
Den Haag/Leiden	NL10446 Den Haag-Bleriotlaan
Rotterdam/Dordrecht	NL10442 Dordrecht-Bamendaweg
Eindhoven	NL10247 Veldhoven-Europalaan
Kerkrade/Heerlen	NL10133 Wijnandsrade-Opfergeltstraat
Zone Noord	NL10938 Groningen-Nijensteinheerd
Zone Midden	
Zone Zuid	NL10241 Breda-Bastenakenstraat

Two sampling points operated by the GGD Amsterdam are appointed as suburban locations in the agglomeration Amsterdam/Haarlem. Additionally, there are no suburban locations for ozone sampling points defined in zone Midden.

When we compare the defined locations against the minimum required suburban locations for ozone sampling points in the zones and agglomerations in the Netherlands, we see in table 12 that based on current legislation three additional locations need to be appointed or set up. These locations are situated in the agglomerations Den Haag/Leiden (1), Rotterdam/Dordrecht (1), and Zone Midden (1).

Table 12 Overview of suburban locations for ozone measurements in the Netherlands

Zone/Agglomerations	Suburban locations	
	2008/50/EG	LML 2019
Amsterdam/Haarlem	2	2
Utrecht	1	1
Den Haag/Leiden	2	1
Rotterdam/Dordrecht	2	1
Eindhoven	1	1
Kerkrade/Heerlen	1	1
Zone Noord	1	1
Zone Midden	1	-
Zone Zuid	1	1
Total	12	9

In the agglomeration Rotterdam/Dordrecht, sampling points from the DCMR might be used to appoint an additional sampling point at a suburban location. In this case, this sampling point from the DCMR should be added as an official EU-reporting station. This will also add to the dependency of measurements from the DCMR in this agglomeration.

One additional ozone sampling point should be appointed or set up at a suburban location in zone Midden.

3.3.1.2 Combination ozone and nitrogen dioxide

Table 13 Overview of sampling points measuring both ozone (O₃) and nitrogen dioxide (NO₂)

Zone/Agglomerations	Ozone sampling points with nitrogen dioxide	
	2008/50/EG	RIVM 2019
Amsterdam/Haarlem	2	1
Utrecht	1	3
Den Haag/Leiden	2	2
Rotterdam/Dordrecht	2	3
Eindhoven	1	2
Kerkrade/Heerlen	1	2
Zone Noord	3	7
Zone Midden	3	9
Zone Zuid	3	7
Total	18	37

From the data in table 13, we can see that currently the monitoring network of the RIVM has enough sampling points in each zone and agglomeration which measures both ozone and nitrogen dioxide, except for the agglomeration Amsterdam/Haarlem. In this agglomeration, at least one sampling point from the GGD Amsterdam should be used with both ozone and nitrogen dioxide measurements to comply with the EU-directive.

3.3.2 Ozone precursors

There must be at least one sampling point per Member State to determine the ozone precursors. These ozone precursors consist of volatile organic compounds (VOCs) in addition to nitrogen dioxide and nitrogen oxide. Appendix IV contains a list of recommended ozone precursors from the European directive.

Ozone precursors, except for formaldehyde and total non-methane hydrocarbons, are currently measured at one sampling point (NL10643) in the agglomeration Utrecht, which is also used for measurements of nitrogen dioxide, nitrogen oxide and ozone.

3.3.3 Conclusions for ozone

Overall, the number of sampling points in the Netherlands is in accordance with the minimum number of sampling points derived from this assessment. In the agglomeration Amsterdam/Haarlem, additional sampling points from the GGD Amsterdam are needed, consisting of stations NL49003 and NL49701, as these have been appointed as suburban stations for ozone. At these locations, measurements of nitrogen dioxide in combination with ozone are performed, which also solves the requirement that one sampling point from the GGD Amsterdam should be added with both nitrogen dioxide and ozone measurements.

The number of available suburban sampling points for ozone measurements is not well enough defined for the agglomerations Den Haag/Leiden, Rotterdam/Dordrecht, and zone Midden. In all these areas, at least one additional suburban sampling point for ozone should be apportioned. The

lack of suburban ozone sampling point in the agglomeration Rotterdam/Dordrecht might be solved with the addition of a sampling point operated by the DCMR, provided this sampling point is in a suburban area. In the other agglomerations and zone Midden, at least one additional sampling point should be redefined or added as a suburban location.

