Health Council of the Netherlands

The influence of nitrogen on health

Gezondheidsraad
Health Council of the Netherlands

To the State Secretary of Infrastructure and the Environment

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The influence of nitrogen on health
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Dear State Secretary,

I hereby present the horizon-scanning report *The influence of nitrogen on health*. It was drafted by the Health and Environment Surveillance Committee, which is tasked with alerting the government and Parliament to important issues in the area of health and the environment, and with identifying any associated opportunities and threats. It was evaluated by the Standing Committee on Health and the Environment.

The horizon-scanning report draws attention to the importance of solid nitrogen policy for public health. The problems caused by an excess of nitrogen in the environment in The Netherlands are well-known. Policy addressing these issues has existed for a long time, primarily focused on redacting of fertiliser surpluses and air pollution. However, the Committee also believes the issue requires additional attention from a public health perspective.

This horizon-scanning report is also relevant to policy areas that other members of government are responsible for. Therefore, I also forwarded this report to the State Secretary of Economic Affairs and the Minister of Health, Welfare and Sport.

Yours sincerely,

(signed)
Professor H. Obertop
Vice President

P.O.Box 16052
NL-2500 BB The Hague
The Netherlands
Telephone +31 (70) 340 73 27
E-mail: pw.van.vliet@gr.nl

Visiting Address
Parnassusplein 5
NL-2511 VX The Hague
The Netherlands
www.healthcouncil.nl

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to:

the State Secretary of Infrastructure and the Environment

the State Secretary of Economic Affairs

the Minister of Health, Welfare and Sport

No. 2012/28E, The Hague, December 10, 2012

The Health Council of the Netherlands, established in 1902, is an independent scientific advisory body. Its remit is “to advise the government and Parliament on the current level of knowledge with respect to public health issues and health (services) research...” (Section 22, Health Act).

The Health Council receives most requests for advice from the Ministers of Health, Welfare & Sport, Infrastructure & the Environment, Social Affairs & Employment, Economic Affairs, and Education, Culture & Science. The Council can publish advisory reports on its own initiative. It usually does this in order to ask attention for developments or trends that are thought to be relevant to government policy.

Most Health Council reports are prepared by multidisciplinary committees of Dutch or, sometimes, foreign experts, appointed in a personal capacity. The reports are available to the public.

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Executive summary

Nitrogen is required for all life forms. For example, it is a key building block for proteins. Plants, animals and humans absorb it as reactive nitrogen. This must be formed from atmospheric nitrogen. In nature, reactive nitrogen is only formed on a limited scale, primarily by microorganisms. The artificial formation of reactive nitrogen was made possible a century ago by the invention of a process for synthesising ammonia. This invention laid the groundwork for the manufacture of artificial fertiliser. This made a huge increase in food production per hectare of land possible. In addition to ammonia, numerous nitrogen-containing compounds are classified as reactive nitrogen, including ammonium and nitrate salts.

Rich regions and countries, including Europe and the Netherlands, have to deal with an excess of reactive nitrogen in the environment. This affects the environment and public health. The excess of reactive nitrogen has two main causes: agriculture and livestock production, and the combustion of fossil fuels.

The Health Council of the Netherlands examined the potential effects of reactive nitrogen on Dutch public health. One of the Health Council's Committees, the Health and Environment Surveillance Committee, evaluated to what degree public health would benefit from a reduction in the amount of reactive nitrogen in our country.

Environmental effects

Once released into the environment, reactive nitrogen is converted into various chemical forms and transitions through the air, soil, vegetation and water. It contributes to the changes that occur in various places and at various moments in time. This includes planned production of vegetable and animal-based foods as well as the unintentional pollution of the environment. The totality of the reactions takes place in a complex network of interconnecting chains and cycles. The movement of reactive nitrogen through this network structure results in series of sequential effects.

An example can clarify this phenomenon. The combustion of fossil fuels releases nitrogen dioxide. This can react to form ammonium salts, contributing to the formation of particulate matter. Rain can cause the ammonium compounds to precipitate to the ground, where they disrupt the composition of natural vegetation. Rain can also flush these compounds into ground or surface water. In the latter case, the compounds may threaten aquatic vegetation and fish. Ultimately, reactive nitrogen may be converted into laughing gas (dinitrogen monoxide), a greenhouse gas.

Effects on Dutch public health

An excess of reactive nitrogen has direct and indirect effects on human health. A direct effect means reactive nitrogen directly affects health. An indirect effect is one caused by harmful effects on the environment which in turn have a negative impact on health. This horizon-scanning report examines the possible negative health effects of average concentrations, and thus does not examine the effects of, for example, short-lasting exposure to high levels due to calamities.

The complex relationship between reactive nitrogen and its effects is only partially understood. Knowledge regarding the unfavourable influence of reactive nitrogen on health is particularly incomplete. However, this knowledge does allow the following conclusions to be drawn.

A significant proportion of the direct health damage caused by reactive nitrogen is due to air pollution, another is due to (contamination of) drinking water and food. Air pollution, caused in part by nitrogen oxides, causes respiratory and cardiovascular damage. For drinking water and food this primarily involves nitrate and its transformation product nitrite, which is linked to cancer, particularly of the gastrointestinal tract. However, it remains unclear how high the additional cancer risk is that people are exposed to. There are also claims that nitrate has a positive influence on the cardiovascular system and protection from infections. How these opposing effects should be weighed against each other remains a topic of active scientific debate.

