Health benefits through cleaner air

To: the State Secretary for Infrastructure and Water Management
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Health Council of the Netherlands

contents

The air in the Netherlands has become much cleaner in recent decades and now meets European standards almost everywhere. Nevertheless, concentrations of particulate matter, nitrogen dioxide and ozone in the air result in an estimated 12,000 premature deaths per year. Considerable health benefits can still be made. In order to achieve this, the World Health Organisation's air quality guidelines could be used to further reduce air pollution. And even less air pollution would be even better. The health-based air quality guidelines are more stringent than the European standards, particularly for particulate matter, but even with concentrations of air pollution below these guidelines, effects on human health have been observed.

Trends in air quality

Air quality in the Netherlands has improved considerably in recent decades. The concentrations of the three main components of air pollution – particulate matter, nitrogen dioxide and ozone – have been reduced (for ozone only during summer episodes). In particular, concentrations of particulate matter and nitrogen dioxide in the air have declined sharply in the last decades so that the European limit values for these substances are now met almost everywhere in the Netherlands, with the exception of a few hot spots in the major cities (nitrogen dioxide) and in areas with intensive livestock farming or industry (particulate matter). When the air quality meets the European limit values, however, this does not mean that public health is fully protected. The European limit values are less stringent than the WHO's air quality guidelines, except for nitrogen dioxide. The expectation is that with the implementation of the current air and energy policy, concentrations of particulate matter and nitrogen dioxide will decline further and that the WHO's air quality guidelines can be achieved in a large part of the country around 2030. The picture is less favourable for ozone: at best, there is no increase in the number of ozone peaks and annual average exposure.

Health effects of air pollution

Exposure to particulate matter, nitrogen dioxide and ozone can cause adverse health effects. It mainly concerns:

- the development and aggravation of respiratory and lung diseases, including lung cancer; and
- the development and aggravation of cardiovascular diseases.

For other disorders, the evidence for a causal relationship is insufficient. Exposure to air pollution can also cause premature death. The concentrations of particulate matter, nitrogen dioxide and ozone in Dutch air resulted in an estimated 12,000 premature deaths in the Netherlands in 2014. Even at concentrations *below* the WHO's health-based air quality guidelines, air pollution can impair health and result in premature death. Thus, more health benefits can be expected from further improvement of the air quality than the WHO advises.

Children, older adults and people with respiratory diseases (especially asthma patients) appear to be particularly vulnerable to the effects of exposure to particulate matter, nitrogen dioxide and ozone. People with cardiovascular diseases are particularly vulnerable to particulate matter.

Focal points for air quality policy

Generic measures to protect all Dutch people
The committee recommends that priority be given to reducing the concentrations of particulate and nitrogen dioxide matter originating from road traffic (in particular diesel vehicles) and dealing with the emissions of ammonia from livestock farming. In this way, the blanket of air pollution over the Netherlands can be reduced. Such a generic approach is expected to yield the most health benefits for the entire Dutch population.

Specific measures to protect high-risk groups
Further health benefits can be achieved by taking high-risk groups into account: people who are exposed to air pollution for a prolonged period and people who are particularly susceptible to air pollution because of age (children and older adults) or illness. In order to protect groups with *high exposure*, the committee recommends extra measures around hot spots: locations with relatively high air pollution, e.g. around busy roads. Examples of the approach of such hot spots in cities are: low-traffic inner cities, environmental zones and speed limits. To specifically protect the *high-sensitivity groups*, the committee advocates a zoning policy for air quality sensitive locations: no facilities for children and older adults in the vicinity of a hot spot. To provide extra protection for sensitive groups the committee advocates the more active dissemination of specific behavioural advice, e.g. not engaging in any heavy effort during the afternoon or staying indoors during episodes of smog by ozone.

International approach
The Netherlands is a small country bordering densely populated neighbouring countries. Nearly half of the particulate matter we breathe in the Netherlands comes from abroad. An international approach is therefore indispensable, not only for particulate matter but also for the other components of air pollution. To effectively lower the ozone concentration in the Netherlands emissions of, for example, nitrogen oxides and methane must be reduced throughout Europe and even in the rest of the northern hemisphere. In addition, it is important that the Dutch policy focuses on reducing the emissions of substances such as ammonia, which also contribute to particulate matter formation in neighbouring countries.

Conditions for health benefits
The amount of health benefits that can be achieved in practice depends on political choices. For a reduction of air pollution to below the WHO's air quality guidelines, additional policy measures are required. The amount of health benefits to be achieved in practice depends, among other things, on how strictly compliance with the regulations can be enforced.

01 introduction

1.1 Trends in air quality in the Netherlands

For many decades now, air pollution has constituted an environmental problem with serious consequences for public health. In the winter of 1952 / 1953, 12,000 people died in London as the result of a smog episode.[1] Dealing with air quality has also been high on the agenda of policymakers in the Netherlands, in particular since the Air Quality Decree came into force in 2001. The smog in London was primarily the result of coal combustion in factories and in households, in combination with wind-still conditions. At present, air pollution is also in part the result of industrial and household activities such as residential heating, wood-burning, et cetera. In addition, agriculture, in particular intensive livestock farming, and road traffic have a significant effect. Dealing with such a multisectoral and cross-border problem requires cooperation at the international, national, and local levels.

Developments in European regulations

Over the last 20 years, extensive European regulations have been established for the assessment and management of air quality. These regulations are based on a source-based approach, with guiding standards (threshold values and target values) for the maximum concentrations of air pollution to which people may be exposed. In 2008, a new European directive came into force in which these values were revised.[2] By now, the member states have converted these standards and values into statutory provisions. In addition, for each country, National Emission Ceilings (NECs) have been set down in the NEC guideline.[3] Via the so-called Euro standards, emission requirements have also been set for the emission of pollutants by road traffic. Additional requirements have also been established, for example with regard to the sulphur content of fuels. The European source control policy has led to the large-scale use of particle filters and catalytic converters for road traffic and to the increased application of technologies for the desulphurisation of flue gases from electrical power stations and industrial sources and the development of cleaner fuels.[4] As a result of the increasingly strict Euro standards and the large-scale use of (diesel) particle filters, the fraction of soot particles and ultrafine particles, in particular, originating from road traffic has been greatly reduced.

Policy developments in the Netherlands

The national air quality policy aims to ensure compliance with the legally established European limit values for air quality and with the national emission ceilings of the NEC guideline referred to above. For example, agreements have been entered into with the industry regarding emission ceilings, measures have been implemented aimed at realising low-emission stables and minimising emissions during the spreading of manure on the land, and subsidy schemes and tax measures must result in a reduction of the pollutants produced by the traffic and transport sector. In the National Air Quality Cooperation Programme (NSL: see text box), agreements have been entered into with local governments aimed at

National Air Quality Cooperation Programme (NSL)

The NSL presents an integrated package of generic as well as location-specific national measures.[5] Generic national measures involve the reduction of air pollution from road traffic and agriculture, whereas location-specific national measures aim to reduce the number of exceedances of limit values along the main road network. In addition, agreements have been entered into with decentralised government bodies to further improve the air quality, in particular within cities and along regional roads. Examples of location-specific measures that can be implemented by decentralised government bodies mentioned in the NSL include environmental zoning, improving traffic flow, and encouraging clean forms of public transport.

further improving the air quality in order to comply with the European limit values.

Air quality has improved in recent decades

As a result of the source-based European policy and its implementation within the framework of air quality policy in the Netherlands, the air quality in the Netherlands has improved significantly in recent decades. The concentrations of the three main components of air pollution – particulate matter, nitrogen dioxide and ozone (see text box) – have been reduced (for ozone only during summer episodes). The reduction in the concentration of particulate matter in the city of Rotterdam over the period from 1985 to 2008 alone is estimated to have resulted in an increase in average life expectancy by 13 months per person.[6] Previously, the concentrations of sulphur dioxide, lead, carbon monoxide, and the carcinogenic substances benzene and benzo(a)pyrene had already decreased.

Important components of air pollution

Particulate matter is a collective name for all solid and liquid particles in the air that are small enough to be inhaled by humans, such as microorganisms, pollen, sea salt, soil particles, soot particles, and pieces of abraded car tyres or road surfaces. The abbreviation PM (particulate matter), followed by a number, is used to specify the size of the particles. For example, PM10 means that 50% of the particles behave in the air like a spherical particle with a diameter of less than 10 μm.7 Three different fractions are differentiated based on the size of the particles: the coarser fraction of particulate matter (2.5 to 10 μm), the finer fraction of particulate matter (PM 2.5: < 2.5 μm), and ultrafine particles (< 100 nm). The ultrafine particle fraction in the Netherlands consists primarily of soot particles emitted by road traffic, in particular by diesel vehicles and by air traffic. Most of the particulate matter is the result of human activities (the so-called anthropogenic contribution), including agriculture, traffic, and industry. Particulate matter that is introduced into the air directly via human activity or natural processes is referred to as the primary fraction. The secondary fraction of particulate matter (secondary particulate matter) consists of chemical components that are formed after chemical reactions in the air with ammonia, nitrogen oxides, and sulphur oxides (also see § 3.1.1).

Nitrogen oxides (nitrogen monoxide and nitrogen dioxide) are released during all combustion processes. The most important source of nitrogen oxides in outdoor air is motorised traffic. In part, nitrogen dioxide is released directly and in part it is formed from nitrogen monoxide in the air.

Ozone is a gas that is naturally present in the air. In the stratosphere, the air layer at a height of 10 to 50 km, ozone has an important protective function against harmful UV radiation. But in the troposphere, the air layer in which we live, nitrogen oxides and volatile hydrocarbons can react under the influence of sunlight resulting in increased ozone concentrations that can be harmful to human beings.

In particular, the concentrations of particulate matter and nitrogen dioxide in the air have declined sharply in the last decades (see Figure 1) so that the European limit values for these substances are now met almost everywhere in the Netherlands, with the exception of a few hot spots in

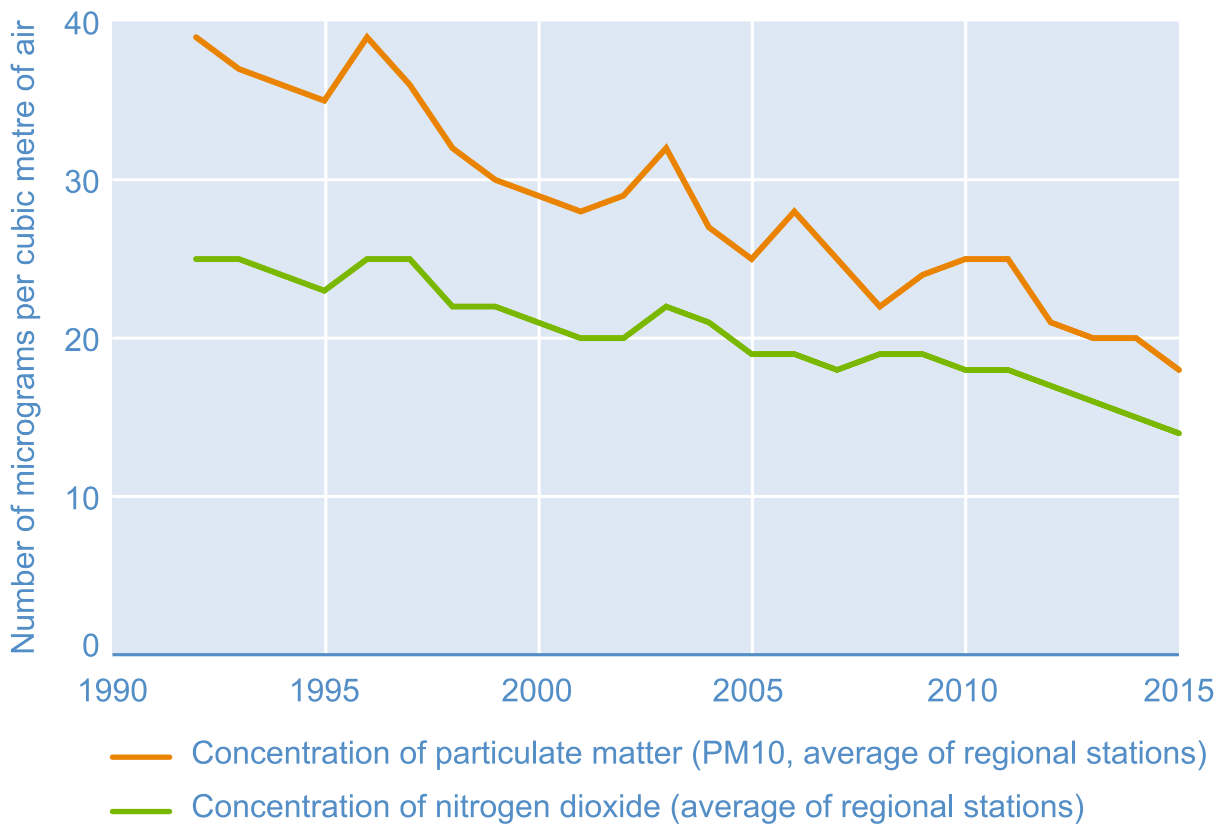

Figure 1. Trends in concentrations of particulate matter (PM10) and nitrogen dioxide (1992-2015: average concentrations at regional measuring stations)
Source: Environmental Data Compendium (www.clo.nl) based on data from RIVM/ DCMR/GGD Amsterdam 2016