3.4 Sulphur dioxide

For sulphur dioxide (SO₂), the EU Directive 2008/50/EC contains assessment thresholds for the protection of both human health and the vegetation. The upper and lower assessment thresholds for health protection are based on the 24-hour limit value of 125 µg/m³, which is not to be exceeded more than 3 times a year. The lower assessment threshold for health protection has not been exceeded since 2009 – 2013, as reported by Mooibroek et al. (2016). This assessment threshold has also not been exceeded during the 2005-2019 period.

The second assessment thresholds for the protection of vegetation only applies to the sampling location NL10934 Kollumerwaard (zone Noord). This sampling point is the only sampling point representative of a sufficiently large area to comply with the assessment for vegetation protection. Since 2009 – 2013, the lower assessment threshold for the protection of vegetation has not been exceeded.

Mooibroek et al. (2016) noted that sulphur dioxide concentration levels have been declining for years. For this reason, the measurement effort in the Netherlands for this component has already been greatly reduced in recent years. Currently, as of 2023, at six rural background sampling locations the SO₂ concentration are monitored by the RIVM, and additional focus is on industrialized areas in the agglomerations Amsterdam/Haarlem and Rotterdam/Dordrecht by the GGD Amsterdam and the DCMR respectively.

Based on GCN model calculations, there is no reason to assume that the lower assessment threshold for sulphur dioxide is exceeded in any of the zones and agglomerations defined in the Netherlands. For reference, the results for the assessment of sulphur dioxide is given in Table 14.

Table 14 Overview of the assessment regimes from Mooibroek et al. (2016), the current study and the minimum number of sampling points based on the current assessment for sulphur dioxide (SO₂).

Zone/Agglomeration	Assessment regime 2009-2013 *	Assessment regime 2015-2019	Minimum sampling points EU
Amsterdam/Haarlem	3	3	-
Utrecht	3	3	-
Den Haag/Leiden	3	3	-
Rotterdam/Dordrecht	3	3	-
Eindhoven	3	3	-
Kerkrade/Heerlen	3	3	-
Zone Noord	3	3	-
Zone Midden	3	3	-
Zone Zuid	3	3	-
Total sampling points			0

* Assessment regimes determined based on Mooibroek et al. (2016).

3.5 Carbon monoxide

For carbon monoxide (CO), upper and lower assessment thresholds for the 8-hour average concentration are established in the EU Directive 2008/50/EC.

The lower assessment threshold for carbon monoxide has not been exceeded during 2015 – 2019, resulting in a continuation of the results from the previous assessment by Mooibroek et al. (2016). In terms of the EU legalisation, measurements of carbon monoxide are therefore not required in all agglomerations and zones. In order to provide a complete overview of all required assessments, the results for the assessment of carbon monoxide are given in table 15.

Table 15 Overview of the assessment regimes from Mooibroek et al. (2016), the current study and the minimum number of sampling points based on the current assessment for carbon monoxide (CO).

Zone/Agglomeration	Assessment regime 2009-2013 *	Assessment regime 2015-2019	Minimum sampling points EU
Amsterdam/Haarlem	3	3	-
Utrecht	3	3	-
Den Haag/Leiden	3	3	-
Rotterdam/Dordrecht	3	3	-
Eindhoven	3	3	-
Kerkrade/Heerlen	3	3	-
Zone Noord	3	3	-
Zone Midden	3	3	-
Zone Zuid	3	3	-
Total sampling points			0

* Assessment regimes determined based on Mooibroek et al. (2016).

In 2019, carbon monoxide has been mainly measured in highly industrialized areas in the agglomerations Amsterdam/Haarlem and Rotterdam/Dordrecht. The highest concentration of these sampling points can be found in Amsterdam/Haarlem and are operated by the GGD Amsterdam. Since early 2020, with the closure of the last remaining sampling points due to monitor failure, no measurements of carbon monoxide are performed by the RIVM.

3.6 Benzene

The upper and lower assessment thresholds for benzene as laid out in the EU Directive 2008/50/EC are derived from the limit value for the annual concentration.

Based on GCN model calculations, there is no reason to assume that the lower assessment threshold for benzene is exceeded in any of the zones and agglomerations defined in the Netherlands. In order to provide a complete overview of all required assessments, the results for the assessment of benzene are given in table 16

Table 16 Overview of the assessment regimes from Mooibroek et al. (2016), the current study and the minimum number of sampling points based on the current assessment for benzene.

