RIVM report 725501004/2001

Effects of short-term abatement measures on peak ozone concentrations during summer smog episodes in the Netherlands

C.J.P.P. Smeets and J.P. Beck

This investigation has been performed within the framework of the RIVM project M/725501/01/OZ , Accidification and large-scale air pollution.

RIVM, P.O. Box 1, 3720 BA Bilthoven, telephone: 31 - 30 - 274 91 11; telefax: 31 - 30 - 274 29 71

Abstract

In recent years thresholds set by the current Council Directive 92/72/EEC on air pollution by ozone have been exceeded substantially in all Member States. The EU obligates all its Member States to carry out a principal investigation of the reduction potential of short-term measures for ozone maxima during episodes. In accordance with this request we conducted a model study and imposed five different short-term scenarios on a nation-wide scale for emissions from 1995 and 2003. The short-term measures solely concerned road traffic since other sectors appeared not very effective in reducing ozon precursor emissions and/or with considerable economic consequences. The nation-wide averaged results suggest an increase of a few percentage points in the ozone maxima in both 1995 and 2003 as a result of short-term measures. It appears that mainly the highly industrialised and populated areas clearly show increased ozone maxima (+5% in 2003), while in the less populated and industrialised areas the maxima vary between –1% and +1%. According to our model study the 10% minimum effectiveness of short-term abatement measures aimed at in the Ozone Position Paper will not be realised in the Netherlands. Permanent and large-scale measures appear to be the only means for realising substantial reductions in the ozone maxima.

Preface

We would like to thank Robert van den Brink, Marian van Schijndel, and Bart Wesselink from the LAE (RIVM) who kindly provided information on the effects of emission reductions other than road traffic. Furthermore, Robert van den Brink also provided details on the effects of emission reduction scenarios for road traffic. Cor van der Kooij from the DCMR Milieudienst Rijnmond is acknowledged for providing information on local short-term measures within the Rijnmond region, Dr. W.D. Garber (Umweltbundesambt, Berlin, Germany) for providing information on the German ozon episodes policy and Mrs. R. de Wijs for editing the manuscript.

Contents

Samenvatting

De huidige Richtlijn 92/72/EEC met betrekking tot luchtverontreiniging door ozon schrijft drempelwaarden voor ozon op grondniveau voor. De afgelopen jaren zijn deze drempelwaarden veelvuldig overschreden in alle landen van de Europese Unie. Verdergaande emissiereducties zijn nodig zoals opgenomen in de Richtlijn inzake nationale emissiemaxima. In de context van de huidige Kaderrichtlijn worden de landen van de Unie verplicht een onderzoek te doen naar het ozon reductie potentieel van korte termijn maatregelen tijdens ozonepisoden. Het Ozone Position Paper geeft aan dat bij een reductie van ozonpieken met minimaal 10% korte termijn maatregelen moeten worden opgesteld en uitgevoerd. De gedachte hierachter is om korte termijn maatregelen te gebruiken voor het reduceren van ozonpieken gedurende de tijd dat permanente – en grootschalige maatregelen nog niet effectief genoeg zijn.

Ozon wordt niet geëmitteerd door antropogene bronnen maar wordt als secundair product gevormd bij de gecompliceerde chemische reacties waarbij onder invloed van zonlicht stikstof oxiden (NO_x) en vluchtig organische stoffen (VOS) reageren. Als ozon eenmaal is gevormd dan kan het langere tijd in de lucht verblijven. In West-Europa wordt het zomersmogprobleem overheerst door het grootschalige transport van luchtmassa's waardoor het een grensoverschrijdend karakter heeft.

In onze modelstudie worden met het Euleriaans luchtkwaliteitsmodel EUROS tijdelijke maatregelen op een nationale schaal bestudeerd. We gebruiken de meteorologie uit het jaar 1994 omdat hierin gunstige condities voor het ontstaan van ozonepisoden optreden (een groot aantal zonnige zomerdagen). We selecteerden drie smogepisoden om te zorgen voor de nodige meteorologische variabiliteit en kozen voor emissies in de jaren 1995, 2003 en 2010. Het jaar 1995 is gekozen als basisjaar en 2003 representeert het tijdstip waarop de nieuwe Kaderrichtlijn voor ozon van kracht wordt. Het jaar 2010 is gekozen als referentie voor het effect van de verminderde emissies als gevolg van het huidige voorgenomen beleid. De korte termijn maatregelen hebben alleen betrekking op wegverkeer. Reducties in andere sectoren zoals scheepvaart, industrie, energie of diensten (HDO) zijn moeilijk uit te voeren en/of leiden niet tot een significante reductie van emissies. De korte termijn maatregelen omvatten snelheidsbegrenzingen op snelwegen, een rijverbod voor wagens zonder katalysator en een rijverbod voor vrachtauto's op binnenstedelijke wegen. In 2010 worden slechts geringe emissiereducties bereikt met wegverkeer zodat hiervoor geen effecten van korte termijn maatregelen zijn doorgerekend.

Voor het verkrijgen van een representieve waarde van de blootstelling van de bevolking aan ozon werden de resultaten per gridcel gewogen met het aantal bewoners. De landelijk gemiddelde en gewogen resultaten geven aan dat korte termijn maatregelen resulteren in een

geringe toename van de ozon maxima (een paar procent) voor zowel 1995 als 2003. Met name op lokale schaal in dichtbevolkte geïndustrialiseerde gebieden in het westen van Nederland wordt een toename van ozon maxima waargenomen (+5% in 2003). In het zuidelijk en oostelijk deel van Nederland, met normaliter de hoogste ozon pieken, zijn veranderingen zeer gering (tussen –1% en +1%). In dichtbevolkte gebieden is de emissie van NO relatief hoog waardoor het fotostationaire evenwicht verschuift en veel ozon wordt afgebroken. Dit proces is ook bekend als NO titratie. Bij een reductie van de NO_x emissies wordt minder ozon verwijderd met als gevolg een hogere concentratie.