the major cities (nitrogen dioxide) and in areas with intensive livestock farming or industry (particulate matter).[8]
At the same time, developments have taken place in recent decades that were less favourable for air quality, such as the increase of motorised freight and passenger traffic, the increase in the share of diesel vehicles, and the increasing scale and intensity of agricultural activities, in particular cattle farming.[9-11] In addition, 'dieselgate' has made it clear that, due to the use of emission cheating software, the actual emission of nitrogen oxides by diesel vehicles in practice is often much higher than is permitted in accordance with the type approval.

1.2 Further improvement of air quality is desirable

The European limit values, with the exception of those for nitrogen dioxide, are less stringent than the health-based air quality guidelines of the World Health Organisation (WHO); see text box.[12] The European values are based in part on considerations of political and economic feasibility. Accordingly, the fact that the air quality meets the European limit and target values does not mean that public health is adequately protected.[13]

European limit and target values and WHO air quality guidelines

The European (EU) limit and target values aim to protect public health. The European Air Quality Directive defines the limit and target values in 2008 as follows.[2]
EU limit value. A level that is determined on the basis of scientific knowledge, with the aim of avoiding, preventing, or reducing harmful effects on human health and/or the environment as a whole, to be attained within a given period and not to be exceeded once attained.
EU target value. A level that is determined with the aim of avoiding, preventing, or reducing harmful effects on human health and/or the environment as a whole, to be attained where possible over a given period.
WHO air quality guidelines are intended to protect public health and are based on scientific research into the health effects of exposure to significant components of air pollution. However, according to the WHO, it can also not be assumed that these guidelines provide adequate protection, as harmful health effects have also been identified at lower levels of air pollution.[12]
The WHO has established a separate project for revising the air quality guidelines, in the course of which all evidence available from research will again be evaluated. The revised guidelines are not expected to be available before 2019.

Table 1 compares the European limit and target values for particulate matter, nitrogen dioxide, and ozone to the WHO air quality guidelines, expressed in micrograms per cubic metre of air (m^3).

Table 1. WHO air quality guidelines and European limit and target values for particulate matter, nitrogen dioxide, and ozone

Substance	WHO air quality guideline (average exposure duration)	European limit and target value
Particulate matter (PM10)	20 micrograms/m^3 (year) 50 micrograms/m^3 (day)	40 micrograms/m^3; limit value (annual average) 50 micrograms/m^3 (daily average: may not be exceeded more than 35 times per year); this corresponds to an annual average concentration of approximately 30-32 micrograms/m^3.
Finer fraction of particulate matter (PM2.5)	10 micrograms/m^3 (year) 25 micrograms/m^3 (day)	25 micrograms/m^3 ; limit value (annual average)
Nitrogen dioxide	40 micrograms/m^3 (year)	40 micrograms/m^3; limit value (annual average) 200 micrograms/m^3 (hourly average: may not be exceeded more than 18 times per year)
Ozone	100 micrograms/ m^3 (8 hours)	120 micrograms/m^3; target value For the short term: highest progressive average over 8 hours per day; may not be exceeded more than 25 days per year; average over three years. For the long term: highest progressive average over 8 hours per day; may not be exceeded; per calendar year.

In 2015, in its report Perspectives for air quality and health (the Perspectives Memorandum), RIVM determined that the presently proposed national and in particular international policy can lead to further improvement of the air quality, including improvement in large cities.[14] For this to happen, the goals of the policy on air quality and the policy on climate and energy need to be realised. This means that European emission standards for road traffic must be strictly complied with, that the use of fossil fuels must be greatly reduced, and that older vehicles and appliances must be replaced. For a reduction of air pollution to levels below the WHO air quality guidelines, additional policy measures and strict enforcement are required.

1.3 Working procedure for answering questions from the State Secretary

On 18 May 2016, the State Secretary for Infrastructure and the Environment (IenM, the present Ministry of Infrastructure and Water Management) asked the Health Council of the Netherlands for advice on how to focus more on public health by further improving air quality. The State Secretary would like to see the above mentioned RIVM Perspectives Memorandum also taken into account in this advice.

The State Secretary asked the Health Council of the Netherlands to address the following points in the advice (for a direct quote of the questions, see Chapter 4):

1. the current state of scientific knowledge on the health effects of air pollution;

2. the sources of air pollution in the Netherlands that are most worthy of attention from a public health perspective;
3. the potential added value of devoting extra attention in the future air quality policy to vulnerable groups;
4. the most important indicators of air quality as focal points for realising health benefits.

The State Secretary aims to place a greater focus on health issues within the framework of air quality policy. For that purpose, a national air quality action plan will be launched in 2018. The air quality plan will also serve to implement the previously mentioned European NEC guideline, which contains emission ceilings.3 The State Secretary wishes to use the advice provided by the Health Council of the Netherlands as the basis for this new plan.

In preparation for the Committee process, interviews were held in the second half of 2016 with around 10 experts on air quality and health from the network of the Health Council, the government, and social organisations.

On 9 January 2017, the Chair of the Health Council established the Air Quality Committee for the purpose of answering the request for advice referred to above.

The Committee's approach

Based on the questions asked by the State Secretary, the Committee defined its central task as determining the most important focal points of Dutch air quality policy. In other words, which components of air pollution and which sources and sectors should future policy focus on in order to realise the maximum possible health benefits? In doing so, the Committee also focuses on what is needed in order to protect vulnerable groups. In addition to these highly sensitive groups, the Committee also focuses on highly exposed groups. After all, the latter are also subject to increased risk of adverse health effects due to air pollution. The Committee therefore chose to answer the third sub-question from the request for advice for both types of high-risk groups, a term that was proposed in 2011 in the advice by the Health Council regarding high-risk groups and that has also been used since then in other reports by the Health Council; see text box.[15]

Two types of high-risk groups: highly sensitive groups and highly exposed groups

The term high-risk groups refers to groups within the population that are at increased risk of being affected by substances that may cause adverse health effects. The Committee distinguishes between two high-risk groups in relation to air pollution: highly sensitive groups and highly exposed groups.

Highly sensitive groups. Increased sensitivity to adverse health effects due to exposure to air pollution can be due to biological factors such as a specific genetic predisposition, a specific life stage, or an underlying medical condition.

Highly exposed groups. Persons subject to higher exposure are primarily those who live, work, or are otherwise present for long periods of time in locations with relatively high levels of air pollution. This often involves a combination of risk factors that can further strengthen each other's effects. For example, air pollution can exacerbate asthma in combination with other factors such as smoking or poor living conditions.

In its advice, the Committee has made a link with the request for advice from the Ministry of Economic Affairs, in which the Health Council was asked to provide an updated overview of the state of knowledge with regard to the health risks associated with living in the vicinity of livestock farms.[16] In Chapters 3 and 4, the Committee answers the sub-question regarding the health risks of exposure to secondary particulate matter due to emissions of ammonia by livestock farming. The other requests for advice with regard to livestock farms are addressed in a separate advice by the Health Council.

Scope

The advice at hand limits itself to the three most important components of air pollution: particulate matter, nitrogen dioxide, and ozone. Most of the adverse health effects caused by air pollution is attributed to these three substances. In carrying out its work, the Committee limited itself to those health effects for which a (likely) causal relationship has been demonstrated (see Chapter 2).

Assessment of evidence based on the literature

In answering the question about the health effects of air pollution, the Committee based itself primarily on the current state of scientific knowledge as summarised in key documents prepared in particular by the WHO and the United States Environmental Protection Agency (EPA).[12,17-22] At the request of these organisations, international committees of experts regularly evaluate the quality of the many hundreds of epidemiological and toxicological studies that are released each year, including tens of systematic literature reviews and meta-analyses. Based on the previously mentioned information, the Committee formed an opinion regarding the weight of evidence for the causal relationships found between important components of air pollution and health effects.[23] In addition, the Committee consulted recent key publications to determine whether new knowledge has become available that would make it necessary to revise the assessments arrived at regarding the weight of evidence for causal relationships between exposure and health effects and regarding the existence of threshold values and high-risk groups.

The Standing Committee on Public Health reviewed the advice. On 23 January 2018, the Chair of the Health Council presented the advice to the State Secretary for Infrastructure and Water Management. The request for advice by the Ministry of Infrastructure and the Environment, the request for advice by the Ministry of Economic Affairs, the members of the committee and the list of experts consulted and the letter of submission are available at www.gezondheidsraad.nl.

1.4 Reading guide

In Chapter 2 of this advice, the Committee describes the health effects of exposure to air pollution. The topics addressed include the nature and seriousness of these effects, the weight of evidence, and which groups of persons are especially sensitive to these effects. Chapter 3 describes focal points for air quality policy, for example which sources must be targeted and how can highly exposed persons be protected? The scope of these chapters is broader than the request for advice. In Chapter 4, the Committee specifically answers the four questions from the State Secretary for Infrastructure and the Environment and the question from the Minister of Economic Affairs regarding the health risks of exposure to secondary particulate matter resulting from the emission of ammonia from livestock farming.

Two background documents are associated with the advice at hand. The Health Effects background document contains information on the mechanisms of health effects caused by air pollution, on the weight of evidence for a causal relationship, and on concentration-effect relationships. In the Air Pollution background document the Committee further discusses the measurement and calculation of air quality.

02
health effects of air pollution

The concentrations of particulate matter, nitrogen dioxide and ozone in air in the Netherlands resulted in an estimated 12,000 premature deaths in 2014 (see § 2.1). Research shows that air pollution can cause adverse health effects even at very low concentrations. The Committee expects that substantial health benefits can be realised if success is achieved in reducing the average concentration of particulate matter (in particular PM2.5), nitrogen dioxide, and ozone not only to levels below the present European limit values but even further to levels below the WHO air quality guidelines. The Committee considers it important, within the above framework, to also take into account persons who are more sensitive to the effects of air pollution, the so-called highly sensitive groups such as children, older adults, and persons with respiratory disorders (in particular asthma patients) and cardiovascular diseases (see § 2.2 - 2.5).

2.1 Nature and seriousness of health effects caused by air pollution

Exposure to particulate matter, nitrogen dioxide and ozone can cause adverse health effects. Scientific research has shown that exposure to these substances is causally related or likely to be causally related to[17-19,24]

- the development and aggravation of respiratory and lung diseases, including lung cancer;
- the development and aggravation of cardiovascular diseases;
- premature death.