Zone/Agglomeration	Assessment regime 2009-2013 *	Assessment regime 2015-2019	Minimum sampling points EU
Amsterdam/Haarlem	3	3	-
Utrecht	3	3	-
Den Haag/Leiden	3	3	-
Rotterdam/Dordrecht	3	3	-
Eindhoven	3	3	-
Kerkrade/Heerlen	3	3	-
Zone Noord	3	3	-
Zone Midden	3	3	-
Zone Zuid	3	3	-
Total sampling points			0

* Assessment regimes determined based on Mooibroek et al. (2016).

In 2019, benzene has been measured in highly industrialized areas in the agglomerations Amsterdam/Haarlem and Rotterdam/Dordrecht. In Rotterdam/Dordrecht, six sampling locations are operated by the DCMR, whereas the GGD Amsterdam operates four sampling points in Amsterdam/Haarlem. The lower assessment threshold is not exceeded at any of the sampling locations.

3.7 Lead (in PM10)

For lead, the Fourth Daughter Directive 2004/107/EC provides assessment thresholds based on the annual limit value. The measured lead concentrations have been below the lower assessment levels since at least 1995-1999 (Van Breugel and Buijsman, 2001).

The lower assessment threshold for lead was again not exceeded based on measurements conducted in 2015-2019. As can be seen in table 17, no sampling points are therefore required in any zones or agglomerations for lead (in PM10).

Table 17 Overview of the assessment regimes from Mooibroek et al. (2016), the current study and the minimum number of sampling points based on the current assessment for lead (in PM10).

Zone/Agglomeration	Assessment regime 2009-2013 *	Assessment regime 2015-2019	Minimum sampling points EU
Amsterdam/Haarlem	3	3	-
Utrecht	3	3	-
Den Haag/Leiden	3	3	-
Rotterdam/Dordrecht	3	3	-
Eindhoven	3	3	-
Kerkrade/Heerlen	3	3	-
Zone Noord	3	3	-
Zone Midden	3	3	-
Zone Zuid	3	3	-
Total sampling points			1^a

* Assessment regimes determined based on Mooibroek et al. (2016).

^a background sampling location for indicative measurements can be fulfilled across contiguous zones in different member states.

Regardless of concentration levels, the Fourth Daughter Directive 2004/107/EC does stipulate that one background site for the indicative measurements of not only lead, but also arsenic, cadmium, nickel (all in PM10) and gaseous mercury in ambient air must be established per 100 000 km². In order to be representative of such a large area, this sampling point is allowed to be applied to contiguous zones in different Member States. The surface area of the Netherlands, approximately 41 500 km², is such that to comply with the Fourth Daughter Directive, indicative measurements for lead, arsenic, cadmium, nickel, and gaseous mercury from neighbouring countries can be used. However, the concentrations of lead in PM10 are measured by the RIVM at a rural background sampling point in the agglomeration Utrecht.

3.8 Arsenic, Cadmium and Nickel (all in PM10)

Like lead, the Fourth Daughter Directive 2004/107/EC provides assessment thresholds based on the annual limit values. The measured concentrations of arsenic, cadmium, and nickel in PM10 have been pretty much constant since 2004 and are below the lower assessment levels. As such, no sampling points are required in any zones or agglomerations for arsenic, cadmium, and nickel (in PM10).

Table 18 Overview of the assessment regimes from Mooibroek et al. (2016), the current study, and the minimum number of sampling points based on the current assessment for arsenic, cadmium and nickel (all in PM10).

Zone/Agglomeration	Assessment regime 2009-2013 *	Assessment regime 2015-2019	Minimum sampling points EU
Amsterdam/Haarlem	3	3	-
Utrecht	3	3	-
Den Haag/Leiden	3	3	-
Rotterdam/Dordrecht	3	3	-
Eindhoven	3	3	-
Kerkrade/Heerlen	3	3	-
Zone Noord	3	3	-
Zone Midden	3	3	-
Zone Zuid	3	3	-
Total sampling points			1^a

* Assessment regimes determined based on Mooibroek et al. (2016).

^a background sampling location for indicative measurements can be fulfilled across contiguous zones in different member states.

However, one background sampling point for the indicative measurements of lead, arsenic, cadmium, nickel (all in PM10) and gaseous mercury in ambient air must be established per 100 000 km². While indicative measurements of lead, arsenic, cadmium and nickel from neighbouring countries can be used (see section 3.7), a sampling point operated by the RIVM in the agglomeration Utrecht is used for this purpose.

3.9 Mercury (gaseous)

There are no assessment thresholds defined in the EU Directives for gaseous mercury measurements, but similar to the assessment of lead, arsenic, cadmium, and nickel, a single background sampling point should be installed for the indicative measurements of gaseous mercury. To fulfil this requirement, indicative measurements of gaseous mercury from neighbouring countries may be used as well (see section 3.7).