De 10% minimum effectiviteit van tijdelijke maatregelen waar naar wordt gestreefd in het Ozone Position Paper wordt volgens onze modelresultaten niet gehaald in Nederland. Tevens dient te worden opgemerkt dat tengevolge van de emissiereducties door grootschalige permanente maatregelen in de nabije toekomst het effect van korte termijn maatregelen op emissies alleen maar kleiner wordt.

Permanente en grootschalige maatregelen blijken de enige manier te zijn om een substantiële verlaging van de ozonpieken te bereiken. Ten opzichte van 1995 leiden de voorgestelde structurele reductiemaatregelen in 2010 tot een reductie van 30(25)% VOS(NO_x) in de EU. Op basis van deze emissies berekenden wij voor Nederland (periode mei tot en met juli) een daling van het aantal overschrijdingen van de informatiedrempel (= 180 $\mu g/m^3$) met 90%, het aantal overschrijdingen van de richtwaarde voor volksgezondheid (= 120 $\mu g/m^3$ gemiddeld over 8 uur) daalde 30%, en de AOT40 (gecumuleerde overschrijding van de 80 $\mu g/m^3$ drempel gedurende daglicht) daalde 25% ten opzichte van 1995.

Summary

The current Council Directive 92/72/EEC on air pollution by ozone set ground-level ozone thresholds. In recent years these thresholds were exceeded substantially and in all Member States. Further reductions will be required as formulated in the National Emission Ceilings Directive. In tandem with the current Framework Directive the Member States are obliged to perform a principal investigation on the ozone-reduction potential of short-term measures during ozone episodes. The Ozone Position Paper states that in case of a reduction of ozone levels of at least 10% short-term action plans should be generated and implemented. The underlying idea here is that short-term measures are believed to reduce the peak ozone levels in order to bridge the gap until the long-term permanent precursor reductions take effect.

Ozone is not emitted by anthropogenic sources but is a secondary pollutant formed by a complicated series of chemical reactions initiated by sunlight, in which nitrogen oxides (NO_x) and volatile organic components (VOC) react. Once ozone has formed it may persist for relatiev long periods. In Western-Europe the summer smog problem is dominated by large-scale transport of air, which makes it a transboundary problem.

In our model study with the Eulerian air quality model, EUROS, we study short-term measures at a nation-wide scale. We use the meteorological data from 1994 since these data represent favourable conditions for the generation of smog episodes (i.e., a high number of warm and sunny days). We selected three smog episodes to implement meteorological variability and chose emissions from the years 1995, 2003 and 2010. The year 1995 was chosen as a base case and 2003 to represent the point in time in which the new Directive will take effect. The year 2010 is chosen as a reference for the effect of reduced emissions resulting from the current policy. The short-term measures concern solely road traffic. Reductions in other sectors such as shipping, industry, energy and services are much more difficult to enforce and/or do not lead to a significant reduction of emissions. The short-term measures include motorway speed limits, driving bans for cars without catalytic converters and driving bans for trucks on inner urban roads. In 2010 only very little emission reductions are obtained and therefore we did not perform calculations on short-term measures for this year.

In order to represent the ozone burden for the total number of inhabitants we weighted each grid-cell value (21 in total for the Netherlands) with the number of inhabitants in a cell. The nation-wide averaged results suggest that the ozone maxima slightly increase (a few percent) in both the year 1995 and 2003 as a result of short-term measures. Increased ozon maxima are mainly observed on a local scale in the highly industrialised and populated grid cells in the west of the Netherlands (+5% in 2003). In contrast, the grid-cells in the southern and eastern part of the Netherlands, usually with the highest ozone maxima, only show very small variations as a result of short-term measures (between –1% and +1%). In densily populated

areas the emission of NO is relatively high, resulting in a removal of ozone due to a shift in the photostationary balance. This process is also known as NO titration. A reduction of NO_x emissions will lead to less removal of ozone, and hence, higher ozone concentrations.

The 10% minimum effectiveness for reducing peak ozone levels as targeted in the Ozone Position Paper is, according to our model study, unattainable by means of short-term abatement measures in the Netherlands. It should be noted that the emission reductions due to permanent measures in the near future further reduce the emission reduction by means of short-term measures.

Permanent and large-scale measures are the only way to obtain substantial reductions in the ozone maxima. Relative to the emissions in 1995 predicted reduction measures lead to a reduction of ozon precursors in 2010 of 30(25)% VOC(NO_x). Based on these emissions we found that in 2010 in the Netherlands (for the periode from may to july) the exceedance of the information level (= 180 μg/m^3) drops 90%, the guideline value for human health (= 120 μg/m^3 mean over an 8 hr period) drops 30%, and AOT40 (accumulation over threshold of 80 μg/m^3 during daylight hours) drops 25% relative to 1995.

1. Introduction

The current Council Directive 92/72/EEC on air pollution by ozone, implemented in 1994, set ground level ozone thresholds and required Member States to monitor and report exceedances of those thresholds. In recent years both the health-related threshold and the vegetation-related thresholds were exceeded substantially and in all Member States. The threshold for providing information to the public was exceeded in almost all Member States, and the warning threshold was reached occasionally (De Leeuw et al., 2001).

Internationally and within Member States measures have already been introduced to reduce precursor emissions over the next decade. In order for the EU to move closer towards its overall objectives of protecting human health and the environment (see for example 6th EAP; EC, 2001) further reductions will be required as formulated in the National Emission Ceilings Directive. The latter is forwarded to the Council in conjuction with the new Directive on ozone in ambient air (one of the 'daughter directives' required by the Council Directive on the Assessment and Management of Ambient Air Quality - the 'Framework Directive'). This new ozone Directive will replace the current Council Directive 92/72/EEC on air pollution by ozone. In order to draft a proposal for this new Directive on ozone an ad hoc working group was set up in 1997 by the Commission. Activities resulted in the 'Ozone Position Paper' (EC, 1999). This paper assessed, amongst other aspects, the effect of the Community-wide control scenarios on typical local situations and the scope for additional local-scale measures.