The indirect negative effects of reactive nitrogen involve, among other things, the contribution of nitrogen dioxide to the formation of ozone at the earth's surface. Inhalation of ozone can lead to airway damage. Additionally, air, soil and water pollution with reactive nitrogen can contribute to global environmental changes such as climate change and damage to ecosystems, thereby potentially causing a multitude of indirect health effects. For example, via climate change, the greenhouse gas laughing gas is linked to a possible rise in infectious diseases. It also affects the ozone layer in the stratosphere, which leads to increased UV radiation, thereby contributing to the risk of skin cancer and cataract. Ecosystem damage can, among other things, threaten food supplies.

Insight into the direct negative influence of reactive nitrogen on health is greater than for indirect effects. The effects of air pollution on public health are also clearer than the threats posed by (contamination of) drinking water and food. From a precautionary standpoint, additional attention for the full spectrum of effects is desirable.

Only a rough indication exists for the full extent of the environmental and public health impact of reactive nitrogen. Expressed in monetary terms, it amounts to € 150-750 per inhabitant per year. The estimate for the Netherlands is € 200-1,000 per inhabitant per year.

Further analysis in the Netherlands may help

The situation in our country is therefore less favourable than average for the EU. This is due to our high population density, intensive agriculture, large industrial capacity and busy traffic. Dutch government policy over the past decades has resulted in a reduction of the amount of reactive nitrogen in our country. However, this process appears to have stagnated in recent years. This is not only unfavourable for the environment, but also for public health. Although the influence of reactive nitrogen on health is still surrounded by uncertainty, available evidence provides sufficient indications that Dutch public health would benefit from further reduction of the amount of reactive nitrogen in our country. From a public health perspective, the Committee is of the opinion that continuation of current nitrogen policy is not only desirable, but that further reduction of the amount of reactive nitrogen in the Netherlands should be accelerated and that the recent stagnation should be addressed.

Further analysis of the damage reactive nitrogen causes to Dutch public health may be helpful in this endeavour. Increasing insight into this damage can help better determine to what degree policy changes are desirable. This can contribute to more effective and cost-effective policy.

Ideally, such additional analyses should be performed by a group of experts in the fields of public health, health economics and the social sciences, among others. Outcomes of research performed for other reasons in the coming years that also evaluate the harmfulness of reactive nitrogen may be used, such as the review of EU air quality standards.

Chapter 1

Introduction

An excess of reactive nitrogen is harmful for the environment. Key sources of air, water and soil pollution by nitrogen are intensive agriculture and livestock production, where the use of fertiliser plays a key role, and the combustion of fossil fuels in transport, industry and homes. In this horizon-scanning report, the Health Council examines the potential negative effects of an excess of nitrogen on health.

1.1 Nitrogen has beneficial and detrimental effects

Plants, animals and humans require nitrogen to function. For example, it is a building block for proteins. The atmosphere contains a large supply of nitrogen in the form of nitrogen gas. In order to fulfil a biological role, this must be converted into a reactive form. Examples include gasses such as ammonia and nitrogen oxides, and salts, such as ammonium and nitrate compounds.

In nature, a limited amount of nitrogen gas is converted into reactive nitrogen. This occurs primarily during storms and by microorganisms. Artificial conversion, the synthesis of ammonia from atmospheric nitrogen, has made the manufacture of artificial fertiliser possible, enabling current agricultural practices in rich countries such as ours.[1]

In the agricultural sector, fertilisation with artificial and animal fertiliser from livestock production is tailored to suit the crop and soil type. Despite this, the farmed crops receive more reactive nitrogen than they can handle, and the soil more than it can store. This results in a great deal of reactive nitrogen being lost. It ends up in the environment, causing damage: fertiliser pollution and acidification of soil and water, caused among other things by released ammonia.

In addition to the food supply (agriculture and livestock production), the second major source of environmental pollution with nitrogen is the combustion of fossil fuels used to power automobiles, industry and homes. Nitrogen oxides play a role here, for example.

1.2 The situation in The Netherlands

The current excess of reactive nitrogen in the Western world is the result of the sharp rise in annual supply that has developed in the agricultural sector and energy supply over the past century. Figure 1 shows this trend for The Netherlands. Our country has one the world's largest amounts of reactive nitrogen per inhabitant and unit of surface area – with the corresponding environmental damage. This is caused by our population density, along with busy roads, a large industrial base and intensive agricultural and livestock production sectors.

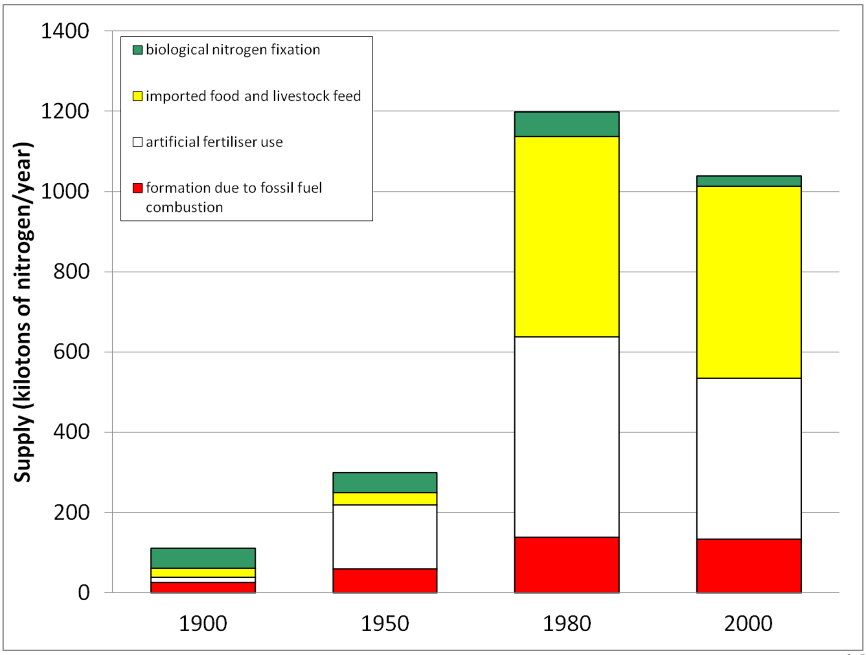

Figure 1 Trend of annual supply (import and production) of reactive nitrogen in The Netherlands.[2-5]

The Dutch government therefore implements policy aimed at reducing the excess of reactive nitrogen. This policy is largely based on EU regulations. Air pollution, soil and surface water pollution with nitrates as well as acidification and fertiliser pollution of ecosystems are combated.