3.10 Benzo[a]pyrene (in PM10)

For benzo[a]pyrene (in PM10), the upper and lower assessment thresholds are defined in the Fourth Daughter Directive 2004/107/EC. These thresholds are based on a percentage of the annual aggregated values.

During 2015 – 2019, benzo[a]pyrene in PM10 was measured in zone Midden and the agglomerations Rotterdam/Dordrecht and Amsterdam/Haarlem. The upper assessment threshold has been exceeded in the agglomeration Amsterdam/Haarlem only one year out of the five years based on measurements at sampling locations impacted by point sources in a highly industrialized area. In this agglomeration, the lower assessment threshold at these sampling locations have been exceeded at three out of five years.

The previous assessment by Mooibroek et al. (2016) also showed higher concentrations of benzo[a]pyrene at sampling locations impacted by point sources in the highly industrialized agglomeration

Amsterdam/Haarlem. As such, higher concentrations of benzo[a]pyrene due to industrialized emissions are still expected in this area. The Fourth Daughter Directive 2004/107/EC recommends the monitoring of pollutant contributions originating from point sources. Due to the exceedance of the lower assessment threshold during 2015 – 2019 continued monitoring of benzo[a]pyrene in the industrialized area is highly recommended and the placement of at least one sampling point in this area is therefore strongly advised, as can be seen in table 19.

As for the concentrations of benzo[a]pyrene measured at other locations, the lower assessment threshold is only exceeded for two out of five years in zone Midden. Due to this result, no measurement obligation in this zone exists since the thresholds should be exceeded at least on three of the five years (Table 19).

Regardless of concentration levels, the Fourth Daughter Directive 2004/107/EC does stipulate that one background site for the indicative measurements' benzo[a]pyrene in ambient air must be established per 100 000 km². In order to be representative of such a large area, this sampling point is allowed to be applied to contiguous zones in different Member States (see also section 3.7). Similar for lead, arsenic, cadmium, nickel, and gaseous mercury, this requirement for benzo[a]pyrene can be fulfilled by using indicative measurements from neighbouring countries

Table 19 Overview of the assessment regimes from Mooibroek et al. (2016), the current study, and the minimum number of sampling points based on the current assessment for benzo[a]pyrene (in PM10).

Zone/Agglomeration	Assessment regime 2009-2013 *	Assessment regime 2015-2019	Minimum sampling points EU
Amsterdam/Haarlem	3	3	1 ^a
Utrecht	3	3	-
Den Haag/Leiden	3	3	-
Rotterdam/Dordrecht	3	3	-
Eindhoven	3	3	-
Kerkrade/Heerlen	3	3	-
Zone Noord	3	3	-
Zone Midden	3	3	-
Zone Zuid	3	3	-
Total sampling points			2^b

* Assessment regimes determined based on Mooibroek et al. (2016).

^a non-mandatory recommendation to continue monitoring the contributions of benzo[a]pyrene originating from point sources in the highly industrialized area.

^b including one mandatory background sampling location for indicative measurements, which can be fulfilled across contiguous zones in different member states.

4 Conclusion

In this report, an overview is given of the mandatory minimum measurement obligation for pollutants listed in EU Directive 2008/50/EC and the Fourth Daughter Directive 2004/107/EC, based on measurements of air pollutants obtained during the five years 2015 – 2019. Measurements of air pollutants during the years 2020 and 2021, while being available at the time of writing, were excluded from this analysis on account of COVID-19 lockdowns and their impact on the concentration of the air pollutants, not only in the Netherlands (Velders et al., 2020) but also on a global scale (Torkmahalleh et al., 2021). As such, the measured concentrations of the air pollutants during these years are not considered to be from a 'business-as-usual' scenario.

The results from this assessment are compared with the previous assessment, based on measurements during 2009 – 2013 (Mooibroek et al., 2016). As with the previous assessment, there is a need to use sampling points from the GGD Amsterdam and the DCMR to fulfil the minimal measurement obligation in the agglomerations Amsterdam/Haarlem and Rotterdam/Dordrecht.

Initially, we found shortcomings for the measurements of particulate matter, nitrogen dioxide and ozone in the agglomeration Den Haag/Leiden. These have been solved for the upcoming years with the installation of a sampling point measuring these pollutants, including PM_{2.5} and PM₁₀, in September 2022.