Underlying the primary issue for the report presented here is Article 7(3) of the Council Directive 96/62/EC. This Article mentions that Member States should be required to inform the Commission on the effectiveness of short-term action plans as a possible (supplementary) abatement approach for protecting the population and vegetation from high peaks during episodes. The Ozone Position Paper proposes that the exceedance of the general alert threshold (i.e. 240 $\mu g/m^3$) is used as a trigger for the performance of a principal investigation of the ozone-reduction potential of short-term measures obligatory. A reduction of peak ozone levels by 10% is considered the minimum improvement to be pursued if a perceptible contribution to reducing the risks and limiting the duration of the exceedances is to be realised.

Short-term measures are, in effect, present on local scale in the Netherlands (the Rijnmond area around Rotterdam), and in Germany on a nation-wide scale until recently (between 1995 and 1999). Germany has also done a considerable amount of underlying research on this subject. Experience with the enforcement and effects of such measures shows the effectiveness to be fairly small and enforcement difficult in the case of nation-wide measures.

The research presented here focus on the ozone-reduction potential of short-term measures in the Netherlands. The following aspects will be discussed. First, we will provide some background information on ground-level ozone air pollution after which we will discuss the current state of knowledge with the aid of a desk study. The results from this study provided a guideline for our model calculations and the development of short-term abatement scenarios. The results from the subsequent simulations led to a discussion from which final conclusions are drawn.

2. Photochemical air pollution

2.1 Introduction

In the lower layers of the atmosphere, ozone is primarily formed by a complicated series of chemical reactions, initiated by sunlight, in which nitrogen oxides ($NO_x = NO + NO_2$) and volatile organic compounds (VOCs) react to form ozone. Consequently ozone is not emitted by anthropogenic sources but is a secundary pollutant. The chemical reactions are not instantaneous, but take place over several hours or even days depending on the specific VOCs. Once ozone has been produced it may persist for several days which makes it a transboundary problem (Simpson et al., 1997). Consequently international collaboration is needed to reduce the pollution from ozone. High ozone concentrations are observed mainly during periods in the summer months when fair weather conditions with high temperatures, abundant sunshine and low wind speeds prevail (for this reason it is also referred to as summer smog). During these conditions transport of air over Western-Europe is governed mainly by east to south-easterly wind directions yielding high background concentrations of ozone and its precursors while it is picked up over highly industrialised areas. Normally, when westerly winds prevail, a much lower global background concentration of ozone (60 to 70 $\mu g/m^3$) moves into Europe over the sea (Borrell et al., 1995).

Besides the secondary anthropogenic sources there are also some natural ozone sources. There is a weak flow of ozone down to the surface from the densely concentrated ozone layer in the higher atmosphere (stratosphere, higher than 20 km). Ozone is also formed by lightning but with highly uncertain amounts (Crutzen, 1995). The total contribution of these natural ozone sources and fluxes to the present average ozone levels near the ground is estimated to be about 20% (EC, 1999).

Since ozone is a powerful oxidant it is able to react with a wide range of cellular components and biological materials. In particular, it can damage all parts of the respiratory tract. Human sensitivity to these effects can vary widely from one person to another (Rombout et al., 1989). Studies in large cities situated in Europe and the USA suggest that ozone may cause severe human effects (Touloumi et al., 1997). Ozone precursor gases and several photochemical by-products are themselves hazardous to human health (NO_2 and important VOC species like benzene, formaldehyde, 1,3-butadiene, etc.). Some are carcinogenic. Secondary particulate matter (PM) is also formed during episodes and contributes to the organic fraction of PM. The latter may, for example, cause severe human health effects and lead to hospital admissions (Commissie van de Europese Gemeenschappen, 1997). At ambient concentrations found in Europe, ozone produces a range of effects on individual crop and tree species, as well as natural vegetation species mixtures, leading to losses in economic value, quality characteristics, and biodiversity. It can also degrade materials in a number of ways.

Within the scientific community there is broad consensus that the problem of elevated ozone levels can only be solved by large scale permanent abatement of precursor emissions. Model calculations show that within Europe precursor emissions should be reduced by more than 75% relative to emissions in 1990 in order to avoid exceeding the information threshold (Derwent and Davies, 1994; Bruckmann and Wichmann-Fiebig, 1997). According to the Ozone Position Paper existing and planned measures will bring precursor emissions down by 55% for NO_x and 60% for VOCs by 2010 compared with 1990 (NEC, 1999). An index of health-related ozone exposure (in which each ozone episode is weighted according to its level and the number of people exposed) indicates a 75% overall reduction in exposure in the Community as a result of these reductions. The AOT40 levels in the Community will be reduced by more than 50% between 1990 and 2010 (EC, 1999).

Photochemical air pollution gained high public awareness during the 1980s and beginning of the 1990s because of the frequent exceedances of the information threshold (92/72 EEC; hourly average of 180 $\mu g/m^3$) and reports on health effects of exposure to ozone. As a result a public debate was started on short-term abatement measures during summer smog episodes in the beginning of the 1990s. Such short-term measures are believed to reduce the peak ozone levels in order to bridge the gap until the long-term permanent precursor reductions take effect. This debate provides background to the study presented here. It should also be mentioned that until the beginning of the 1990s only some scientific literature dealing with short-term measures during summer smog episodes was available.

2.2 Short-term abatement measures on local and regional scale: a literature review

The photochemical or summer smog issue has been known since the beginning of the 1950s, when publications were issued discussing the very high ozone concentrations observed in the Los Angeles-basin (Haagen-Smit, 1952). During the 1970s America developed strategies mainly for the reduction of VOC in order to reduce ozone peaks. Nevertheless, many areas still failed to meet the standards by the end of the 1980s, which initiated a new series of research and monitoring campaigns specifically aimed at reducing the ozone peak concentrations on urban and regional scales (Duncan and Chameides, 1998). Extrapolation of the results found in the USA to European conditions is not straightforward because of the much larger size of American cities, the prevailing meteorological conditions (30 to 35ºC is normal), and the much larger influence of biogenic VOC emissions. When the so-called Pollution Standard Index (PSI) exceeds 100 points during ozone episodes, e.g. when ozone concentration exceeds 240 µg/m³, the American public is then informed. including appeals to car drivers to abstain from driving or to pool cars.