The effects on the airways and lungs include reduced pulmonary function and respiratory symptoms such as coughing, shortness of breath, and wheezing. In addition, exposure to air pollution also leads to the development and aggravation of asthma and COPD (*Chronic Obstructive Pulmonary Diseases*.[20] It was recently proven that persons who have been exposed to air pollution for many years are at a higher risk of developing lung cancer due to such exposure.[24] The effects on the cardiovascular system are expressed as (an aggravation of) heart condition or high blood pressure. The effects on the airways, lungs, heart and blood vessels can be so serious that they can result in hospital admission and premature death. Such cases often involve persons with chronic respiratory and lung disorders or cardiovascular disease as well as children or older adults with increased sensitivity to the effects of air pollution. More information about the mechanisms of the health effects of air pollution, the weight of evidence for a causal relationship, and concentration-effect relationships can be found in the Health Effects background document.

Burden of disease: premature death and years of life lost

At the population level, the seriousness of the health effects of air pollution is often expressed in terms of burden of disease, in other words the loss of health in a population caused by disease.[25] The burden of disease is the total sum of the years of life lost due to premature death and the *disability-adjusted* life years. If the Committee refers to years of life lost in this advice, it is referring to years of life lost as the result of premature death.

In the Netherlands, almost 6% of the total burden of disease is attributed to exposure to environmental factors.[26] The exposure to particulate matter (PM2.5) alone is responsible for approximately 4% of the burden of disease. After smoking (13%), air pollution is therefore one of the most important risk factors, being of the same order of magnitude as obesity (5%) and too little physical activity (3-4%).[25]
Death caused by air pollution is often quantified in two different ways, namely as the number of premature deaths per year or as the total reduction in life expectancy per person by years or months. How these parameters are calculated is explained in the Health Effects background document.

Premature death attributable to long-term exposure: estimates for 2013
How great the effect is of exposure to air pollution depends in part on the duration of the exposure. RIVM has calculated that long-term exposure to *particulate matter (PM2.5)* is associated with a reduction in the average life expectancy in the Netherlands by approximately *nine months*, based on a population-averaged exposure in 2013 to a PM2.5 concentration equal to 14 micrograms/m^3. Every reduction of 5 micrograms/m^3 of PM2.5 therefore translates into a benefit by approximately three months.[14]
Calculations also show that the average life expectancy of Dutch people is reduced by *four months* due to long-term exposure to *nitrogen dioxide*. RIVM estimates the effect in comparison to a situation *without* air pollution and bases itself on the relative risks from the WHO key document *Health Risks of Air Pollution In Europe* (2013).[21]

Premature death attributable to long-term exposure: estimates for 2014
The Committee is of the opinion that it is not realistic to compare the current situation characterised by annual average concentrations to a situation *without* air pollution. After all, part of the background concentration cannot be influenced. In order to also take into account that part of the background concentration that cannot be influenced, the Committee therefore prefers to use a recent calculation of the number of premature deaths and years of life lost carried out by the *European Environment Agency* (EEA), which applies more realistic thresholds for targeted annual average background levels: 2.5 micrograms/m^3 for PM2.5, 20 micrograms/m^3 for NO_2 and 70 micrograms/m^3 as 8-hour maximum for ozone.[27] On this basis, the EEA estimates that in 2014 approximately 9,200 persons died prematurely in the Netherlands as the result of exposure to particulate matter (PM2.5), 2,600 due to exposure to nitrogen dioxide, and 250 as the result of exposure to ozone (see Table 2).[27]

In 2014 the concentrations of particulate matter, nitrogen dioxide and ozone in air in the Netherlands resulted in an estimated 12,000 premature deaths and approximately 131,000 years of life lost. The total number of years of life lost is not simply a function of the number of premature deaths, as both parameters are calculated in different ways.

Table 2. Premature death in the Netherlands attributable to air pollution in 2014[27]

Air pollution components	Number of premature deaths	Number of years of life lost
Particulate matter (PM2.5)	9,200	100,400
Nitrogen dioxide	2,600	27,800
Ozone	250	2,700
Total	12,050	130,900

Another way of expressing the seriousness of the health impact of air pollution is to consider the average reduction in life expectancy per person. To calculate this figure, the number of years of life lost must be divided by the total number of natural deaths. In the Netherlands, approximately 140,000 persons died in 2014 of natural causes, in other words not as the result of traffic accidents or crimes. The average reduction in life expectancy for the general population due to air pollution is then calculated as almost one year per person.

Emergency admissions as a result of increased short-term exposure
Daily variations in exposure to air pollution can also result in health effects. In 2013, increased short-term exposure to particulate matter led to an estimated 4,600 emergency hospital admissions of persons with acute respiratory and heart symptoms.[28] Increased short-term exposure to ozone led to an estimated 12,000 emergency hospital admissions of persons with acute respiratory and heart symptoms.[29]

Other consequences for quality-of-life and daily activities
Exposure to air pollution can also cause a range of health outcomes that are less serious than diseases, morbidity and premature mortality described previously, but which can still have a negative impact on the quality of life of the persons in question and their performance of daily activities at school and work.[30]
Estimates of the degree to which air pollution contributes to an increased risk of various health effects (expressed in so-called relative risks) can be found in tables with concentration-effect relationships in the Health Effects background document.

2.2 Health effects of particulate matter

The degree to which particles can penetrate into the respiratory tract and lungs and further into the body depends upon the size of the particles (see Figure 2). Particles larger than 10 μm are removed in the throat and nose, which act as a kind of filter. The coarser fraction of particulate matter (particles with a diameter of 2.5 μm to 10 μm) end up primarily in the mucous membranes of the upper respiratory tract and are practically not exhaled. Of the particulate matter with a diameter of 0.1 μm to 2.5 μm, approximately 80% *is* exhaled; the remaining 20% penetrate deeper into the lungs and reach the long alveoli (tiny air sacs).[31] Particles that are even smaller, the so-called ultrafine particles, tend to remain behind in the lungs and can even penetrate into the bloodstream.[32] The previously

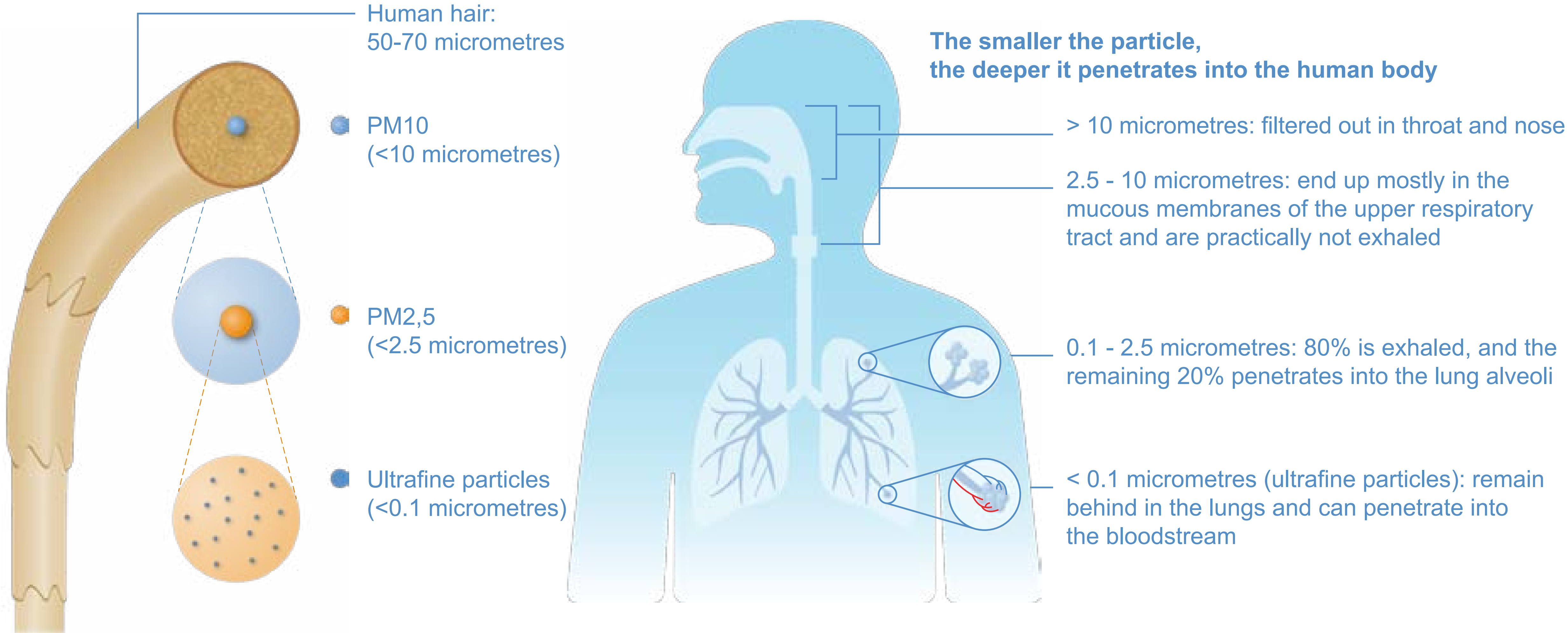

Figure 2. Size of various particulate matter fractions

discussed pathways explain in part why the health effects of the different fractions of particulate matter can differ from each other.

2.2.1 Weight of evidence for health effects of particulate matter

Since 2005, the year in which the WHO set health-based air quality guidelines for particulate matter, a great deal of knowledge has become available from epidemiological research on short-term as well as long-term exposure to particulate matter.

Health effects of particulate matter: state of knowledge EPA report 2009

With regard to adverse effects on the cardiovascular system, the United States Environmental Protection Agency (EPA) stated in 2009 that such effects can definitely be attributed to short-term (approximately 1 day to 1 week) as well as long-term (approximately 1 to 10 years) exposure to particulate matter (PM2.5).[17] With regard to adverse effects on the respiratory tract and lungs, a causal relationship with exposure to PM2.5 is likely, according to the EPA (see Table 3). The EPA also stated that there is convincing evidence that an increased exposure to PM2.5 results in an increased number of premature deaths. This applies to all-cause mortality as well as – in the case of increased long-term exposure – cause-specific mortality from cardiovascular diseases and respiratory & lung diseases. As increased short-term exposure can also lead to serious effects on health, in particular for highly sensitive groups (see§ 2.2.3), the EU and the WHO apply a separate limit value or guideline with regard to PM2.5. for short-term exposure during 24 hours.

Table 3. Weight of evidence for causal relationships between short-term and long-term exposure to PM2.5 and health effects (EPA, 2009)[17]

Health effects in relation to exposure duration	Weight of evidence for causal relationship
Short-term exposure to PM2.5 (about 1 day to about 1 week)	
Adverse effects on the cardiovascular system	Demonstrated
Adverse effects on respiratory tract and lungs	Likely
All-cause mortality	Demonstrated
Long-term exposure to PM 2.5 (about 1 year to 5 to 10 years)	
Adverse effects on the cardiovascular system	Demonstrated
Adverse effects on respiratory tract and lungs	Likely
All-cause mortality	Demonstrated

Health effects of particulate matter: state of knowledge 2017

Since the release of the 2009 EPA report referred to previously, a great deal of new knowledge has become available regarding the health effects of exposure to particulate matter. This knowledge, which is collected in a 2013 WHO report, has strengthened the evidence for the health effects that, according to the EPA, are certainly or most likely caused by exposure to particulate matter.[17] For example, additional evidence is available for the effects on the cardiovascular system as well as for premature death attributable to short-term and long-term exposure to low concentrations of PM2.5 (see § 2.2.2). In the meantime the *International Agency for Research on Cancer* (IARC) has included particulate matter on the list of substances that have been shown to be carcinogenic for humans based on the increased risk of lung cancer.[24] Relationships were also found with diseases/disorders of the central nervous system, including cognitive impairment in children as well as older adults, and birth outcomes including premature birth and low birth weight.[33-35] A recent meta-analysis suggests that long-term exposure to PM2.5 can also promote the development of diabetes.[36] However, with regard to the latter health effects, the Committee finds that there is still insufficient evidence to infer a (likely) causal relationship with exposure to particulate matter.