Concentration levels of most of the mandatory pollutants listed in EU Directive 2008/50/EC and the Fourth Daughter Directive 2004/107/EC continue to decline, as can be seen by a decrease in the minimum required number of sampling points in several zones and agglomerations for particulate matter and nitrogen dioxide.

For particulate matter, the concentration levels are now below the upper assessment levels for the agglomerations Utrecht, Eindhoven and Heerlen/Kerkrade. This change leads to a possible reduction of one sampling point in each of the agglomerations above compared to the previous assessment (Mooibroek et al., 2016).

The results for nitrogen dioxide showed a decrease in the number of required sampling points in the agglomerations Utrecht, Eindhoven and Heerlen/Kerkrade and zone Noord. However, based on modelling results, the final assessment regimes were adjusted towards the slightly more conservative side by only putting the agglomeration Heerlen/Kerkrade and zone Noord in a lower regime. The lower regime means that one less sampling point is required for the agglomeration Heerlen/Kerkrade and the number of required sampling points in zone Noord is decreased by three.

Ozone is one pollutant that shows no signs of a decrease in concentration levels, as all zones and agglomerations are still subjected to the highest regime. When looking at the additional requirements, not

all zones and agglomerations have sampling points located in suburban background locations. As such, in the agglomerations Den Haag/Leiden, Rotterdam/Dordrecht, and zone Midden, at least one additional suburban sampling point for ozone should be apportioned.

No changes with the previous assessment were found for the pollutants sulphur dioxide, carbon monoxide, benzene, lead, arsenic, cadmium, nickel, and gaseous mercury. All these pollutants remain in their lowest regime, although in the cases of lead, arsenic, cadmium, nickel, and gaseous mercury, indicative measurements at a background sampling location are still required.

The highest concentration of benzo[a]pyrene is still observed in the agglomeration Amsterdam/Haarlem, where it is necessary to monitor the contributions of point sources in the highly industrialized area. In addition, one indicative measurement of benzo[a]pyrene at a background sampling location is required.

Below is a list containing an overview per agglomeration and zone, detailing possible shortcomings and additional information, such as the requirements for the usage of sampling points from the GGD Amsterdam and the DCMR to fulfil the minimum measurement obligation based on current EU-legislation.

Agglomeration Amsterdam/Haarlem

- Particulate matter
 - Six PM sampling points from the GGD Amsterdam are required (preferably PM_{2.5}, but some can be PM₁₀), one required at urban background, the other five can be at rural background, urban background, or traffic-oriented locations.
- Ozone
 - Two ozone sampling points from the GGD Amsterdam are required, with at least one sampling point also measuring nitrogen dioxide. Both ozone sampling points are preferably situated at suburban locations (i.e., NL49003 and NL49701). If not, two other suburban locations need to be appointed in this agglomeration.

Agglomeration Rotterdam/Dordrecht

- Particulate matter
 - One PM sampling point from the DCMR is required (preferably PM_{2.5}, but it can be PM₁₀) at rural background, urban background, or traffic-oriented location.
- Ozone
 - One additional ozone sampling point at a suburban location. Sampling points from the DCMR might be used for this purpose, but this sampling point should then also be added as an official EU-reporting station to comply with EU-legislation. If not, a new ozone sampling point in this agglomeration needs to be set up.

Agglomeration Den Haag/Leiden

- Ozone
 - One ozone sampling point should be appointed to, or set up at a suburban location.

Zone Midden

- Ozone
 - One ozone sampling point should be either appointed to or set up at a suburban location.

The EU Directive 2008/50/EC and the Fourth Daughter Directive 2004/107/EC are currently being revised with updated information (e.g. guidelines, pollutants, limit values, long-term objectives and assessment thresholds). Based on the available information, the limit values and derived assessment thresholds are lower in the new directive than the current values. As such, while present pollutant concentrations might indicate a lower measurement regime based on the current assessment thresholds, the levels from the new directive might lead to higher assessment regimes than reported in this study and, therefore, to an increase of sampling points. As the details of the new directives are not fully known at this time, the RIVM advises to be cautious with any reductions in sampling points until the impact of the update of the directives can be fully assessed.

Due to reorganisations in the boundaries of the municipalities, the boundaries of several agglomerations and zones have changed. In this report, the following changes to the boundaries of the air quality areas were made before their official implementation in the Dutch legislation.

- Nissewaard (2015) is added to the agglomeration Rotterdam/Dordrecht.
- Beekdaelen (2019) is added to the agglomeration Heerlen/Kerkrade.