In Europe, Athens has conditions comparable to those found in the Los Angeles basin. Several studies were performed in this area. These included the MEDCAPHOT-TRACE experiment (MEDCAPHOT-TRACE, 1998) which, amongst other factors, addressed the effectiveness of emission reduction on a local scale. Model calculations showed that in this case especially VOC reductions would be effective. A reduction of NO_x would paradoxically lead to higher ozone levels, the result of NO titration (see Appendix A for a brief review of photochemistry). In Greece short-term measures exist for Athens at the local level. The trigger for such measures is not ozone but NO_2. When 500 µg/m³ is exceeded, alternating driving bans come into force for odd and even licence numbers. While these are effective for NO_2 levels they do not seem to contribute to a reduction in maximum ozone concentrations during episodes (LFU, 1998). Other studies performed in the south of Europe and aimed at local emission control strategies were performed in Milan (Finzi et al., 1998), the Valencia region (Cuvelier and Thunis, 1998) and Geneva (Krüger et al., 1998).

The above mentioned research specifically addressed the dispersion of air pollution strongly influenced by local topography and meteorology. In large parts of Western Europe the dominant mechanism for transport of air pollution is advection (see Annex B, Ozone Position Paper). Legislation on short-term measures exists (or existed recently) in a few countries in Western Europe. In its national air pollution law of 1996 France mentions alert values of 360 µg/m^3 for ozone, 400 µg/m^3 for NO_2 and 600 µg/m^3 for SO_2, which trigger short-term measures including driving restrictions for vehicles that are relatively polluting. Austria has two alert levels of 300 µg/m^3 and 400 µg/m^3 in its ozone law of 1992, which trigger short-term measures, including driving restrictions. In Germany a recent immediate programme (BMU, 2000) was proposed for a rapid, permanent and significant reduction in ozone precursors. Until recently, Germany also had an ozone law (from July 1995 till December 1999) which triggered short-term measures at an alert level of 240 µg/m^3 and included large-scale driving bans for relatively high-polluting vehicles. The experiences with this law showed that the monitoring of selective driving bans is very laborious and not very efficient (UBA, 2001). In the Netherlands a statutory regulation on ozone was established in 1991 (VROM, 2001), which states that, in principle, no nation-wide short-term measures are to be taken. During the preparation of this legislation it was concluded from several (model) studies (De Leeuw, 1984; De Leeuw, 1987; Van den Hout et al., 1985; Van den Hout en De Leeuw, 1987) that short-term measures imposed on industry and/or traffic during summer smog episodes would have a very small effect on ozone levels (VROM, 1991). However, on a local scale in the Rijnmond area (around the city of Rotterdam) a so-called code regulation (in Dutch: Coderegeling) from 1973 is enforced by the DCMR (in Dutch: Dienst Centraal Milieubeheer Rijnmond); an environmental service in the Rijnmond area. The latter also monitors the several code levels for SO_2/particulate matter, odour and reactive hydrocarbons (comparable to VOC in this report). Short-term measures are applied to industrial activities such as appeals to reduce industrial emissions or activities and to make legally required reductions of the transhipment capacity. Short-term measures can be triggered by several levels of SO_2 concentrations, the development of meteorological conditions and/or complaints of local residents concerning odour. A code concerning NO_x was also in effect but was excluded in 1984 due to its ineffectiveness (i.e., NO_x emissions are dominated by traffic). In general the experience with emission reductions of VOC imposed by the code regulation (in effect, on an average of about six times per year at a low level and mainly in the case of odour complaints) is that they do not lead to noticeable reductions of ozone concentrations in the Rijnmond area.

Besides the previously mentioned model studies conducted in the Netherlands, a large part of the research on ozone episodes under conditions comparable to those found in the Netherlands is conducted in Germany. A well-known example is the field experiment conducted in the urban area around Heilbronn/Neckarsulm (400 km^2) during an ozone episode in June 1994 (Bruckmann and Wichmann-Fiebig, 1997; Moussiopoulos et al., 1997). A speed limit of 70 km/hr or less was imposed on all roads including motorways, and industry and smaller enterprises promised emission reductions on a voluntary basis. In the downtown area (45 km^2) traffic bans were enforced for cars without controlled catalytic converters and high emitting diesel vehicles. Exempted from these bans was essential traffic such as fire brigades and suppliers of fresh food. Typical emission reductions of precursor concentrations were 30% for NO_x and 15% for VOC. However, no significant changes of the ozone burden could be detected for which three main reasons were revealed: the area with strict abatement measures was too small, reductions in the industrial sector were not sufficient and due to the meteorological conditions the ozone concentrations were mainly influenced by regional transport instead of local production. Bruckmann and Wichmann-Fiebig (1997) give an overview of a variety of model- and field experiments conducted throughout the 1990s in Germany: enforced speed limits in Hessen during the summers of 1993 to 1995, the combined model and field experiment FLuMOB in Berlin/Brandenburg, detailed model calculations for North-Rhine-Westphalia dealing with implied short-term abatement strategies in an industrialised region of 34000 km^2 (comparable to the surface area of the Netherlands, i.e. 40000 km^2), a comprehensive model study considering various short-term abatement scenarios applied to national and regional scales. Some of the main conclusions from these investigations:

- Only large scale and permanent reductions in precursor emissions will solve the problem of elevated zone levels.
- Regional short-term measures can effectively (meaning at least 10%) reduce ozone peak concentrations within the urban plume found downwind of large conurbations (several million people and/or a corresponding emission flux) when abatement measures reduce precursor emissions significantly (>20%).
- The high ozone background levels (>180 $\mu g/m^3$) frequently observed during fair weather in summer cannot be reduced by regional actions alone.

- Because of the non-linearity of the ozone-precursor relationship, ozone peaks within the urban plume can be reduced by no more than 10-15% if precursor emissions are reduced by 30-40%.
- Nation-wide speed limits (80/60 km/h) are not very effective and only serve as additional measures.