Specific effects of particulate matter fractions

There is an increasing body of epidemiological and toxicological research available that suggests that different components and fractions of particulate matter are associated with different health effects. For example, more information is now available about the specific effects of coarse particles, secondary particles, ultrafine particles, and black carbon.

A review of the epidemiological literature shows that short-term exposure to the coarser fraction of particulate matter (PM2.5-10), which also includes particles from natural sources, is associated with adverse effects on the respiratory tract, the lungs, and the cardiovascular system, and with an increased number of premature deaths.[37] However, the causal relationship in this regard is not as strong as it is in relation to PM2.5. An explanation of this difference in strength of the causal relationship is that coarse particles are trapped higher up in the respiratory tract, where they can be removed more effectively due to the presence of cilia.[20] Toxicological studies, by the way, make it clear that the coarser fraction of particulate matter can be just as toxic per microgram as PM2.5.

With regard to secondary particulate matter, epidemiological studies suggest that sulphate and nitrate particles (components of secondary inorganic particulate matter) have an adverse effect on the cardiovascular system. However, there is as yet only limited toxicological evidence for these effects.[33]

There is only limited epidemiological evidence for a causal relationship between short-term exposure to ultrafine particles and adverse effects on the respiratory tract, the lungs, the cardiovascular system, and the central nervous system.[32] A plausible explanation for these effects is that the immune system is not as effective in recognising such extremely tiny particles. As a result, these particles can move more easily from the lungs to other parts of the body where they can cause adverse health effects (see Figure 2 in § 2.2). The ultrafine particle fraction in the Netherlands consists primarily of black carbon particles emitted by diesel-powered vehicles.

More is now known about the health effects of black carbon as a component of (ultrafine) particles. Black carbon is generated by the incomplete combustion of fossil fuels and biomass for energy production. In 2012, the WHO concluded that black carbon – in situations dominated by primary combustion aerosols – can, in addition to particulate matter, be an additional indicator of hospital admissions for persons with cardiovascular and respiratory disorders, premature mortality from cardiovascular diseases, and all-cause mortality.[38] The WHO based this conclusion on epidemiological studies of the health effects of short-term exposure to black carbon. The same conclusion may also apply to long-term exposure to black carbon, but these studies in are very limited in number as well as contradictory.

Conclusion on health effects of particulate matter fractions

The new knowledge here has, in general, not changed the WHO's vision regarding particulate matter: the WHO is still of the opinion that PM2.5 and PM10 can serve as the best indicators of all health effects associated with exposure to particulate matter, regardless of composition and source.[20] Even though more knowledge is now available regarding the specific effects of the various components and emission sources of particulate matter, according to the WHO, this body of knowledge is still insufficient to determine separate guidelines for different groups, for example secondary inorganic particulate matter, black carbon, and ultrafine particles. The Committee shares the WHO's vision.

2.2.2 Effects of low concentrations of particulate matter.

Epidemiological studies have found adverse health effects after *short-term exposure* (about 24 hours) to very low concentrations of particulate matter (PM2.5).[17] No threshold value was found below which significant health effects no longer occurred. In other words, every reduction of exposure to PM2.5 contributes to improved public health. Studies into the health effects of *long-term exposure* also did not produce any evidence of a 'safe' threshold value. In fact, recent studies even found an increased number of premature deaths associated with long-term exposure below the health-based air quality guideline set by the WHO.[39-42]

The Committee considers it very likely that a reduction of the average PM2.5 concentration to levels below the WHO guideline can yield substantial health benefits. Each reduction of 5 micrograms/m^3 corresponds to an average increase in the life expectancy of all Dutch residents by about three months.[14]

2.2.3 Groups highly sensitive to particulate matter

Based on the body of scientific knowledge presently available, the United States EPA has identified the population groups with an increased sensitivity to the health effects of particulate matter.[17] According to the EPA, sufficient evidence exists to conclude that the following at-risk groups have an increased sensitivity to the effects of a short-term increased exposure to particulate matter: children, older adults, persons with respiratory diseases (in particular asthma patients) and persons with cardiovascular diseases. This conclusion is based on epidemiological studies in which the health effects of exposure to particulate matter were analysed separately for potentially sensitive groups within the population.

2.3 Health effects of nitrogen dioxide

Nitrogen dioxide is considered to be an important indicator for the mixture of air pollutants originating from combustion processes. Nitrogen dioxide in and of itself also causes adverse health effects.

2.3.1 Weight of evidence for health effects of nitrogen dioxide

Health effects of nitrogen dioxide: state of knowledge EPA report 2016
Table 4 presents the weight of the evidence currently available for the occurrence of health effects after short-term and long-term exposure to nitrogen dioxide as such. These data are based on an Integrated Science Assessment for Oxides of Nitrogen published by the EPA in 2016.[18] The EPA concluded that there is a causal relationship between short-term exposure to nitrogen dioxide and adverse effects on the respiratory tract and lungs. This conclusion was based, in part, on experiments in which test subjects were exposed to nitrogen dioxide. With regard to long-term exposure, the EPA concluded that a causal relationship is likely to exist with an increased incidence of asthma in children and that the consistency of the findings in this matter points to an effect of nitrogen dioxide as such.

Table 4. Weight of evidence for causal relationships between short-term and long-term exposure to nitrogen dioxide and health effects (EPA, 2016)[18]

Health effects in relation to exposure duration	Weight of evidence for causal relationship
Short-term exposure to nitrogen dioxide (lasting a few minutes to about 1 month)	
Adverse effects on respiratory tract and lungs	Demonstrated
Long-term exposure to nitrogen dioxide (1 month to about 10 years)	
Adverse effects on respiratory tract and lungs, in particular an increased incidence of asthma in children	Likely

According to the 2016 report, the evidence for a causal relationship with adverse effects on the cardiovascular system was less strong (suggestive) for short-term as well as long-term exposure. In this regard, the EPA noted that it is not clear whether these adverse effects are caused by nitrogen dioxide alone or are exacerbated or whether other components of air-pollution also play a role.[18]

Health effects of nitrogen dioxide: state of knowledge 2017
The EPA Integrated Science Assessment for Oxides of Nitrogen referred to previously was published at the beginning of 2016. More recently, epidemiological studies have increasingly been applying so-called co-pollutant models in order to study the health effects of nitrogen dioxide in combination with particulate matter and ozone and, to a more limited degree, with other components of traffic-related pollutants such as black carbon and ultrafine particles. This type of model makes it possible to investigate the role played by nitrogen dioxide as such (independently of other factors) by adjusting for the other pollutants as much as possible.[30] A number of relevant studies on the health effects of increased long-term exposure are not discussed in the EPA report referred to. For example, the Committee notes the failure of the report to include a 2014 meta-analysis of more than 10 cohort studies on the effects of long-term exposure to nitrogen dioxide on premature death.[43] This meta-analysis finds an increased mortality from cardiovascular and respiratory diseases and an increase in all-cause mortality. A number of the underlying studies

make it clear that the effects found for nitrogen dioxide do not change or hardly change after being adjusted for particulate matter or black carbon. An important cohort study from 2015 is also missing from the EPA report. This study found a strong association between long-term exposure to nitrogen dioxide and premature mortality from cardiovascular diseases, chronic respiratory diseases and lung cancer and all-cause mortality, which was practically independent of particulate matter and ozone.[39]
Based on the previously mentioned studies, the EEA has quantified the effects of long-term exposure to nitrogen dioxide on deaths in Europe (also see Table 2).[27] While doing so, it was repeatedly emphasised that although the relationships found are independent of exposure to particulate matter, it is still not yet clear whether these relationships are based on the effects of nitrogen dioxide itself or in part on the effects of other traffic-related pollutants such as black carbon and ultrafine particles, which are also independent of the effects of particulate matter.
A meta-analysis of some dozens of time-series studies recently appeared on the effects of short-term exposure to nitrogen dioxide, which dealt with the effects on all-cause mortality, on mortality from cardiovascular and respiratory diseases, and on hospital admissions.[44] These effects also turn out to be independent of the effects of black carbon and particulate matter, and the number of premature deaths is of the same order of magnitude as the number of deaths caused by exposure to particulate matter. However, the reserves mentioned previously regarding the independent role of nitrogen dioxide apply here as well.

2.3.2 Effects of low concentrations of nitrogen dioxide

There are not many recent studies available that describe the shape of the relationship that exists between long-term exposure to nitrogen dioxide and premature death. A recent study indicates that the relationship is proportional in nature.[39] According to this study, the risk increases strongly for exposure to concentrations rising from 0 to 40 micrograms/m^3. Above that level, the risk increases less rapidly. In the opinion of the committee, this means that it is very unlikely that a threshold value can be found below which health effects do not take place. Accordingly, health benefits can also be realised if the exposure to (mixtures indicated by) nitrogen dioxide is reduced to far below the WHO guideline.
This is also the point of departure for the previously mentioned estimate by the EEA of the number of deaths that can be attributed to long-term exposure to nitrogen dioxide.[27] As, discussed in § 2.3.1, the Committee notes that the matter at hand here involves relationships between death and short-term and long-term exposure to mixtures of which nitrogen dioxide is an indicator, independently of relationships with particulate matter.

2.3.3 Groups highly sensitive to nitrogen dioxide

In 2016, the United States EPA determined that sufficient evidence exists that children, older adults, and persons with respiratory diseases have a higher sensitivity to the health effects of (short-term) exposure to nitrogen dioxide.[18] More specifically, the effects on these groups are marked by an exacerbation of respiratory symptoms such as wheezing, shortness of breath, and coughing. The strongest evidence that asthma patients in particular are exposed to increased health risks upon exposure to nitrogen dioxide is provided by an analysis of controlled exposure studies. This analysis makes it clear that asthma patients exposed to higher concentrations of nitrogen dioxide show a higher airway reactivity than persons without asthma. Epidemiological studies also show that children between the ages of 0 and 14 who are exposed to increased concentrations of nitrogen dioxide suffer from an asthma attack more frequently than persons between the ages of 15 and 64. Furthermore, there is a sufficient body of consistent data available to determine that increased concentrations of nitrogen dioxide lead to a higher number of hospital admissions and a higher number of emergency department visits for children with asthma exacerbations. There are also sufficient indications that adults older than 65 who are exposed to higher concentrations of nitrogen dioxide visit the emergency department and are admitted to hospital more frequently for an exacerbation of respiratory symptoms than is the case for adults younger than 65.

2.4 Health effects of ozone

Increased ozone concentrations occur primarily on warm and windless days. The most important compounds that play a role in the development of increased ozone concentrations are nitrogen oxides, methane, carbon monoxide, and volatile organic compounds. A great deal of knowledge is available regarding the health effects of short-term increases in ozone concentrations. As long ago as the 1970s, toxicological and clinical studies involving human subjects had made it clear that the inhalation of ozone caused damage to the respiratory tract and lungs.[19] Much less is known about the effects of long-term exposure. That is also why the WHO has not yet set any guidelines for long-term exposure to ozone. However, the 2013 WHO report Health risks of air pollution in Europe (HRAPIE project) did recommend that the effects of long-term exposure to ozone on premature deaths be quantified.[21] The estimates by the EEA of the premature deaths that can be attributed to ozone in 2014, as presented in Table 2, are also based on this.[27]

2.4.1 Weight of evidence for health effects of ozone

Health effects of ozone: state of knowledge EPA overview 2013

The most recent EPA overview for ozone dates from 2013.[19] In that report, the EPA concludes, based on epidemiological studies, that *short-term (peak) exposure* to ozone certainly causes adverse effects on the respiratory tract and lungs and very likely has adverse effects on the cardiovascular system and all-cause mortality (see Table 5). Furthermore, the EPA concludes that a causal relationship is likely to exist between *long-term exposure* to ozone and adverse effects on the respiratory tract and lungs, in particular resulting in new cases of asthma in children.