In the past, separate policies addressed various forms of reactive nitrogen. This did not always have the desired effect. Measures targeting one form of nitrogen sometimes had the desired effect, but also an undesired side-effect on another form of nitrogen. This is known as pollution swapping: one undesired effect is limited, while another becomes a bigger problem. For example, injection of animal fertiliser into the soil reduced atmospheric ammonia emissions, but promoted the emission of laughing gas (dinitrogen monoxide).[6] Laughing gas is a greenhouse gas. It also reduces the ozone concentration in the stratosphere. Another example of a measure with pollution swapping effects is the introduction of the three-way catalytic converter in automobiles. While it does reduce the emission of nitrogen oxides, it is also responsible for the production of ammonia.[7] Such experience has resulted in policy that is pre-emptively tested for such pollution swapping.

As a consequence of implemented policy, the amount of reactive nitrogen in The Netherlands has dropped over the past decades.[2-5,8] Despite this progress, problems remain. For example, The Netherlands is still unable to meet the European standard for atmospheric nitrogen dioxide levels. The European Commission granted our country a few years respite to meet this standard.[9] In general, the effects of nitrogen policy implemented in the past years appear to be stagnating and progress slowing.[10]

1.3 Dutch public health

Reactive nitrogen harms public health. Air pollution causes and worsens airway conditions, for example. Therefore, good nitrogen policy is important for the Dutch environment as well as Dutch public health. A key question is to what degree further reduction of the amount of nitrogen in our country (less supply, less use and less loss of reactive nitrogen) can benefit public health.

Within the EU, our country has the largest supply and the greatest loss of reactive nitrogen per inhabitant per year – and thus likely the most reactive nitrogen-related damage to public health. In order to gain insight into this damage, the Health Council examined the effect of nitrogen on Dutch public health.

1.4 Overview report

A European overview report was used in drafting this monitoring report: *European Nitrogen Assessment* (ENA).[11] It was drafted by a large group of European researchers, and provides a summary of available scientific data on sources and effects of nitrogen (in all of its chemical forms), and describes the relationship between both. The focus lies on Europe, but the situation elsewhere in the world is also taken into consideration with regard to aspects such as artificial fertiliser requirements, food supply, public health, climate change and the protection of ecosystems. The emphasis lies on the negative effects of excess nitrogen. A large part of Europe, including The Netherlands, faces these problems.

The report is written from a European perspective. Scientists around the world endorse the findings. The problems caused by excess nitrogen in the environment are also recognised in the USA.[12,13] The US confirmation supports the use of the ENA as the foundation for the current analysis.

1.5 Committee and methods

This horizon-scanning report was drafted by the Health and Environment Surveillance Committee. The task and membership of the Committee are listed in Annex A.

A draft of this report was evaluated by the Standing Committee on Health and The Environment, a permanent group of Health Council experts.

1.6 Structure of this report

The Committee first provides a brief summary of the sources of reactive nitrogen, its environmental effects and the links between them. It then describes the influence an excess of nitrogen has on health and the possibilities for reducing this influence. Finally, it draws conclusions about Dutch public health and makes recommendations for its protection.

Chapter 2

Cycles and chains

Analyses of the nitrogen issue generally examine the so-called nitrogen cascade (see Figure 2). Once released into the environment, an atom of reactive nitrogen is sequentially converted into various forms and transitions through the air, soil, vegetation and water. It contributes to various effects that generally occur in different places and at various moments in time. This includes beneficial effects on agriculture and detrimental effects on the environment.

The foundation of the cascade consists of various cycles. Figure 2 displays the conversion of nitrogen into reactive nitrogen on the left, and the conversion back to nitrogen on the right. Examining the connections between various nitrogen compounds, insofar as these are even understood, lies beyond the scope of this horizon-scanning report. For the sake of clarity, the schematic only touches on the main pathways.

The nitrogen cycle and the causal effects connected to it often consist of chains with several steps and cross-linkages, creating a complex network. Furthermore, the nitrogen cycle intersects with the cycles for water and other elements that also play key roles in environmental issues. These elements include phosphorous, which plays a major role in the eutrophication of surface water, and carbon, which plays a key role in climate change and air pollution. The carbon and nitrogen cycles intersect in plant growth, among other areas. Nitrogen fertilisation stimulates growth, which leads to absorption of atmospheric carbon dioxide. Another intersection is the formation of laughing gas. This is formed from fertiliser and acts as a greenhouse gas.

As shown in Figure 2, an excess of reactive nitrogen has various major, unfavourable effects on the environment: it threatens air, water and soil quality and is a danger to the greenhouse gas equilibrium and the continued existence of ecosystems and biodiversity.