Regarding large conurbations, the Derwent and Hough (1987) study for the London area and the model study, OFIS (Moussiopoulos et al., 1998), which considered abatement scenarios for 23 European urban areas both support the conclusions concerning urban plumes. A major drawback of reducing the ozone burden within the urban plume is the likeliness of an increase of the ozone peaks within the urban centre itself (although these are usually much lower than in the urban plume) due to the reduction of NO_x concentrations. As an alternative to the former model research Vanderstraeten et al. (1996) studied the effects on ozone concentrations under the influence of differences in precursor emissions between weekdays and weekends in Brussels, Belgium. This more or less natural emission variation with lower precursor emissions during weekends appeared to yield higher ozone concentrations during weekends probably due to reduced NO titration (Appendix A). The same effects were observed in the Netherlands by Diederen et al. (1981) and De Leeuw (1987).

2.3 Conclusions of the literature review for a model study in the Netherlands

The dominant mechanism for transport of air pollution in the Netherlands is probably advection, comparable to that of Germany, for example, where high background ozone levels are often observed during summer smog episodes. Furthermore, in the Netherlands there are no large conurbations of several million people, therefore it is unlikely that local/regional short-term measures will lead to a significant decrease of ozone maxima during smog episodes. Experience with local-scale short-term abatement measures in the Rijnmond area seem to confirm this. In line with this, our model calculations using the Eulerian air quality EUROS model (e.g. Van Loon, 1996) will be applied to national scale short-term abatement measures.

3. Simulations of short-term abatement measures with the air quality model EUROS

3.1 Introduction

The Eulerian air quality model called EUROS is used for simulating emissions input, transport processes, chemical transformation, and dry and wet deposition processes of various air polluting compounds. The model can be used to examine the time and spatial behaviour of SO_x, NO_x, O_3, Volatile Organic Compounds (VOC), Particulate Matter (PM) and Persistent Organic Pollutants (POP) in the lower troposphere over Europe. Previous versions of EUROS have been described in, for example, Jacobs and Van Pul (1996), Van Loon (1996) and Delobbe et al. (2001). The modelled area extends over a large part of Europe and its base grid consists of 52 x 55 grid cells with a 0.55° x 0.55° longitude-latitude resolution (~60 x 60 km) on shifted pole coordinates. In this report we used EUROS to calculate hourly averaged ozone concentrations at measurement level. The meteorological data of the year 1994 is chosen as input because it represents highly favorable meteorological conditions for generating smog episodes. A relatively high number of so-called 'summer days' (daily maximum temperature above 25°C) were observed as being an exceptional amount for the Netherlands. Consequently the number of so-called 'smog days', a day during which an hourly average ozone concentration exceeds 180 $\mu g/m^3$, was also high. To include some variability in the meteorological conditions we selected three summer smog episodes, i.e. 1 July to 4 July, 11 July to 16 July, and 21 July to 31 July, representing the longest three episodes in 1994. See Van Doesburg (1995) for an extensive survey of all smog episodes in the Netherlands during the summer of 1994.

As a starting point for our model study we used the emission base year 1995 described in the 5th National Environmental Outlook (furtheron referred to as MV5, an abbreviation used in Dutch; RIVM, 2000). In order to estimate the effect of short-term measures by the time the new Directive on ozone in ambient air comes into effect we added the case year 2003. Since this is an unusual year in scenario studies we interpolated the emissions from those in 2000 and 2005 using MV5 estimates. In order to compare the effects of short-term measures in 1995 and 2003 with the effects of permanent measures in effect in the near future we arbitrarily added the case year 2010EC (2010 European Coordination scenario) furtheron simply referred to as 2010. A summary of the emission levels for the different case years and the various sectors is given in Appendix B. The short-term measures applied in our model study concern solely road traffic. Reductions for other sectors are much more difficult to realise or simply not effective enough as will be argued below.

Other forms of traffic such as shipping or the sector 'other traffic' (e.g. tractors or cranes) also contribute considerable and their emissions hardly seem to vary in time (Table 1,

Appendix B) but reductions in these sectors are difficult to obtain. Considering their low speed, speed reductions are no option and neither will they lead to reduced emissions. The only possible measure to reduce their emissions would be a complete or partial ban, wich is obviously very difficult to enforce and which has considerable economic consequences. The sector Services also emits considerable (Table 1, Appendix B). When considering NO_x emissions in industrial processes, refineries and within the energy sector, the main concerns are continuous production processes. The emissions cannot be stored or buffered temporarily and stopping these processes is technically and economically unrealistic, and would even result in a temporary significant increase in emissions. For VOC emissions more or less the same arguments hold except maybe in part for the reduction of transhipment activities (also described in the code regulation in effect in the Rijnmond area). In principle, it is relatively simple to stop these activities but this would lead to serious congestion in harbours, for example, and as a result, considerable economic consequences. Furthermore, the total emissions covered by these activities is fairly small (see Table 2 in Appendix B) and a complete stop of all transhipment activities would only yield a maximum reduction of <1%, 2% and 3% total VOC emissions for 1995, 2003 and 2010, respectively, when using the estimated maxima in Table 2 of Appendix B.

The main characteristics of the short-term measures applied to road traffic are given in Table 1 (see Appendix C for a comprehensive overview of the emission reductions for each traffic sector in 1995 and 2010). It is assumed that the distances covered by road traffic are not influenced by the restrictions imposed. Traffic on rural roads is not accounted for within these scenarios since there is only little knowledge about driving behaviour on such roads. Given the low average speed on these roads, it is likely that speed reductions would rather increase than decrease precursor emissions as a consequence of the emission characteristics of cars. This is especially true for VOC with slowly increasing emissions below 80 km/hr (e.g., Geiβ et al., 1996, Fig. 1).