Table 5. Weight of evidence for causal relationships between short-term and long-term exposure to ozone and health effects (EPA, 2013)[19]

Health effects in relation to exposure duration	Weight of evidence for causal relationship
Short-term exposure to O_3 (about 1 hour to about 1 week)	
Adverse effects on respiratory tract and lungs	Demonstrated
Adverse effects on the cardiovascular system	Likely
All-cause mortality	Likely
Long-term exposure to O_3 (1 summer season to about 10 years)	
Adverse effects on respiratory tract and lungs, in particular increased incidence of asthma under children	Likely

Health effects of ozone: state of knowledge 2017

The number of cohort studies into the health effects of exposure to ozone is slowly growing. When the EPA overview of 2013 was completed, there was only one cohort study available that showed an effect of *long-term exposure* to ozone on mortality from respiratory diseases.[45] A meta-analysis of recent studies on the effects of long-term exposure to ozone provides insufficient evidence of an effect of annual average ozone concentrations on the all-cause mortality or the mortality from respiratory or cardiovascular diseases, respectively.[46] However, the meta-analysis does identify effects of ozone concentrations measured specifically in the warm season. In three underlying studies, this applied to mortality from respiratory and cardiovascular diseases; in four underlying studies, no effects were found on all-cause mortality. Two large US cohort studies that were published after this meta-analysis show that long-term exposure to ozone is associated with an increase in all-cause mortality as well as mortality from respiratory and cardiovascular diseases.[47] Canadian studies provide more specific indications of a relationship between ozone concentrations in the warm season and an increased mortality from cardiovascular diseases but not from respiratory diseases.[39,48]

2.4.2 Effects of low concentrations of ozone.

An important question is whether threshold values exist below which no effects of *short-term exposure* to ozone can be demonstrated. This question is difficult to answer, as very few days actually occur with very low ozone concentrations, especially in the warm season. This refers to 8-hour measurements with maximum concentrations of about 40 micrograms/m^3 or less. As such low concentrations occur very infrequently, it’s very difficult to determine whether adverse health effects also take place even at very low ozone concentrations. According to the EPA, no threshold values were found in most of the studies on the effects of short-term exposure to ozone.[19]

Not enough studies have been carried out on the health effects of *long-term exposure* to ozone to draw a conclusion about the existence of threshold values. One study shows a roughly positive linear association between long-term exposure to ozone and mortality from respiratory diseases starting at concentrations of about 100 micrograms/m^3.[45] Another study shows a positive but irregular association that becomes steadily stronger from 80 micrograms/m^3 and upward.[47] The latter study focuses on the association with mortality from respiratory and cardiovascular diseases.

2.4.3 Groups highly sensitive to ozone

According to the EPA, sufficient evidence exists to conclude that the following groups have an increased sensitivity to the health effects of exposure to ozone: persons with a specific genetic predisposition to airway reactivity, asthma patients, children, older adults, persons with insufficient intake of vitamin C and E, and persons who are active outdoors.[19] The EPA based its conclusions on epidemiological studies and controlled experiments with human and animal subjects.

2.5 Conclusions and recommendations

Based on the findings described in this chapter (and the more detailed supporting arguments in the Health Effects background document), the Committee comes to the following conclusions and recommendations:

- Over the past years, a considerable weight of evidence has been accumulated regarding the relationship between exposure to air pollution and health effects, even at concentrations below the WHO guidelines.
- The most important components from a health perspective are particulate matter, nitrogen dioxide, and ozone. In 2014, the concentrations of these substances in the air in the Netherlands led to an estimated 12,000 premature deaths and a decrease in the average life expectancy per person by almost 1 year. Substantial health benefits can therefore be expected to be realised if the air quality not only improves to levels better than the European standards but also to levels better than the WHO guidelines.
- Reducing the concentrations of particulate matter contributes the most to these health benefits. Each reduction of 5 micrograms/m^3 of PM2.5 in the air would add about three months to the average life expectancy of the population.
- Recent epidemiological studies suggest that exposure to nitrogen dioxide also has health effects, in addition to the effects of particulate matter, but some uncertainty still exists with regard to the magnitude of these effects.
- Recent studies provide increasing and continuing indications that long-term exposure to ozone leads to an increased risk of premature death.
- The Committee finds it important, within the framework of striving to achieve health benefits, to take into account persons with increased sensitivity to air pollution, the so-called highly sensitive groups. These consist primarily of children, older adults, and persons with respiratory diseases (see Figure 3). Based on the present state of knowledge, it's

not possible to accurately determine how large the health benefits are that would be realised.

- Finally, the Committee advocates the more active dissemination of specific behavioural advice to highly sensitive groups, for example during periods of (ozone) smog not engaging in any heavy effort outdoors in the afternoon or else staying indoors.

In particular children, older adults and persons with respiratory diseases are highly sensitive to air pollution

	PM2.5	NO2	Ozone
Children	⚠	⚠	⚠
Older adults	⚠	⚠	⚠
Persons with respiratory diseases (asthma)	⚠	⚠	⚠
Persons with cardio-vascular diseases	⚠		
Persons who are active outdoors			⚠
Persons with an insufficient intake of vitamins C and E			⚠

Figure 3. Highly sensitive groups

03 focal points for air quality policy

The most important sources of pollution must be dealt with in order to further reduce air pollution in the Netherlands and the associated health effects. In the Netherlands, this means that measures must primarily be aimed at reducing emissions from agriculture and road traffic throughout the Netherlands (§ 3.1). The generic approach to dealing with these sources must, in particular, reduce the blanket of particulate matter in the air as a whole (§ 3.2). In addition, specific attention should be paid to persons with a relatively high exposure to air pollution because they live or remain in the direct vicinity of sources that result in higher local concentrations. (§ 3.3).

3.1 Most important sources of air pollution in the Netherlands

The concentrations of air pollutants in the Netherlands originate primarily in agriculture and road traffic. Part of the emissions produced outside the Netherlands also reach the Netherlands.

A brief description is given of what is currently known about the origin of the three components of air pollution that play a central role in the report at hand: particulate matter, nitrogen dioxide, and ozone. With regard to these components, the Committee concluded in the previous chapter that a reduction of their concentrations, even to levels below the WHO guidelines, would yield health benefits. This means that an approach that targets the sources that contribute the most to the concentrations of these three components could also make the largest contribution to the realisation of health benefits.

3.1.1 Origin of particulate matter: primarily agriculture and road traffic

Particulate matter that is introduced into the air directly via human activity or natural processes is referred to as the *primary fraction*. Besides agriculture and motorised road traffic, shipping and industry are also important sources.[49] In addition, particulate matter also contains components from natural sources such as sea salt and windblown soil particles; these contribute less than 5% to the concentration of particulate matter in the Netherlands.[50]

The secondary fraction of particulate matter (secondary particulate matter) consists of substances that are formed as the result of chemical reactions between so-called precursors in the air. Reactions involving ammonia, nitrogen oxides, and sulphur dioxide lead to the formation of secondary inorganic aerosols such as ammonium nitrate and ammonium sulphate. Reactions with volatile hydrocarbons lead to the formation of secondary, organic aerosols. The formation of secondary particulate matter takes some time. During this time period, it can be distributed evenly and over large distances.

Spatial differences in particulate matter concentrations

Figure 4 shows that particulate matter (PM2.5) covers large parts of our country in the shape of a blanket. The explanation for this is that more than half of the concentration of PM2.5 in the Netherlands, including urban areas, consists of secondary particulate matter that spreads itself out over large distances.[4] The concentrations in urban areas in the South and East are on average 2 micrograms/m^3 higher.[49] Near cities, this is caused by the higher population density; in the South, the density of livestock farms and the vicinity of cross-border emission sources play a role. In addition, weather conditions play a large role in determining the distribution of particulate matter over large distances.

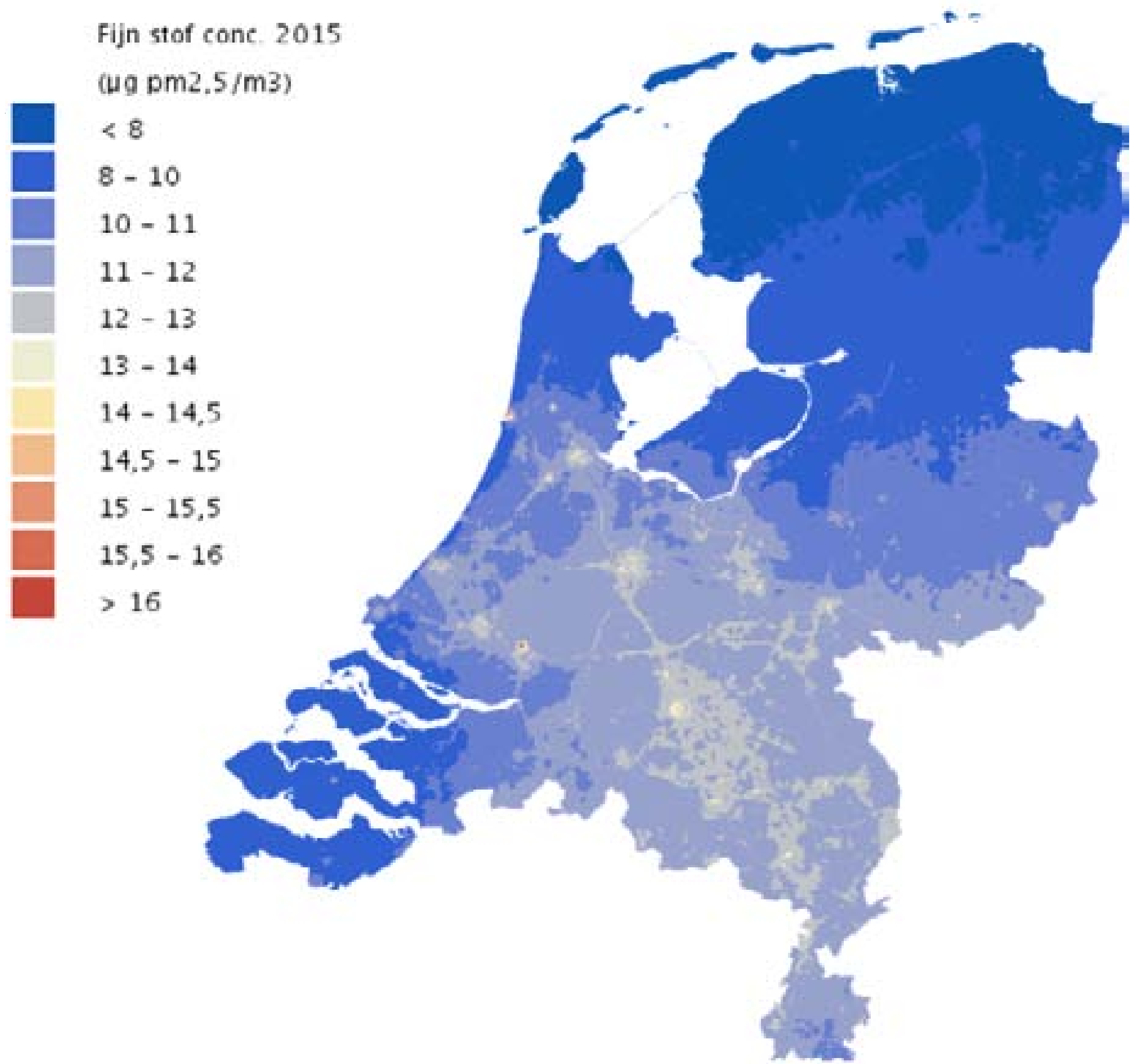

Figure 4. Average PM2.5 concentration in 2015
Source: Atlas of the Living Environment