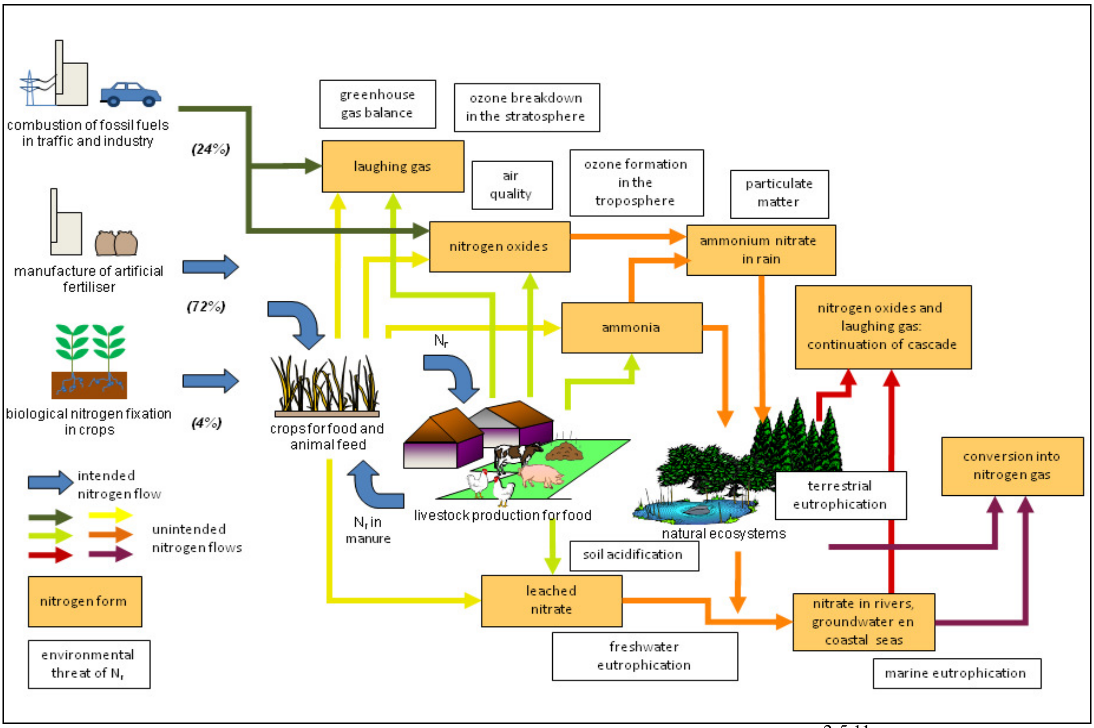

Figure 2 Nitrogen cascade. The supply percentages relate to The Nethelrlands in the year 2000.[2-5,11] N_r: reactive nitrogen; eutrophication: increase in nutrient concentration.

Chapter 3

The negative influence of nitrogen on public health

An excess of reactive nitrogen has various harmful effects on human health. These occur at the extremes of various cause and effect chains.

3.1 Distinction between direct and indirect effects

The origin of the reactive nitrogen does not matter when it comes to effects, including health effects. What does matter is the transformations the substance goes through and the compounds formed. Different nitrogen compounds have different health effects. As it did in previous publications on global environmental effects on health, the Committee distinguishes between[14,15]:

- direct effects of exposure to reactive nitrogen (such as airway conditions due to the formation of particulate matter caused by the release of ammonia and nitrogen dioxide)
- indirect effects (such as skin and gastrointestinal complaints after swimming in recreational waters contaminated with cyanobacteria (known as blue-green algae) resulting from the presence of nitrate).*

* This classification also covers extremely indirect effects, in which the social environment plays a key role in addition to the physical environment (for example infectious disease outbreaks following refugee movements after flooding caused by climate change due to laughing gas release). The extent of and risk of this type of effects are extremely difficult to estimate.

3.2 The pathways along which reactive nitrogen affects public health

Reactive nitrogen has a direct negative effect on health via contamination of the air and soil, surface and drinking water. Additionally, our food contains a great deal of reactive nitrogen, more than required for good health, which makes direct unfavourable effects on health possible via that route. Finally, reactive nitrogen has a direct undesired effect on health via global processes such as climate change, transportation of air pollution across long distances and damage to ecosystems and biodiversity.

The main nitrogen compounds with negative health effects, or for which such effects are plausible will be detailed below. Average environmental concentrations play a key role. The main focus is not the consequences of exposure to high concentrations, such as the ammonia found in the vicinity of livestock farms. The consequences of brief exposure to localised peak concentrations, for example due to a cloud of ammonia released due to leaking coolant, will also not be examined.

3.3 Air

The air pollution caused by reactive nitrogen is primarily due to ammonia (from livestock production) and nitrogen oxides (from the combustion of fossil fuels in traffic and industry). The most important nitrogen oxide is nitrogen dioxide, as atmospheric nitrogen monoxide is quickly oxidised to nitrogen dioxide. The chemical reactions involving these nitrogen compounds are only partially understood.

Ammonia

Ammonia is a component of animal fertiliser. This fertiliser has a strong smell, causing nuisance smells at low concentrations. Inhalation of far higher concentrations of ammonia is required to cause harmful effects such as eye and airway irritation.[16] At average atmospheric concentrations, ammonia itself is unlikely to affect Dutch public health.

However, ammonia may cause health damage via an intermediate step. For example, it can react with ammonium compounds, found in particulate matter*

* This is secondary particulate matter, formed in the air from precursors. Primary particulate matter is formed directly at the source, such as soot or soil dust.

and a major harmful component of air pollution.[17,18] Inhalation of the latter can lead to airway and cardiovascular damage.[19]

How much health damage ammonia causes via these pathways remains unclear, as air pollution is a complex mix with a variable composition, and health effects cannot easily be attributed to individual components.

Nitrogen dioxide

The role of nitrogen dioxide in the development of health damage due to air pollution is also difficult to unravel. As above, the health effects of air pollution cannot simply be attributed to individual components. The scientific debate surrounding the harmfulness of nitrogen dioxide is focused on three key questions[20]:

- Does exposure to nitrogen dioxide itself cause health damage?
- Does nitrogen dioxide cause damage by contributing to the formation of ozone and nitrate particles?
- Is exposure to nitrogen dioxide associated with health damage because it is part of a mixture of air pollutants, and it serves as an indicator for this mixture?