Effective 24 March 2022, the municipality Weesp is combined with municipality Amsterdam, leading to an expansion of the agglomeration Amsterdam/Haarlem. This change should also be incorporated when updating the zones and agglomerations in the Dutch legislation and communicated to the EU.

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6 Annex I Overview of history of zones and agglomerations

Directive 2008/50/EC states in the introduction that during the assessment of air quality data, Member States should consider the size of populations and ecosystems exposed to air pollutants. In order to allow the use of common assessment criteria, the directive states in article 4 that the Member States shall classify their territory into zones and agglomerations, reflecting the population density. Article 4 of 2008/50/EC further stipulates that air quality assessment and air quality management shall be carried out in all zones and agglomerations. Air quality management is performed by developing air quality plans for each zone and agglomeration with exceedances of relevant air quality target values or limit values.

Directive 2008/50/EC precedes the First Daughter Directive 1999/30/EC, which came into effect in 1999. Before the implementation of directive 1999/30/EC, the Member States were required to describe the air quality in their countries using a preliminary assessment. For the Netherlands, this preliminary assessment is described in more detail by Van Breugel and Buijsman (2001). Part of this preliminary assessment was the classification of zones and agglomerations in the Netherlands. The necessary procedure assigns areas as agglomerations using the spatial distribution of the population density on a scale of 1x1 km². Connected areas with a population density exceeding 750 residents per km² and leading up to a total number of residents of at least 250.000 are nominated as an agglomeration. This approach led to the definition of six different areas with sufficient population density in the Netherlands.

In order to establish the boundaries of these agglomerations using these areas, four criteria have been used. These criteria were (cited from Van Breugel and Buijsman (2001)):

- The borders are taken as the boundaries of areas used by local air quality management authorities. These authorities are responsible for taking measures in case of exceedances in their area.
- Adjacent areas with interrelated air quality should preferably be combined since only co-ordinated measures will be useful. Dependency on air quality may be the case if there is a substantial impact on local air quality by dispersion in one to another area or if areas have the same source characteristics and density.
- Adjoining areas with the same levels of air pollution concerning the limit values and assessment threshold levels of the EU directives should be combined in one zone. Combining these areas enhances the possibility of getting a good overall picture of air quality and of the efficiency of reporting by reducing the number of zones.
- Choices are not determined by science alone. The definition of zones and agglomerations should be as workable and feasible as possible.

The administrative division of the Netherlands can be considered as a decentralised unitary state with three levels of government, as defined by the Dutch constitution. These levels of government are state, province, and municipality. Each of these levels can be considered an air quality management authority, ranging from local (municipality) to nation-wide (state). Within the definition of the zones and agglomerations, Van Breugel and Buijsman used the municipalities as basic boundaries. Whereas zones can consist of multiple provinces, Van Breugel and Buijsman did not allow agglomerations to cross the province boundaries. With this approach, the boundaries of six different agglomerations were derived.

The spatial distribution of the concentration levels of several pollutants in 2000 clearly showed different levels in the north, middle, and south of the Netherlands. This information was used to divide the remaining territory into three different zones. This classification of zones and agglomeration has been laid down in national legislation.

7 Annex II Overview recent municipality reorganisations

The website of the Statistic Netherlands (Centraal Bureau voor de Statistiek (CBS)) gives an overview of recent reorganisations in 2021, 2022 and 2023.

The 2022 reorganisation involving the municipality Weesp is the only reorganisation impacting the boundaries of an air quality area (i.e., agglomeration Amsterdam/Haarlem). All other reorganisations occur within air quality areas and no boundaries are affected.

2021 (Centraal Bureau voor de Statistiek, 2021)

- Delfzijl, Appingedam and Loppersum are merged into a new municipality (Eemdelta). No influence on zone Noord.
- Municipality Haaren is split up and divided over several other municipalities. With the current zone and agglomeration classification, this has no effect on the boundaries of zone Zuid.

2022 (Centraal Bureau voor de Statistiek, 2022)

- Beemster and Purmerend are merged into a new municipality (Purmerend). No influence on the boundaries of zone Midden.
- Weesp is combined with Amsterdam, effective 24-03-2022. This will lead to an expansion of the agglomeration Amsterdam/Haarlem.
- Langedijk and Heerhugowaard are merged into a new municipality (Dijk en Waard). No influence on the boundaries of zone Midden.
- Uden and Landerd are merged into a new municipality (Maashorst). These municipalities are situated in zone Zuid and have no influence on the boundaries.
- Boxmeer, Cuijk, St. Anthonis en Mill en Sint Hubert are merged into a new municipality (Land van Cuijk). These municipalities are situated in zone Zuid and have no influence on the boundaries.