Increased concentrations of particulate matter on a regional and local scale

The spatial distribution of PM10 is similar to that of PM2.5, except that the regional increases in PM10 are much greater, particularly in the vicinity of heavy industry such as the basic metal industry in the IJmond, harbours, in particular the harbour area of Rotterdam, and intensive livestock farms.[8] The Committee does not expect the concentrations of secondary particulate matter (PM2.5) to be greatly increased in the immediate vicinity of intensive livestock farms as a result of ammonia emissions, as secondary particulate matter is formed over a longer period of time and therefore spreads itself out over larger areas. Recently, indications have findings to health issues is presently under investigation.[52] The contribution from air traffic to regional PM2.5 concentrations is relatively small.[49,53]

Most of the particulate matter in the air above the Netherlands comes from outside the country. The most important sources inside the Netherlands are agriculture and road traffic

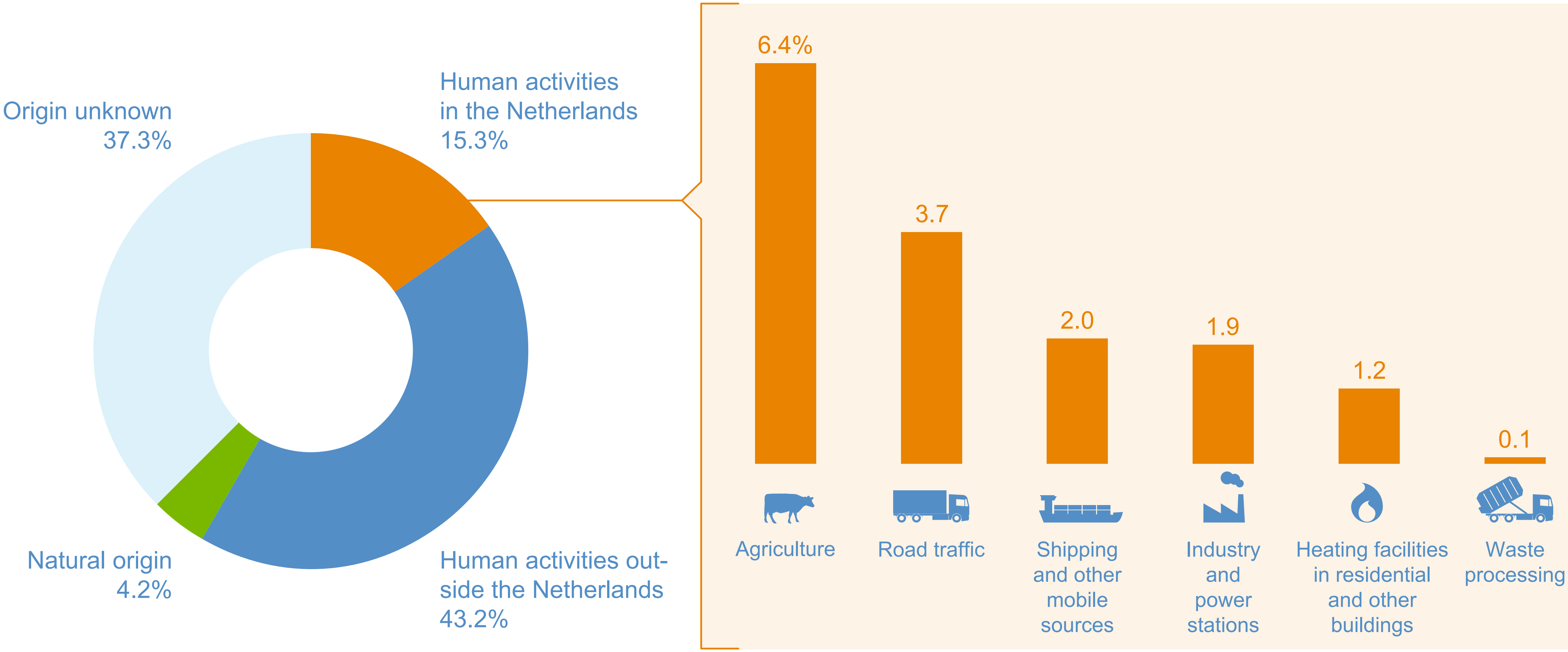

Figure 5. The origin of the average concentration of particulate matter (PM2.5)
Bron: Hendriks et a.[50]

Origin of blanket of particulate matter

Figure 5 shows where the mentioned blanket of particulate matter comes from: the origin of the average concentration of particulate matter (PM2.5) in the air in the Netherlands, measured over an entire year.

The emissions of particulate matter from agriculture and road traffic in the Netherlands, taken together, account for about 10% of the average PM2.5 concentration in the air.[50] The contribution from agriculture includes the particulate matter emitted from poultry barns and pig stalls and ammonium from cows. The contribution from road traffic consists primarily of emissions from diesel-powered vehicles.

The emissions from shipping, industry (including power generation), heating facilities, and waste processing collectively account for about 5% of the average PM2.5 concentration in the Netherlands. Heating facilities include wood-burning by individuals as well as all other heating facilities in residential and other buildings. Of course, these contributions can be much higher or lower on a local scale.

The amount of particulate matter that enters the air over the Netherlands originating from human activities in other countries is clearly bigger (40-45%) than the amount of particulate matter contributed by all sources in the Netherlands together (about 15%). In particular, the contribution by European industry is very substantial. Vice versa, emissions from Dutch sources also contribute to exposure to particulate matter in other countries. It should be noted that 35-40% of the concentrations of particulate matter cannot yet be attributed to specific human activities.

Origin of increased black carbon concentrations in cities

In past years, the emission of particulate matter by road traffic inside and outside the Netherlands accounted for about half of the locally increased black carbon concentrations in urban areas.[49] Due to the increased use of (diesel) particle filters, emissions from road traffic are expected to decrease, which means that other sources will contribute a relatively higher percentage to the black carbon concentrations in urban areas. The relative contribution from wood-burning, for example, will increase from roughly 20% in 2015 to 30% in 2020.[54] At present, it is not possible to arrive at a reliable estimate of the local contribution by wood-burning to air pollution, as there is not enough information available on the locations of these sources and wood-burning behaviour (see Air Pollution background document).

Uncertainties

Determining the origin of particulate matter concentrations in the air is no simple matter. The Committee wishes to point out that emission inventories and explanatory models are associated with various uncertainties, as they are based on the present state of knowledge, which is far from complete. None of the Dutch or international models can fully explain the origin of the concentrations of particulate matter measured. This is caused primarily by a lack of knowledge about how the organic component of particulate matter is formed and its origin. In the Air Pollution background document, the Committee discusses in greater detail, specifically for particulate matter, the uncertainties involved in the measurement and calculation of air quality.

3.1.2 Origin of nitrogen dioxide: primarily diesel engines

Spatial differences in nitrogen dioxide concentrations

The nitrogen dioxide concentrations in the air above the Netherlands are distributed according to a noticeable spatial pattern. As Figure 6 shows, the average nitrogen dioxide concentrations in 2015 varied from less than 10 micrograms/m³ in the sparsely populated north of the Netherlands to more than 20 micrograms/m³ in the densely populated urban areas.

Elevated nitrogen dioxide concentrations regionally and locally

Figure 6 shows that elevated concentrations of nitrogen dioxide are primarily found in the cities and alongside motorways. At some monitoring stations in the vicinity of road traffic, average concentrations of more than 40 micrograms/m³ were measured. All such cases involved busy roads in urban areas. In addition, regionally elevated concentrations of more than 40 micrograms/m³ can be seen in the Rotterdam port area. The latter hotspots are primarily caused by emissions from diesel engines on (inland) shipping vessels and from mobile machines used for storing and transferring containers.

Origin of elevated nitrogen dioxide concentrations

Motorised road traffic remains the most important source of nitrogen dioxide: 90% of the emissions from road traffic comes from diesel-powered vehicles.[55] The quantity of nitrogen dioxide emitted by road traffic

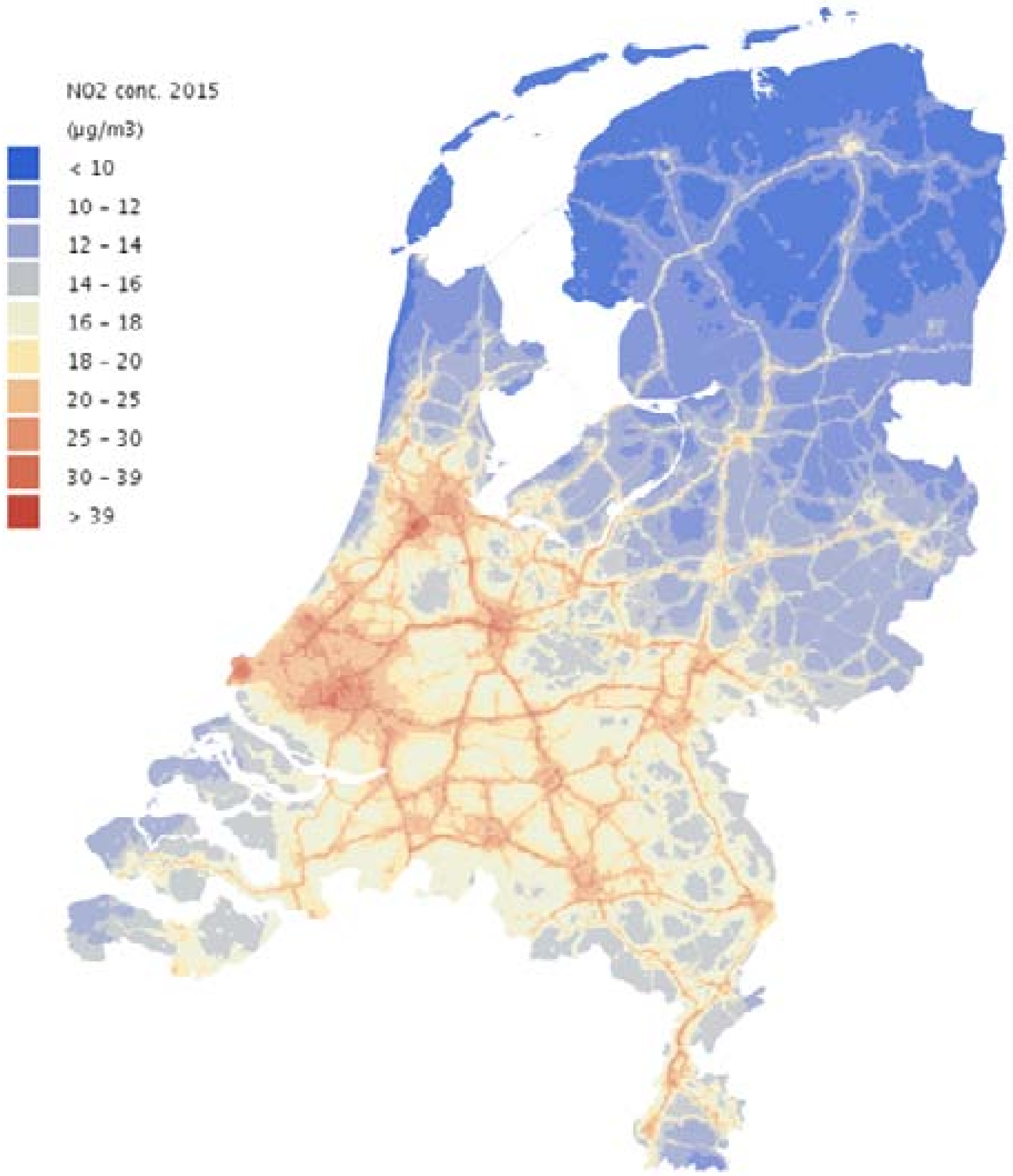

Figure 6. Annual average nitrogen dioxide concentration in 2015
Source: Atlas of the Living Environment

entering the Netherlands from across the border is responsible for a bit more than 35%.[49]

3.1.3 Origin of ozone: precursor gases from other parts of the world

The annual average ozone concentrations in 2015 were around 40 micrograms/m³ (or 20 ppb). There was a slight increase from 2012 to 2015. The average concentrations in 2016 were lower than in 2015, probably due to the poor summer. Sunlight plays an important role in the formation of ozone. Under the effects of sunlight, it is formed in the air from nitrogen oxides, carbon monoxide, volatile hydrocarbons, and methane.