Table 1. An overview of the short-term action abatement measures as used in the model study presented here

Label	Scenario
S1	Motorway speed limit: cars 80 km/hr, delivery vans and trucks 60 km/hr
S2	Driving bans for cars without catalytic converters
S3	Driving bans for trucks on inner urban roads
S4	Combination of S1, S2 and S3

In Table 2 we present the emission reductions calculated relative to road traffic, total traffic sector, and the national emission total. As mentioned before, 2003 is an unusual year in scenario studies and we derived the emissions reductions for 2003 from those in 1995 and 2010. The imposed speed limitations under S1 are not very effective and even slightly increase the emission of VOC, as explained from the emission characteristics of cars (Geiβ et al., 1996). Cars without catalytic converters (S2) contribute considerably to the national transport precursor emissions in 1995 whereas in 2010 their contribution is very small because by then most cars will be equipped with catalytic converters. S3 is very effective on a local scale (i.e. within urban areas) but on a national scale the contribution of the reductions is small. On the whole it does not appear easy to gain a significant reduction of precursor emissions in the Netherlands by only considering road traffic, and this difficulty increases in time as can be seen in Appendix B.

Table 2. An overview of the effects of short-term abatement scenarios on precursor emissions specified for road traffic, the total traffic sector and the national emission total. Values are a percentage relative to the yearly emissions of the specified sector.

		%	S1	S2	S3	S4
Effect on road traffic	**NO_X**	**1995**	-8	-33	-7	-45
		2003	-7	-17	-9	-30
		2010	-6	0	-10	-16
	VOC	**1995**	+1	-39	-3	-40
		2003	+1	-20	-3	-21
		2010	+1	0	-2	-1
Effect on total traffic sector	**NO_X**	**1995**	-5	-22	-5	-30
		2003	-4	-9	-5	-16
		2010	-3	0	-4	-7
	VOC	**1995**	0	-31	-2	-33
		2003	0	-15	-2	-17
		2010	0	0	-1	-1
Effect on national emission total	**NO_X**	**1995**	-3	-14	-3	-19
		2003	-2	-6	-3	-11
		2010	-1	0	-2	-3
	VOC	**1995**	0	-13	-1	-14
		2003	0	-5	-1	-6
		2010	0	0	-1	-1

Since S1 and S3 are comparably effective in reducing precursor emissions we arbitrarily omitted S3 from the model study. We also added scenario S4, which simply consists of a combination of S1, S2 and S3. It should be noted that cars without catalytic converters (S2) are also represented in S1 and scenarios can therefore not simply be added up (i.e., the sum of S1, S2 and S3 is therefore somewhat larger than S4). We will refer to scenario S0 when no reduction scenarios are applied to the emissions from the years 1995, 2003 or 2010. We did not apply reduction scenarios to the case year 2010 since by that time there is not much to gain from the emission reductions as can be seen in Table 2. Details on the application of scenarios in our model runs are given in the next section.

As already mentioned in our desk study (chapter 2) advection of air with a heavy precursor and ozone load probably plays a crucial role in the Netherlands because of the countries small size (roughly 150 km times 300 km). Even in case of low wind speeds (say an average of 3 m/s) the air mass over the Netherlands is interchanged within a single day. In order to test the dependence of observed ozone concentrations on advected air thoroughly we added two more scenarios. A hypothetical scenario S00 and an international scenario Sint. S00 presumes no NO_x and VOC production in the Netherlands, hence the ozone concentrations observed are solely due to advected air with a high ozone and precursor load. This scenario represents the bottom-end extreme of the sensitivity of ground level ozone concentrations to temporary variations in precursor emissions in the Netherlands. The international scenario is added because it refers to Article 8.2 (new ozone Directive), which states that Member States shall, if appropriate, prepare and implement joint short-term action plans under Article 7 covering neighbouring zones in different Member States. The Sint scenario presumes that Belgium, Luxembourg and North-Rhine-Westphalia (a German state adjacent to the border of the Netherlands) also enforce the S4 scenario (see Appendix E for a map showing the gridded area wherein emission reductions are imposed in the EUROS grid). For simplicity we assume that the reduction of road traffic emissions in these countries is equal to that in the Netherlands (i.e., in terms of percentage the reductions on national emission totals are equal, see Table 1 and 2). In Table 3 we summarize the short-term scenarios that were applied to the different emission years for all three smog episodes.

Table 3. Overview of the scenario types that were applied to each emission year.

	S0	S1	S2	S3	S4	S00	Sint
1995	•	•	•		•	•	•
2003	•	•	•		•	•	•
2010	•						

Before we present our results we first illustrate the effects of the differences in emissions on ozone concentrations between the three case years in the Netherlands. In Figure 1 we plotted the time series of ozone concentrations for smog episode 2 for all three emission years and no emission reductions applied, i.e. scenario S0. In addition, the time series for episode 1 and 3 are included in Appendix D.