2023 (Centraal Bureau voor de Statistiek, 2023)

- Brielle, Hellevoetsluis and Westvoorne are merged into a new municipality (Voorne aan Zee). These municipalities are situated in zone Midden and have no influence on the boundaries.

8 Annex III Pollutant based regime classification for each assessment threshold

8.1 Particulate matter

Table 20 Overview assessment thresholds for PM₁₀ and PM_{2.5}

	24-hour average PM₁₀	Annual average PM₁₀	Annual average PM_{2.5}
Upper assessment threshold	70 % of limit value (35 µg/m ³ , not to be exceeded more than 35 times in any calendar year)	28 µg/m ³	17 µg/m ³
Lower assessment threshold	50 % of limit value (25 µg/m ³ , not to be exceeded more than 35 times in any calendar year)	20 µg/m ³	12 µg/m ³

Table 21 Overview of the final assessment regime classification based on the assessment thresholds for PM₁₀ and PM_{2.5}

Zone/Agglomeration	Classification in regimes based on thresholds			
	Assessment regime	24-hour average PM₁₀	Annual average PM₁₀	Annual average PM_{2.5}
Amsterdam/Haarlem	1	1	2	2
Utrecht	2	2	3	3
Den Haag/Leiden	1	1	2	3
Rotterdam/Dordrecht	1	1	2	2
Eindhoven	2	2	2	3
Kerkrade/Heerlen	2	2	3	3
Zone Noord	1	1	2	3
Zone Midden	1	1	2	3
Zone Zuid	1	1	2	2

Table 22 Distribution PM_{2.5} and PM₁₀ sampling points within the RIVM network

Zone/Agglomeration	Distribution Rural, Urban and Traffic sampling points							
	PM _{2.5} R	PM _{2.5} U	PM _{2.5} T	PM _{2.5} sum	PM ₁₀ R	PM ₁₀ U	PM ₁₀ T	PM ₁₀ sum
Amsterdam/Haarlem	-	-	-	-	-	-	1	1
Utrecht	-	1	1	2	-	-	2	2
Den Haag/Leiden	-	1	-	1	-	2	1	3
Rotterdam/Dordrecht	-	1	1	2	-	2	1	3
Eindhoven	-	1	-	1	-	1	2	3
Kerkrade/Heerlen	-	1	1	2	1	1	1	3
Zone Noord	1	2	1	4	6	-	1	7
Zone Midden	4	1	2	7	7	-	2	9
Zone Zuid	2	1	1	4	5	1	1	7
Total sampling points	7	9	7	23	19	7	12	38

8.2 Nitrogen dioxide and nitrogen oxides

Table 23 Overview assessment thresholds for NO₂ and NO_x

	Hourly limit value for the protection of human health (NO ₂)	Annual limit value for the protection of human health (NO ₂)	Annual critical level for the protection of vegetation and natural ecosystems (NO _x)
Upper assessment threshold	70 % of limit value (140 µg/m ³ , not to be exceeded more than 18 times in any calendar year)	80 % of limit value (32 µg/m ³)	80 % of critical level (24 µg/m ³)
Lower assessment threshold	50 % of limit value (100 µg/m ³ , not to be exceeded more than 18 times in any calendar year)	65 % of limit value (26 µg/m ³)	65 % of critical level (19.5 µg/m ³)

Table 24 Overview of the final assessment regime classification based on the assessment thresholds for NO₂ and NO_x

Zone/Agglomeration	Classification in regimes based on thresholds			
	Assessment regime	Hourly limit value NO ₂	Annual average NO ₂	Annual level NO _x
Amsterdam/Haarlem	1	2	1	-
Utrecht	2	3	2	-
Den Haag/Leiden	1	2	1	-
Rotterdam/Dordrecht	1	2	1	-
Eindhoven	2	3	2	-
Kerkrade/Heerlen	2	3	2	-
Zone Noord	3	3	3	3
Zone Midden	1	2	1	-
Zone Zuid	1	2	1	-

Table 25 Distribution NO₂ sampling points within the RIVM network

Zone/Agglomeration	Distribution Rural, Urban and Traffic sampling points			
	NO ₂ R	NO ₂ U	NO ₂ T	NO ₂ sum
Amsterdam/Haarlem	-	-	1	1
Utrecht	-	1	2	3
Den Haag/Leiden	-	2	1	3
Rotterdam/Dordrecht	-	2	1	3
Eindhoven	-	1	2	3
Kerkrade/Heerlen	1	1	1	3
Zone Noord	6	1	1	8
Zone Midden	7	1	2	10
Zone Zuid	7	1	1	9
Total sampling points				43

8.3 Ozone

Table 26 Overview assessment thresholds for O₃.