Spatial differences in ozone concentrations

During summer smog episodes, short-term ozone peak concentrations occur in the Netherlands in an area covering a few hundred square kilometres. The most smog days occur in the south and in the east of the country (see Figure 7). This is due, in part, to the higher average temperatures in these areas and the inflow of ozone-rich air from the southern and eastern part of Europe.[56] Furthermore, elevated ozone concentrations actually occur more frequently in rural areas, as opposed to the other components of air pollution. This is because, in urban areas, ozone is broken down by the nitrogen monoxide present in exhaust gases.

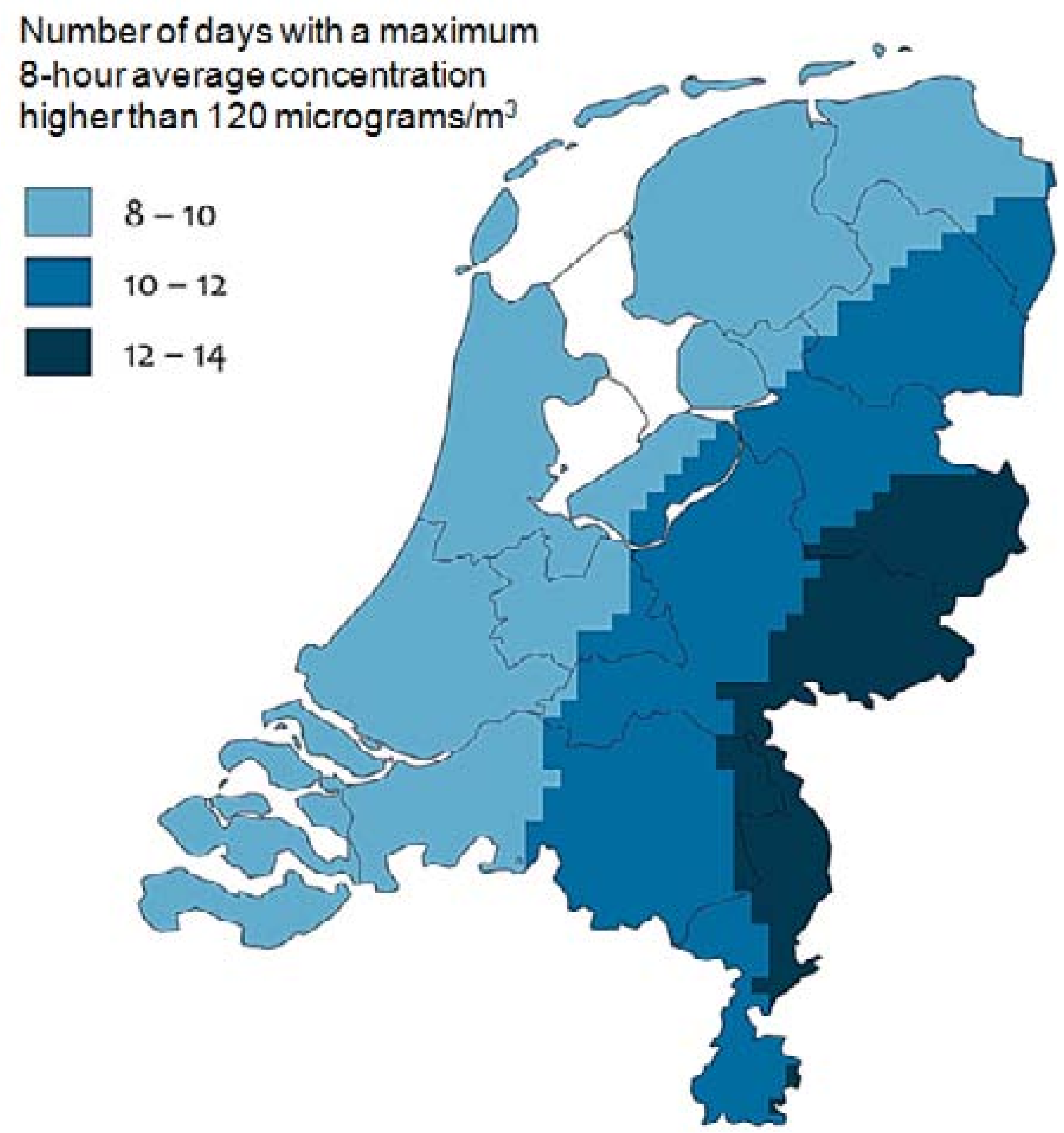

Figure 7. Spatial distribution of exposure to ozone expressed as the number of days with a maximum 8-hour average concentration higher than 120 micrograms/m³ (average over 2010-2012)
Source: Environmental Data Compendium (www.clo.nl), based on data from RIVM 2013

The number of smog days has decreased since the 1990s (see Air Pollution background document), but the average concentration of ozone in the Dutch atmosphere measured over an entire year is not decreasing.[56] The long-term exposure to ozone of the entire population of the Netherlands is therefore also not decreasing. Measurements at urban background monitoring stations in 2004 revealed an average ozone concentration of 39 micrograms/m^3 for all of the Netherlands. In 2015 this concentration had increased to 43 micrograms/m^3. This is due to the decreasing emissions of nitrogen oxides in combination with an increasing import of ozone from outside the country. In fact, more ozone is being formed in the entire northern hemisphere due to the increasing emissions of so-called ozone precursor gases such as nitrogen oxides and methane. Climate change could lead to a further increase in ozone concentrations in the air, due to an increase in the number of hours of sunshine per day and an increase in the naturally occurring emissions of volatile hydrocarbons from trees.

Origin of elevated ozone concentrations

The gases from which ozone is formed (carbon monoxide, volatile hydrocarbons, and methane) are released into the air largely as a result of human activities, including road traffic, shipping, and heating facilities. During warm weather, volatile hydrocarbons are also released into the air by trees. Sources inside the Netherlands hardly play a role in the development of elevated ozone concentrations. The formation of ozone takes place on a continental and global scale.

3.2 Generic policy aimed at protecting the entire Dutch population

A generic approach, in other words an approach that applies to the Netherlands as a whole and that aims to reduce the blanket of particulate matter, would result in the maximum possible health benefits. Every reduction in PM2.5 concentration of 5 micrograms/m^3 results in an increase in life expectancy by approximately three months (see Chapter 2).[14]

Reducing the blanket of particulate matter

According to the committee, the first thing that needs to be done in order to deliver health benefits to the Dutch population as a whole in the coming years is to reduce the emissions from the sources that cause the blanket of particular matter over the Netherlands. The most important sources inside the Netherlands that can be influenced are:[50]

- agriculture;
- road traffic.

Followed by:

- shipping and mobile machines;
- industry and power stations;
- heating facilities, in particular the burning of wood.

In the following section, the Committee provides some examples of focal points for generic policy. The Committee points out that the amount of health benefits that can be achieved in practice depends on political choices. For a reduction of air pollution to below the WHO's air quality guidelines, additional policy measures are required. The amount of health benefits to be achieved in practice depends in part on how strictly compliance with the regulations can be enforced.

Reducing emissions from livestock farming

In the first place, emissions of primary particulate matter and in particular ammonia from livestock farming contribute to the formation of secondary particulate matter and the blanket of particulate matter. A nationwide approach to dealing with ammonia emissions would have to be an indispensable element of an air quality policy aimed at improving the air quality throughout the Netherlands. However, this would require strict enforcement of the regulations that apply to manure. The approach needed to reduce other emissions from the livestock farming sector is dealt with in a separate advice from the Health Council.

Reducing emissions from diesel-powered vehicles

In order to achieve a further reduction in the emissions of and exposure to particulate matter, black carbon, and nitrogen dioxide, it would seem logical to reduce the use of diesel as a fuel for motorised road traffic. The Committee is of the opinion that the most health benefits can be realised by reducing the share of diesel-powered vehicles using the roads. Such measures are being prepared in various major cities in Europe. In part thanks to the increasing use of particle filters in diesel-powered vehicles, the emission of black carbon from road traffic is falling sharply. The use of emission cheating software, as a result of which the actual emission of nitrogen oxides by diesel vehicles is much higher in practice than is permitted in accordance with the type approval, underlines the importance of strictly enforcing regulations.

Reducing emissions from private wood-burning

Wood-burning contributes not only to the local exposure to particulate matter and especially black carbon (see § 3.3), but also to the formation of the blanket of particulate matter. Examples of measures considered by the Committee that would reduce wood-burning emissions include stricter emission standards for wood-burning stoves and measures aimed at discouraging the use of wood stoves and pellet stoves in private homes, for example public information campaigns about wood-burning.

International approach

As the amount of particulate matter that enters the Netherlands from outside the country is larger than all the contributions from sources inside the Netherlands, international agreements are also needed, in particular targeting the emissions from industry and electrical power stations. In addition, international policy is important in order to reduce the emissions of particulate matter and in particular ammonia from the agricultural sector. The proposed national emission ceilings will result in a barely perceptible decrease in the emissions of ammonia in the countries surrounding the Netherlands by the year 2030. The Committee therefore recommends evaluating, in consultation with neighbouring countries, whether measures that have proven effective in the Netherlands could also have a greater impact outside the Netherlands. Examples of such measures include efforts made to minimise emissions during the spreading of manure on the land (incorporation of manure into arable land within a specified timeframe and injection of liquid manure into grassland) and the installation of air scrubbers at stables.

In order to ensure that the annual average ozone concentration does not increase any further, the emissions of ozone precursor gases (nitrogen oxides, volatile organic substances, carbon monoxide, and methane) would have to be reduced, in Europe as well as the rest of the northern hemisphere. An international approach is needed to achieve this as well. If the emissions of nitrogen oxides were to decrease in the Netherlands alone and the present import of precursor gases from other parts of the world were to remain the same, it could actually lead to an increase in the ozone concentration in the Netherlands. That is because nitrogen oxides not only contribute to the formation of ozone but also to ozone being broken down near the source.[56] This would then take place primarily in urban areas. As these areas contain many local emission sources, the decrease in the emission of nitrogen oxides will be the greatest there and less ozone will be broken down as well.

A reduction of methane emission is beneficial for the climate as well as for a reduction of ozone formation. A reduction in the use of fossil fuels would also lead to a reduction in the emission of other precursor gases. In general, the Committee recommends integrating air-quality aspects more closely into the formulation of international energy and climate plans. More specifically, it argues that the new European air quality regulations should be based on the health-based WHO air quality guidelines.

3.3 Location-specific policy aimed at protecting high-risk groups

In addition to a generic approach, the Committee proposes implementing additional measures at a local level for the protection of so-called high-risk groups. This can lead to further health benefits. Based on the present state of knowledge, it’s not possible to accurately determine how large these health benefits would be. The Committee finds it important to ensure, with the help of location-specific policy, that the number of persons belonging to the group defined as highly exposed is further reduced and, in particular, the number of persons within that group who are also highly sensitive. These location-specific measures consist, on the one hand, of tackling local sources, and on the other, of formulating zoning plans that take air quality sensitive locations into account, for example by structuring the living environment in such a manner as to maximise the distance between residential neighbourhoods, schools or childcare centres, and local sources of particulate matter and nitrogen dioxides (see § 3.3.2).

3.3.1 Tackling local *hot spots*

Location-specific measures are needed to tackle high-exposure situations. This includes traffic-related exposure as well as exposure in the vicinity of local industry, harbours, and intensive livestock farming sites. Providing extra protection for high-risk groups near these locations can deliver further health benefits as long as it does not lead to an increase in the average exposure of the population as a whole. In particular, cities can influence local hotspots of nitrogen dioxide and primary particulate matter, for example by targeting black carbon emissions and tire and road surface abrasion. The Committee is of the opinion that local sources of air-pollution must also be dealt with on a local level. The most important of these are mobile sources such as road traffic, shipping, and mobile machines. Potential measures that are worth considering include the reduction of car traffic (promoting walking, cycling, and public transport), a ban on certain types of vehicles in environmental zones (e.g. old cars, certain types of trucks, diesel-powered vehicles, scooters et cetera), implementing maximum speed limits, promoting electrical vehicles, encouraging the use of low-emission and zero-emission mobile machines, implementing facilities for shore-based electrical power in harbours, and a ban on wood-burning in certain residential neighbourhoods. These examples of local measures were assessed as being promising when it comes to reducing local exposure levels.[57] The Committee refers the reader to a separate advice from the Health Council with regard to measures aimed at reducing the emissions from intensive livestock farming facilities.