Nitrogen dioxide itself

Observational studies into the health effects of traffic-related air pollution have not yielded an answer to the question of whether exposure to nitrogen dioxide itself is harmful to health. Nitrogen dioxide concentrations correlate with those of other components of air pollution, including particulate matter, as all come from the same source. Thanks to, among other things, cleaner vehicles and industries, the concentrations have been dropping for years.[21]

Observational studies in houses with relatively high concentrations of nitrogen dioxide show no negative effect on the inhabitants' airways.[22-25] No cardiovascular effects were observed in volunteers performing moderate exercise while inhaling pure nitrogen dioxide in a concentration equivalent to that found in diesel exhaust, and over one hundred times higher than found in ambient air.[26]

Studies with volunteers performing moderate exertion at locations with mixed composition air pollution did find negative effects of nitrogen dioxide on the airways.[27,28] This was also true for other components, including the particulates. These findings are important for a better understanding of the complex relationship between air pollution composition and public health.

Ozone formation

Nitrogen dioxide is responsible for health damage due to its contribution to the formation of ozone, a major harmful component of air pollution. Inhalation of ozone can cause airway damage.[19]

Nitrate formation

Nitrogen dioxide can react into nitrate and thus contribute to the formation of particulate matter. Two factors that influence the concentration and composition of traffic-related air pollution have been unknown until recently.

First, improved catalytic converters in vehicles have reduced the emission of particulate matter by diesel engines. The emission of nitrogen oxides by diesel engines remains unchanged, however; nitrogen dioxide emissions have even risen.[20] This has changed the relationship between nitrogen dioxide and other parts of the mix.

Furthermore, the test conditions under which vehicles are evaluated for emissions insufficiently reflect driver behaviour. Before being allowed on to the EU market, the emissions of new vehicle models must be examined and meet certain standards. These tests are conducted under standardised conditions prescribed by the EU. These conditions insufficiently reflect urban driving behaviour, characterised by frequent acceleration and braking.[29,30] A change to EU regulations for test protocols and vehicle standards has already been initiated.

These new insights may impact the estimates of health damage that (traffic-related) air pollution causes, and the assessment of the role played by various components.

Role as an indicator for combustion gasses

Nitrogen dioxide plays a key role as indicator for the harmful substances released during combustion processes. As outlined in the previous section, the relationship between nitrogen dioxide concentration and the toxicity of air pollution is not static. For example, the emission of nitrogen dioxide may remain the same or increase, while the overall harmfulness of the mix decreases. This insight is also important for deciding on the further approach to air pollution.

3.4 Drinking water and food

Nitrate is chiefly responsible for the contamination of ground and surface water with reactive nitrogen. This is largely from artificial and animal fertilisers, although some may precipitate out of the air. Excess nitrogen is removed in the preparation of drinking water, or the concentration is lowered by mixing it with cleaner water. Drinking water is not the only source of nitrate for humans. The other is food. This was taken into account in determining the standard for drinking water.

Sources of exposure

Nitrate is a normal compound found and produced within the body. Additionally, people ingest it via drinking water and food. Intake is far higher than the amount formed inside the body.[31]

Vegetables, particularly leafy vegetables, are nitrate-rich. It is added to some foods, such as meats, to prevent spoiling and discolouration. In general, vegetables are the main source of nitrates, followed by drinking water and other foodstuffs.

Health damage

The worry about excessive exposure to nitrate applies to its metabolites and reaction products, particularly nitrite and nitrosamines. Exposure to excess nitrate is associated with cancer, particularly of the gastrointestinal tract.[31,32]

Nitrate and nitrite are both used to conserve food. Nitrate can be converted into nitrite in the gastrointestinal tract. The primary source of nitrite exposure is formation from nitrate. To what degree nitrate and nitrite intake can cause cancer is controversial.

Nitrite can react with proteins from food in the digestive tract and form carcinogenic nitrosamines.[33,34] Additionally, carcinogenic nitrosamines may already be formed during the preparation of protein-containing food.

The *International Agency for Research on Cancer* of the WHO believes it is likely nitrate and nitrite are carcinogenic to humans when ingested under circumstances that allow nitrosamines to form.[32] Nitrosamine formation may be partially responsible for the correlation between meat consumption and cancer incidence, particularly gastrointestinal cancer, observed in epidemiological research.

A diet rich in protein and nitrate and nitrite rich vegetables or vegetable juices, on the other hands, does not or hardly lead to formation of nitrosamines in the body.[33] The *European Food Safety Authority* (EFSA) balanced the additional cancer risk due to nitrate and nitrite in vegetables against the nutritional value of vegetables.[31] According to the EFSA, the positive effects of vegetable consumption on health far outweigh the negative effects.

During the preparation of protein-rich food, other harmful nitrogen compounds can also form. Carcinogenic heterocyclic compounds may be formed during frying and broiling meat and fish.[35] The formation of these compounds may also explain part of the association between meat consumption and cancer.

Beneficial health effects

Some scientists claim nitrate has health-promoting effects. There are indications that nitrate has a positive effect on cardiovascular health and the immune system.[31,36]

Drinking water standard

There are long-standing disagreements among scientists investigating nitrates with regard to the interpretation of available data on and the health effects of nitrate intake. The indications of positive effects outlined above play a role. The discourse extends to the desirable level for the drinking water standard.[11,36] Some scientists claim the EU standard for drinking water insufficiently reflects the beneficial effects, and is therefore unnecessarily low. In part because of this, there is no broad support for the nitrate standard.