Objective (O ₃)	Averaging period	Long-term objective
Protection of human health	Maximum daily eight-hour mean within a calendar year	120 µg/m ³
Protection of vegetation	May to July	AOT40 (calculated from 1 h values) 6000 µg/m ³ ·h

8.4 Sulphur dioxide

Table 267 Overview assessment thresholds for SO₂

	Health protection (SO ₂)	Vegetation protection (SO ₂)
Upper assessment threshold	60 % of 24-hour limit value (75 µg/m ³ , not to be exceeded more than 3 times in any calendar year)	60 % of winter critical level (12 µg/m ³)
Lower assessment threshold	40 % of 24-hour limit value (50 µg/m ³ , not to be exceeded more than three times in any calendar year)	70 % of winter critical level (8 µg/m ³)

8.5 Carbon monoxide

Table 278 Overview assessment thresholds for CO

	Eight-hour average (CO)
Upper assessment threshold	70 % of limit value (7 mg/m ³)
Lower assessment threshold	50 % of limit value (5 mg/m ³)

8.6 Benzene

Table 289 Overview assessment thresholds for C₆H₆

	Annual average (C ₆ H ₆)
Upper assessment threshold	70 % of limit value (3.5 µg/m ³)
Lower assessment threshold	40 % of limit value (2 µg/m ³)

8.7 Lead (in PM10)*Table 3029 Overview assessment thresholds for Pb*

	Annual average (Pb)
Upper assessment threshold	70 % of limit value (0.35 µg/m ³)
Lower assessment threshold	50 % of limit value (0.25 µg/m ³)

8.8 Mercury (gaseous)

No assessment thresholds defined.

8.9 Arsenic, Cadmium and Nickel (in PM10)*Table 301 Overview assessment thresholds for NO₂ and NO_x*

	Annual average (As)	Annual average (Cd)	Annual average (Ni)
Upper assessment threshold	60 % of target value (3.6 ng/m ³)	60 % of target value (3 ng/m ³)	60 % of target value (14 ng/m ³)
Lower assessment threshold	40 % of limit value (2.4 ng/m ³)	40 % of limit value (2 ng/m ³)	40 % of limit value (10 ng/m ³)

8.10 Benzo[a]pyrene (in PM10)*Table 32 Overview assessment thresholds for Benzo[a]pyrene (BaP)*

	Annual average (BaP)
Upper assessment threshold	60 % of target value (0.6 ng/m ³)
Lower assessment threshold	40 % of limit value (0.4 ng/m ³)

9 Annex IV Number of residents in urban areas (PM2.5)

Table 33 List of agglomerations or municipality with a total number of residents larger than 100.000 based on the number of inhabitants in the Netherlands on January 1st, 2020 (Centraal Bureau voor de Statistiek, 2020).

Agglomeration/Municipality	Residents
aggl. Amsterdam/Haarlem	1763650
aggl. Rotterdam/Dordrecht	1361910
aggl. Den Haag/Leiden	1204782
aggl. Utrecht	505314
aggl. Eindhoven	465380
aggl. Heerlen/Kerkrade	246514
Groningen	232874
Tilburg	219789
Almere	211893
Breda	184069
Nijmegen	177659
Apeldoorn	163818
Arnhem	161348
Enschede	159640
Amersfoort	157276
's-Hertogenbosch	155111
Zwolle	128840
Zoetermeer	125285
Leeuwarden	124084
Maastricht	121575
Ede	117165
Alphen aan den Rijn	111897
Alkmaar	109436
Emmen	107048
Venlo	101802
Deventer	100719
Total residents	8518878

10 Annex V Overview of recommended measurements of ozone precursors (volatile compounds).

Table 314 List of recommended measurements of ozone precursors

Volatile compounds (ozone precursors)	
ethane	isoprene
ethylene	n-hexane
acetylene	i-hexane
propane	n-heptane
propene	n-octane
n-butane	i-octane
i-butane	benzene
1-butene	toluene
trans-2-butene	ethyl benzene
cis-2-butene	m+p-xylene
1,3-butadiene	o-xylene
n-pentane	1,2,4-trimethylebenzene
i-pentane	1,2,3-trimethylebenzene
1-pentene	1,3,5-trimethylebenzene
2-pentene	formaldehyde
Total non-methane hydrocarbons	

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