3.3.2 Zoning policy for air quality sensitive locations

In a previous advice, the Health Council argued for a zoning policy that takes into account the sensitivity of certain population groups to air pollution in order to limit the health effects of air pollution.[58] The goal of such policy is to structure the living environment in such a way as to ensure that long-term increased exposure to air pollution is prevented as much as possible, in particular for highly sensitive groups. Children, older adults, and persons with respiratory disorders, in particular asthma patients, are all highly sensitive groups.
Zoning policy that takes air quality sensitive locations into account can, for example, include measures that prohibit the construction of childcare centres, schools, or residential care centres alongside busy roads or within specified zones near motorways. Vice versa, road construction plans should also take into account the presence of sensitive locations. Such policies could reduce the health risks of highly sensitive groups that live or stay in situations characterised by locally increased air pollution levels.

3.4 Conclusions and recommendations

Conclusions

- The collective contribution of foreign sources to the particulate matter concentrations in the Netherlands is greater than the total contribution of all sources inside the Netherlands. Vice versa, emissions from Dutch sources also contribute to exposure to particulate matter in other countries.
- Inside the Netherlands, agriculture and road traffic are the most important preventable sources of air-pollution, especially particulate matter.
- Chemical reactions of particulate matter with ammonia, nitrogen oxides, and sulphur dioxide in the air result in the formation of secondary particulate matter. This secondary particulate matter forms a blanket that covers large parts of the Netherlands and has a major impact on the annual average concentrations to which the entire Dutch population is exposed.
- In cities, people are exposed in particular to black carbon and nitrogen dioxide alongside busy roads. This is caused primarily by diesel-powered vehicles.
- The annual average concentration of ozone in the air layer in which we live is not decreasing; an increasing trend is expected, in part due to climate change.

Recommendations

- In order to reduce the blanket of particulate matter (PM2.5) covering all of the Netherlands, the policy measures taken will have to be primarily of a generic nature and target the sources and sectors that contribute the most to the average exposure to particulate matter. The most important of these are the agricultural sector and road traffic.
- Measures targeting road traffic can also reduce the emissions of nitrogen dioxide.
- In order to ensure that the annual average ozone concentration does not increase any further, the emissions of ozone precursor gases, such as nitrogen oxides and volatile organic substances, from traffic and the emission of methane from livestock farming have to be reduced, not only in Europe but also in the rest of the northern hemisphere. This can be realised only via an international approach.
- The proposed national emission ceilings will result in a barely perceptible decrease in the emissions of ammonia in the countries surrounding the Netherlands by the year 2030. The Committee therefore recommends evaluating, in consultation with neighbouring countries, whether measures that have proven effective in the Netherlands, such as efforts made to minimise emissions during the spreading of manure on the land and the installation of air scrubbers at stables, could also have a greater impact there as well.
- Location-specific measures that target sources will have to be implemented in order to reduce long-term exposure to local

air-pollution. Examples of such measures include low-traffic inner cities, environmental zones, maximum speed limits, and promoting the use of electrical transport, bicycles, and walking. Such measures provide extra protection to the highly exposed group and also contribute to an effective reduction of average exposure for all residents of the Netherlands.

- In addition to the source-based approach at the local level, the Committee also advocates a zoning policy that takes into account the sensitivity of certain population groups to air pollution. This means that, within the framework of zoning policy, the building of facilities intended for children, older adults, and other highly sensitive groups would not be allowed in locations with increased exposure to air-pollution. This is in line with a previous recommendation from the Health Council.
- None of the Dutch or international models can fully explain the origin of the concentrations of particulate matter measured. According to the committee, measuring the specific components of particulate matter – such as ammonium salts, components released during the burning of wood, organic compounds, and rubber particles - would make it easier to trace air pollutants to specific sources. It therefore argues for research projects that focus on tracking down the specific source of emissions and that improve our knowledge of the formation of secondary particulate matter (see Air Pollution background document).
- For a reduction of air pollution to levels below the WHO's air quality guidelines, additional policy measures are required. The Committee recommends that cost-benefit analyses be carried out for the various policy measures in order to allow for a careful and transparent decision-making process. The Committee is of the opinion that the costs should be compared not only to the potential health benefits but also to other benefits, such as the contribution made to the realisation of the energy and climate policy goals. The Committee also recommends taking into account that the amount of health benefits to be achieved in practice depends, among other things, on how strictly compliance with the regulations can be enforced.

04
answers to the requests for advice

In this chapter, the Committee formulates answers to the questions asked by the State Secretary for Infrastructure and the Environment (§ 4.1 up to and including 4.4) and to the sub-question in the request for advice from the Ministry of Economic Affairs regarding livestock farms (§ 4.5). In doing so, the Committee notes that the scope of the conclusions and recommendations in Chapters 2 and 3 extends beyond simply answering the questions of the ministers.

4.1 Health effects of air pollution

'What is the current state of scientific knowledge on the potential health effects of air pollution?'

It is clear that air-pollution, even at present concentrations, can still result in significant adverse health effects. For example, exposure to particulate matter, nitrogen dioxide, and ozone is estimated to result in approximately 12,000 premature deaths per year in the Netherlands. Even at concentrations below the health-based WHO guidelines, adverse effects on the respiratory tract, lungs, and cardiovascular system have been observed that result in premature death. Health benefits can be realised for every increment of reduction of air pollution. For particulate matter (PM2.5) – the most relevant component of air pollution from a health perspective – each additional reduction of 5 micrograms/m^3 would lead to an average increase of three months in the life expectancy of the Dutch population. The Committee thinks it plausible that exposure to nitrogen dioxide also has health effects, in addition to the effects of particulate matter, but some uncertainty still exists with regard to the magnitude of these effects. Recent studies provide increasing indications that long-term exposure to ozone also results in premature death.

4.2 Sources of air pollution

'Can the Health Council specify which sources are presently the most important sources of air pollution in the Netherlands? Which sources should be given priority from a public health perspective?'

The sources and sectors that contribute the most to the average exposure to particulate matter (PM2.5) are agriculture and motorised road traffic, inside as well as outside the Netherlands. Polluted air from outside the Netherlands is responsible for almost half of the concentrations of particulate matter observed in our country. Motorised road traffic, in particular diesel-powered vehicles, is the most important source of nitrogen dioxide. Ozone is formed in the air from nitrogen oxides and hydrocarbons. The most important sources of hydrocarbons in the Netherlands are road traffic and methane emissions from livestock farming. The Committee finds it troubling that the annual average concentration of ozone in the Netherlands is no longer decreasing and that an increasing trend is expected, in part due to climate change.

The Committee recommends that national policy should give priority to:

- reducing the emission of particulate matter and nitrogen dioxide from diesel-powered vehicles and reducing the share of diesel-powered vehicles on the roads;
- reducing the emissions of ammonia from livestock farming, which serves as a precursor for the formation of secondary particulate matter, via measures aimed at minimising emissions during the spreading of manure on the land and the installation of air scrubbers at stables (for more information, refer to the advice of the Health Council on health risks in relation to livestock farming).

From an international perspective, it's important that policy also focus on encouraging other European countries to reduce the emission of substances that contribute to the formation of particulate matter and ozone. One way to do so is to evaluate how the injection of manure and the use of air scrubbers in the neighbouring countries can be more effective in reducing the emissions of ammonia and therefore also the formation of secondary particulate matter. To effectively lower ozone concentration in the Netherlands, the emissions of nitrogen oxides and methane must be reduced throughout Europe and even in the rest of the northern hemisphere. After all, these emissions determine the ozone concentrations in the Netherlands and cannot be influenced via Dutch national policy.

4.3 Added value of extra focus on high-risk groups

'In addition, I request that, in your advice, you also focus specifically on the potential added value of devoting extra attention to vulnerable groups within the framework of future air-quality policy.'

The Committee uses the term high-risk groups instead of vulnerable groups to refer to groups within the population that not only incur a high risk of adverse health effects due to their higher sensitivity (the highly sensitive groups) but also due to higher exposure to air pollution (the highly exposed groups). The most important highly sensitive groups are children, older adults, and persons with respiratory disorders. Persons with cardiovascular diseases, persons who are active outdoors, and persons with a reduced intake of vitamins C and E are at increased risk of adverse health effects from specific components of air pollution (see Figure 3 in Chapter 2).

Extra health benefits can be realised by implementing local policy measures aimed at protecting high-risk groups, in addition to generic air-quality policy measures. Based on the present state of knowledge, it's not possible to accurately determine how large the health benefits are that would be realised. Low-traffic inner cities, environmental zones, maximum speed limits, and promoting the use of electrical transport, bicycles, and walking are examples of location-specific measures aimed at tackling local increases in exposure to air pollution. In addition, zoning policy that take into account air quality sensitive locations are a potential tool for protecting highly exposed groups that are also highly sensitive to air-pollution. The implementation of such policy would prevent the building of facilities intended for children, older adults, and other highly sensitive groups in locations with increased exposure to (traffic-related) air pollution. Finally, the Committee advocates the more active dissemination of specific behavioural advice to highly sensitive groups, for example during periods of ozone smog not engaging in any heavy effort outdoors in the afternoon or else staying indoors.

4.4 Health-relevant air quality indicators

'What are potentially the most important focal points for air-quality policy? Are nitrogen dioxide and particulate matter still the most appropriate indicators for evaluating and updating air-quality policy or are there any other substances or indicators that provide better instruments for realising health benefits, and if so which?'

The Committee recommends using the annual average exposure of the general population to particulate matter (PM2.5), nitrogen dioxide, and ozone as the most important health-based indicators of air quality, and recommends the implementation of generic measures to reduce the average exposure. Reducing the concentrations of particulate matter blanketing the Netherlands contributes the most to these health benefits. Each reduction of 5 micrograms/m^3 of PM2.5 in the air would add about three months to the average life expectancy of the entire Dutch population.

4.5 Health risks of local residents near livestock farms due to secondary particulate matter

The Ministry of Economic Affairs has asked the Health Council, also on behalf of the Ministry of Infrastructure and the Environment and the Ministry of Health, Welfare and Sport, for an advice with regard to the health risks associated with living in the vicinity of livestock farms.[16] In Chapter 3 of the advice at hand, the Air Quality Committee has answered the following sub-question regarding the exposure to secondary particulate matter as a result of the emission of ammonia from livestock farming.

'What is known about the health risks of exposure [to secondary particulate matter resulting from the emission of ammonia], about the livestock farming sector as a source of secondary particulate matter, and about risk mitigation measures? Are additional studies on this topic worth carrying out and, if so, which studies should be given priority?'

The emission of ammonia from livestock farms contributes to the formation of secondary particulate matter (ammonium salts) and therefore makes an important contribution to the total concentration of particulate matter in the Netherlands and neighbouring countries. As it takes quite

some time for secondary particulate matter to be formed and it has by then spread over large distances, the concentrations of secondary particulate matter on a very local scale, in the immediate vicinity of livestock farms, are not expected to be significantly higher than in locations further away. It is therefore not likely that the health risks related to secondary particulate matter differ significantly between local residents living near livestock farms and persons living further away.
The Committee advocates research projects that focus on tracking down the specific source of emissions and that improve our knowledge of the formation of secondary particulate matter. As it turns out, none of the Dutch or international models can fully explain the origin of the concentrations of particulate matter measured.

For more information, the Committee refers the reader to the advice by the Health Council regarding health risks in the vicinity of livestock farms.

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