3.5 Ground and surface water

Nitrate in ground and surface water can, via intermediate steps, also cause health damage. Nitrate in the ground water contributes to an increase in surface water nitrate concentrations via a slow exchange process.[11] Too much nitrate in the surface water leads to eutrophication. This can negatively affect fish populations and thus food supply, among other things. However, it does not seem likely this will lead to problems in The Netherlands. This may be relevant in other parts of the world. If eutrophication of surface water expresses as contamination with cyanobacteria, swimming in these waters can result in health complaints. Ingestion of water can cause gastrointestinal complaints, and contact with skin or eyes can lead to local irritation.

3.6 Global environmental changes

Reactive nitrogen also indirectly negatively affects health via air, soil and water pollution, by contributing to global processes including climate change and damage to ecosystems and biodiversity. Laughing gas, for example, which is formed in combustion processes, the manufacture of artificial fertiliser, livestock production and crop farming, is a greenhouse gas and a factor that contributes to climate change. The warming of the earth may lead to health threats, including a rise in infectious diseases. Laughing gas, if it reaches the stratosphere, can also degrade the ozone present there. This can allow more UV radiation to reach the earth, increasing the risk of skin cancer and cataracts.

Another example of the indirect effect of reactive nitrogen on health is the previously mentioned formation of ozone at the earth's surface due to nitrogen dioxide. This can inhibit crop growth, reducing food productions.[11] In more general terms, excess reactive nitrogen can threaten the so-called ecosystem services. These are the benefits ecosystems provide for people.[37] These benefits are associated with four kinds of ecosystem functions: 1) providers of, among other things, food, water, wood and fibres; 2) regulatory functions with effects on climate, flooding, disease, waste and water quality; 3) cultural functions that allow activities such as recreation, and fulfil aesthetic and spiritual needs; 4) supporting functions, such as soil formation, photosynthesis and nutrient circulation. Protecting these functions indirectly benefits health. More details on the influence of harm to ecosystems and other global environmental changes on health may be found in the previously mentioned publications, among other places.[14,15]

The processes involved are complex and many nitrogen compounds play a part. There are large gaps in the understanding of these processes, so insights into interconnectedness is lacking. Therefore, the consequences of high levels of reactive nitrogen for Dutch health via global environmental changes are difficult to quantify.

3.7 Extent of health damage

Excessive exposure to reactive nitrogen can cause health damage via air, soil, water anddiet, and via global environmental changes. Insight into the negative health effects leaves something to be desired. This applies to both direct and indirect effect, but particularly the latter.

Initial estimate for the EU and The Netherlands

The only estimate of the damage caused to public health by reactive nitrogen was made within the framework of the ENA.[11] The negative effects of nitrogen on the environment and health are expressed in monetary terms for the EU and The Netherlands. The figures apply to the year 2000 and to direct and indirect effects.

According to the authors of the ENA, the total social costs of the influence of nitrogen on the environment amount to a sum of € 150-750 per EU inhabitant per year. About 60 percent of this cost is due to health damage. The largest contribution is made by direct damage attributed to air pollution, including airway disease. Next – in order of decreasing magnitude – are eutrophication and reduction of biodiversity, the formation of greenhouse gasses, direct health damage due to water contamination, indirect health damage due to ozone layer depletion (skin cancer and cataracts) and crop damage due to ozone formation at the earth's surface. The margin in the amount indicates the large degree of uncertainty.

According to the Dutch researchers involved in the estimation process, the amount for The Netherlands is € 200-1,000 per inhabitant per year.[38] Here too, the Dutch figure is higher than the EU figure. This is consistent with the reactive nitrogen burden per hectare. This is the highest in The Netherlands among all EU countries.

According to these estimates, nitrogen oxides make the greatest contribution to health damage via air pollution, in both the EU and The Netherlands.

Meaning of the estimate

The quantification of the environmental and health damage caused by reactive nitrogen is expressed in monetary terms. The *willingness to pay* method was used, in which individuals express the amount they would be willing to pay to address unfavourable circumstances. The primary advantage of monetary valuation is the simplicity of the end result: the above-mentioned different types of damage are expressed as monetary amounts, with a distribution due to uncertainty, and subsequently added up to a single sum with an uncertainty interval.

The simplicity of this metric is also its greatest weakness. The underlying gaps in knowledge are only partially reflected by the results. First, only those effects that can be quantified at the moment the estimation is made are reflected in the results. The reliability of these figures varies. The non-quantifiable effects perforce remain unexamined. An example of such an effect is the influence of reactive nitrogen on public health via climate change. Only the effect of laughing gas could be estimated with a reasonable degree of confidence.

As a consequence of limited knowledge, the estimate should be considered an initial, rough estimate of the damage reactive nitrogen causes the environment and health.

In addition to the non-quantifiable effects, the method used also fails to provide insight into the nature of the quantifiable effects. This means information on the type of health damage and the group affected by this health damage is quickly lost: is it the entire population, children, urban dwellers, people who live near motorways, and so forth. This makes it easy to lose sight of who benefits and who suffers the burdens of measures under consideration. There are solutions for this. For example, the final sum can be split per characteristic. However, this would entail other uncertainties. An alternative is to explicitly include the data in question in the analysis, by using tools such as multi criteria analysis, in which various different types of data are evaluated and weighed against each other in a structured manner.[39]

An advantage of the method used is that the outcomes of the monetary valuation of health damage can in principle be used as part of a broader social cost-benefit analysis, in which all quantifiable negative and positive effects can be estimated and compared, and the negative effects may be subtracted from the positive.