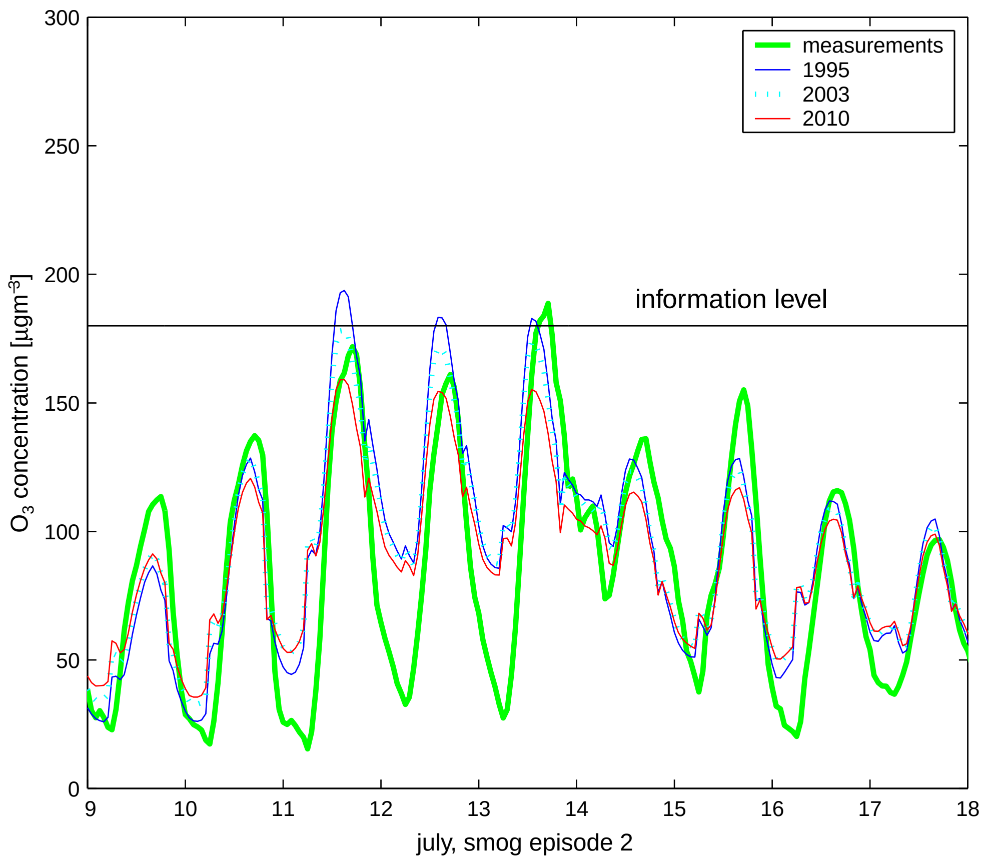


Figure 1. Averaged time series of ozone concentrations for smog episode 2 calculated with emission scenarios of the base years 1995, 2003 and 2010 (MV5; RIVM, 2000). The information level is indicated by the solid horizontal line. The average originally consisted of 15 time series calculated for 15 different locations in the Netherlands at measurement level. A time series of measurement data is shown in thick solid green being an average for the same 15 locations in 1994.

The measurement data were taken from 1994 and are approximately comparable to our model results with 1995 emissions. On average, night time and daytime values appear systematically too high and too low, respectively, which probably results from a too simple representation of the vertical mass exchange (see also the study by Delobbe et al., 2001). In our case it is most important to observe that the model slightly underestimates the day time maxima. In order to quantify this roughly we calculated the average ozone maxima for 15 locations during all three smog episodes, yielding 205 and 185 $\mu g/m^3$ for measurements and model results, respectively. Notice that this difference is biased by a small emissions input difference (a few percent) since we used 1995 emissions while the measurements are from 1994. Compared to 1995 the ozone peak concentrations in the year 2010 are significantly reduced whereas those in 2003 are about intermediate. This reduction in 2010 compared to 1995 results from a European wide significant decrease of precursor emissions. Moreover, the emission reductions obtained in 2010 mainly reduce the high ozone peaks during the smog episodes; see 12, 13 and 14 July in Figure 1. Under conditions representative for a normal situation, that is, a westerly flow with transport of air over sea, substantially lower ozone concentrations are observed (e.g. 17 July) and the differences between the various scenarios are rather small.

3.2 Model results

As stated in section 1, it is proposed in the Ozone Position Paper to use exceedance of the general alert threshold, i.e. 240 μg/m^3, as a trigger for the research presented here. The level for triggering specific actions and the design of the short-term action plans are not prescribed. In our model simulations for summer smog episodes we chose to initiate the short-term measures in our model runs the day after exceedance of the information threshold of 180 μg/m^3 in a grid cell. The resulting points in time for all three smog episodes were estimated using the base year 1995 runs and adopted for the base years 2003 and 2010 so as to compare their mutual differences. It should be realised that as a result of this adoption the exceedance of the threshold level is premature for 2003 and 2010 if compared to 1995 because of their lower emission levels. Several reasons can be given for choosing this trigger threshold in our model runs. First of all, it ensures that short-term measures are initiated before the general alert level is exceeded, i.e., it is a surrogate for an alert level forecast. Second, as observed in the previous section, the model slightly underestimates the ozone peaks so that in the case of a trigger level of 240 μg/m^3 the grid cells would often yield no exceedance. In line with this we also have to consider that the permanent emission reductions realised between the years 1995 and 2010 will lead to a significant reduction in ozone peaks (see Figure 1). In addition we note that exceedance of the alert level at a measurement location only occurred six times in total during the years 1997, 1998 and 1999 (RIVM, 1999; RIVM, 2001a).

In order to establish the correct point in time to initiate short-term measures we first ran the model for all three summer episodes using only case year 1995 emissions and then studied the results of these runs. Next we ran the model for every combination of summer episode and short-term scenario from the point in time at which the short-term measures were initiated using a so-called 'warmstart' file to ensure that from the point in time when short-term scenarios are imposed the concentration fields in the model are fully adapted to the local situation. It is suggested in the Ozone Position Paper to measure the effectiveness of short-term measures with the reduction of peak ozone values for which 10% is considered the minimum to be aimed at. In our study we represented the peak ozone value with a statistical equivalent, the 95-percentile of the ozone concentrations calculated for every grid cell. This method of studying the effects from short-term measures is more robust than using the number of exceedances of the information level (180 μg/m^3) for example. The latter method is a kind of binary statistic, which cannot be translated straightforward into a percentage reduction of ozone peak concentrations. The values are calculated for the time span between the initiation of the short-term scenarios and the end of an episode. We averaged the values for all 21 cells with an overlap into the Netherlands. Since not every grid cell has a complete overlap with the Netherlands and inhabitants are not homogeneously divided over the Netherlands, we weighted the results from each grid cell with the ratio between the number of Dutch inhabitants living in a grid cell and the total number of Dutch inhabitants (see

Appendix F for an overview of these statistics, including the surface area per grid cell; Appendix E shows the grid-cell coverage of the Netherlands). The results for all emission reduction scenarios for the year 1995 and 2003 are summarised in Tables 3 and 4, respectively. Additionally we included the same results but weighted with the area of Dutch territory within a grid cell in Appendix G (the outcome is comparable and therefore not discussed separately). As already mentioned in Section 3.1, no scenario runs were performed for the year 2010 and the results are solely used here as a reference to permanent measures.