Chapter 4

Possibilities for reducing health damage

Added value of integral policy

Integral policy is the most suitable tool for reducing the amount of reactive nitrogen in the environment, as it takes into account the relationships between various involved parties, sources of reactive nitrogen, and the links with other environmental issues, such as climate and energy supply. Other parties also call for integral policy.[11,12]

The strength of an integral approach is that it becomes easy to determine which interventions or combinations of interventions avoid the most environmental damage, and which are most cost-effective. This applies to the situation in The Netherlands, but also to making international agreements within the EU and worldwide. A good example of successful integral policy on a global scale is the international agreement on tackling cross-border air pollution.[40] A large group of countries is taking part; per country, the most cost-effective and efficient measures for controlling air pollution that can be transported in the upper atmosphere over long distances were identified. The treaty also provides handholds for nitrogen policy. A special working group on reactive nitrogen was appointed under the treaty.

Integral policy may be conducted by utilising synergy* and preventing pollution swapping, for example. For example, synergy may occur in the

* cooperation in which yield is greater than the sum of the benefits for individual units

application of sustainable energy sources that lead to reduced nitrogen monoxide, nitrogen dioxide and laughing gas emissions (such as wind energy, but not biomass). Synergy within a broader context than nitrogen issues alone may be achieved by using engines that emit less nitrogen and carbon dioxide. Many measures that aim to reduce the amount of nitrogen in the air have the additional advantage that they also address levels of other air pollutants. This includes carbon monoxide, particulate matter and volatile organic compounds. Such measures therefore also have other effects that benefit public health.

Coordinating scenarios

Scenarios, images of potential futures, are a key tool in integral analysis and decision-making. Within the scope of this monitoring report, there are Dutch scenarios for the development of air quality in our country (nitrogen dioxide, particulate matter and sulphur dioxide)[41] as well as scenarios from the IPCC regarding carbon dioxide emissions.[42,43] Certain combinations of Dutch and IPCC scenarios may not be compatible.[44] This could result, for example, in air quality in our country improving less than expected. Additionally, this inconsistency makes estimating the indirect effects of global climate change and the effects on ecosystems and agriculture more difficult, making combined scenarios for carbon dioxide and nitrogen dioxide, particulate matter and sulphur dioxide all the more essential. There may be benefits to coordinating Dutch scenarios with the newest IPCC scenarios in future.

Approach in The Netherlands

Various directions for solutions have been proposed for reducing, or at least stabilising the amount of reactive nitrogen[11]:

- in transportation, energy production and industry: by implementing emission-limiting technology and energy sources with lower emissions
- in agriculture: for example by developing more nitrogen-efficient crops, low emission stables and improving livestock feed composition
- in waste recycling: for example by reclaiming nitrogen from the sludge produced in sewage processing
- influencing the public: by stimulating different consumption behaviours, such as purchasing cleaner cars, reducing domestic energy use and eating fewer animal products.

The Committee endorses these solution directions. At the same time, it realises that existing regulations in the area of reactive nitrogen and related issues such as climate and energy, are extensive and complex. Dutch environmental policy is organised along a number of axes: sectors (such as agriculture, traffic and industry), media (such as air and surface water) and issues (themes including climate, ecosystems, biodiversity, water quality and air pollution). This is largely based on EU regulations. Additionally, our country participates in international negotiations. Taken together, this makes additional nitrogen policy – integral or otherwise – difficult to realise in The Netherlands.

At the very least, international research and negotiations remain of major importance to Dutch public health. These are issues that require the long view. From a public health perspective, optimal utilisation of available national policy space is desirable.

The Committee does not believe its task includes evaluating the merits and possibilities of various solution directions. It has identified one that falls within the Dutch policy space and may aid to speed the reduction of excess reactive nitrogen in The Netherlands. This may be realised independently of regulations and international negotiations, as it is a relatively separate issue with no major disadvantages.

Stimulating different food consumption

The Dutch diet contains more animal protein than required from a health perspective. It is unknown whether the relatively large amount of animal protein in the Dutch diet is unhealthy.[45]

The production of animal protein leads to relatively large reactive nitrogen losses to the environment. These losses may be reduced by decreasing consumption of animal protein, replacing animal protein sources with vegetable ones, and replacing animal sources with relatively low nitrogen efficiency (beef) with more efficient sources (pork or chicken).[11,45,46]

From an environmental perspective, there is good reason to recommend the general public consume less or different food of animal origin and use the recommended amounts – which safeguard health – as upper limits.[47] The nitrogen-related health arguments for such a change in diet are less convincing. It is plausible that exposure to harmful compounds will decrease, leading to less health damage. Furthermore, a vegetable-based diet has the advantage of being associated with a lower risk of cardiovascular disease.[45]

In a letter on nitrogen policy, the State Secretary of Economic Affairs, Agriculture and Innovation informed Parliament that he wishes to inform the public via awareness raising campaigns in order to promote conscious decisions on the amount and type of animal products consumed.[48] According to the Committee, different eating patterns may contribute to the reduction of the amount of reactive nitrogen circulating in our country without disadvantages – perhaps even with advantages – to public health. This call for stimulating different consumption behaviour is in line with a previous, general horizon-scanning report on sustainable diet [45]. Experts in the field of communication and behavioural change may provide important advice on implementation.

Develop indicators

Indicators are required in order to determine which combinations of measures are optimal for monitoring the progression of policy implementation.[49] This may include indicators for the total amount of reactive oxygen, potentially divided into agriculture plus livestock production and traffic plus industry, and for the effect of reactive nitrogen on health. Which indicators are suitable depends on the policy question. A range of indicators is useful to account for aspects such as scale in terms of space (local, The Netherlands, global), scale in terms of time between when reactive nitrogen enters the environment and its effects are seen, the costs and benefits, and groups affected by these costs and benefits.

No large research programme is required in order to develop a set of indicators, as the groundwork has already been laid by the method for determining an ecological footprint. This is a figure that represents how much biologically productive soil and water surface a certain population group uses to maintain its consumption level and process its waste.[50,51] This footprint can also be calculated for an individual, product, company or policy domain. Variants may be developed that could be useful for nitrogen policy. This would allow virtual nitrogen loss to the environment to be calculated. The first steps towards a footprint specifically for nitrogen have already been made.[52] Software already exists that allows people to determine their own footprint.[53] Different behaviour – such as eating fewer animal products, purchasing cleaner cars and lowering domestic energy use – can reduce this footprint.

Further research into the cascade

The links within the cascade are not all fully understood and quantitative interpretation leaves something to be desired. Important knowledge gaps include spatial distribution of various forms of nitrogen and their effects, mutual interactions, rates of processes and terms within which effects occur. This leads to differences in cause-effect relationships in the nitrogen cascade in terms of supporting evidence (qualitative and quantitative). This has an important effect on the insight into the influence of reactive nitrogen on public health. Further fundamental research into the connections in the cascade is required to increase insight into the issue, and therefore into possible solutions.

The Committee believes it would be useful to occasionally evaluate the effects of policy and whether adjustment is required. Naturally, the newest scientific insights should be the starting point. This may eventually lead to cost savings. Changes in course may be warranted if follow-up analyses of new data indicate that the same health damage can now be prevented with lower spending.

Chapter **5**

The Committee's vision

Health damage due to nitrogen in The Netherlands deserves more attention

Reactive nitrogen affects public health directly and indirectly. Excess reactive nitrogen damages the environment, and thus also affects public health in our country.

An important part of the direct health damage is due to air pollution, another is caused by drinking water and diet. This justifies continued government attention for these areas. The effects of air pollution on public health are clearer than the threats posed by contamination of drinking water and food. From a precautionary perspective, both require attention.

The indirect effects of reactive nitrogen on health are far less clear. From a precautionary perspective they also require additional attention.

Damage in The Netherlands is above average

A rough estimate of the extent of the damage caused to the environment and public health by reactive nitrogen is available. This damage is significant, and higher than average for the EU in The Netherlands.

The influence of reactive nitrogen on health is surrounded by uncertainties. However, available evidence provides sufficient indications that Dutch public health would benefit from further reduction of the amount of reactive nitrogen in our country. From a public health perspective, the Committee is of the opinion that not only is continuation of current nitrogen policy desirable, but that further reduction of the amount of reactive nitrogen in The Netherlands should be accelerated and that the recent stagnation should be addressed.

Further analysis may help

Further analysis of the damage reactive nitrogen causes to Dutch public health may be helpful in this endeavour. Increasing insight into this damage can help better determine to what degree policy changes are desirable. This can contribute to more effective and cost-effective policy.

The Committee recommends follow-up analyses of the damage caused to Dutch public health by reactive nitrogen be performed by a group of experts, including specialists in the fields of public health, health economics and social sciences. Outcomes of research performed for other reasons in the coming years that also evaluate the harmfulness of reactive nitrogen, such as the review of EU air quality standards, may be used for these follow-up analyses.

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A The Committee

Annex

Annex **A**

The Committee

The Health and Environment Surveillance Committee has the task of bringing subjects concerning health and the environment to the attention of the government and Parliament, and of highlighting threats and opportunities. This may be in relation to new issues but may equally concern topics that require attention once again.

Members of the Committee charged with the preparation of the present horizon-scanning report:

- Prof. W.F. Passchier, *chairman*
  Emeritus Professor of Risk Analysis, Maastricht University
- Prof. M. van den Berg
  Professor of Toxicology, Institute for Risk Assessment Sciences, Utrecht University
- Prof. J.W. Erisman
  Professor of Integrated Nitrogen Issues, VU University, Amsterdam; Director of the Louis Bolk Institute, Driebergen
- P.J. van den Hazel
  Physician, Specialist in Environmental Medicine, Public Health Service Central Gelderland, Arnhem
- Prof. E. Lebret
  Professor of Environmental Health Impact Assessment, Institute for Risk

Assessment Sciences, Utrecht University / National Institute for Public Health and the Environment, Bilthoven

- Prof. R. Leemans
  Professor of Environmental Systems Analysis, Wageningen University and Research Centre
- Dr. J.P. van der Sluijs
  Senior Researcher in Novel Risks, Copernicus Institute for Sustainable Development, Utrecht University
- Prof. D.R.M. Timmermans *(till 1 January 2012)*
  Professor of Risk Communication and Patient Decision Making, EMGO Institute, VU University Medical Centre, Amsterdam
- Dr. P.W. van Vliet, *secretary*
  Health Council of the Netherlands, The Hague

When drawing up this horizon-scanning report, the Committee consulted dr. H. van Grinsven of the PBL Netherlands Environmental Assessment Agency in Bilthoven.

The Health Council and interests

Members of Health Council Committees are appointed in a personal capacity because of their special expertise in the matters to be addressed. Nonetheless, it is precisely because of this expertise that they may also have interests. This in itself does not necessarily present an obstacle for membership of a Health Council Committee. Transparency regarding possible conflicts of interest is nonetheless important, both for the chairperson and members of a Committee and for the President of the Health Council. On being invited to join a Committee, members are asked to submit a form detailing the functions they hold and any other material and immaterial interests which could be relevant for the Committee's work. It is the responsibility of the President of the Health Council to assess whether the interests indicated constitute grounds for non-appointment. An advisorship will then sometimes make it possible to exploit the expertise of the specialist involved. During the inaugural meeting the declarations issued are discussed, so that all members of the Committee are aware of each other's possible interests.