Table 4. Results for all three smog episodes of averaged 95 percentile values of hourly ozone concentrations for all 21 grid cells in overlapping parts of the Netherlands for the years 1995 and 2010. Before calculating the average, the value for each grid cell was weighted with the ratio of Dutch inhabitants living within each cell relative to the total number of inhabitants in the Netherlands.

O_3 [µg/m^3]	S0 1995	S1 1995	S2 1995	S4 1995	S00 1995	Sint 1995	S0 2010
Episode 1	158	159 (+1%)	160 (+1%)	164 (+4%)	162 (+3%)	161 (+2%)	139 (-12%)
Episode 2	170	172 (+1%)	173 (+2%)	175 (+3%)	171 (+1%)	174 (+2%)	147 (-13%)
Episode 3	163	165 (+1%)	166 (+2%)	169 (+4%)	168 (+3%)	164 (+1%)	141 (-13%)

Differences between the emission reduction scenarios and the base year 1995 referred to as S0 are given in parentheses.

Table 5. Results for all three smog episodes of averaged 95 percentile values of hourly ozone concentrations for all 21 grid cells in overlapping parts of the Netherlands for the years 2003 and 2010. Before calculating the average, the value for each cell was weighted with the ratio of Dutch inhabitants living within the grid cell relative to the total number of inhabitants in the Netherlands.

O_3 [µg/m^3]	S0 2003	S1 2003	S2 2003	S4 2003	S00 2003	Sint 2003	S0 2010
Episode 1	153	154 (+1%)	154 (+1%)	156 (+2%)	150 (-2%)	154 (+1%)	139 (-9%)
Episode 2	163	164 (+1%)	163 (+0%)	165 (+2%)	157 (-4%)	164 (+1%)	147 (-9%)
Episode 3	157	158 (+1%)	157 (+0%)	158 (+1%)	155 (-1%)	156 (-1%)	141 (-9%)

Differences between the emission reduction scenarios and the case year 2003 referred to as S0 are given in parentheses.

For 1995 and 2003 the short-term scenarios S1, S2 and S4 appeared only to result in a small variation of the peak ozone concentrations and in almost all cases even a slight increase instead of decrease is observed on average. As already mentioned, this is probably due to the so-called NO titration effect as explained in Appendix A. The concentrations for the year 2003 are, relative to the base year, 1995, reduced which is conform the decrease in time of emission reductions, as observed in Table 2. Only the permanent emission reductions for the year 2010 show significant reductions in ozone maxima. For S00 the average results indicate a small suppression of the ozone burden in the Netherlands in 2003, but this obviously contrasts strongly with the unrealistic effort of reducing all precursor emissions to zero. Notice that in contrast to this the results for 1995 show slightly enhanced values. This difference results from differences in the variation of the 95-percentile values at grid-cell level (discussed in the next section). The international scenario Sint does show an overal improvement compared to S4 for both 1995 and 2003; however, the effects are very small.

This is the only scenario noted to show decreased values (between –1 and -4% for 1995) for the grid cells in the southern and eastern part of the Netherlands, proving the dominance of advection for the transport of air pollution in this part of the Netherlands, usually having the highest ozone maxima. In Figure 2 we plotted the time series of ozone during episode 2 to illustrate the effects of all short-term scenarios in the time series of ozone concentrations.

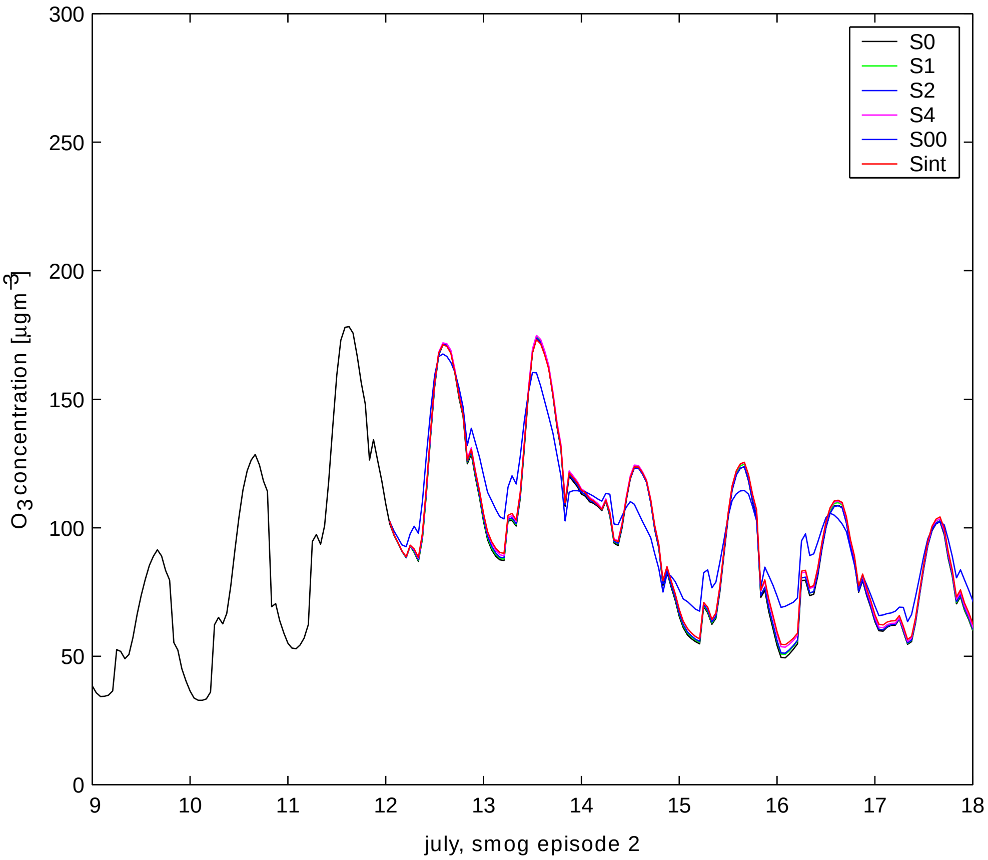


Figure 2. Time series of smog episode 2 showing the average simulated ozone concentrations for the 12 most important cells in the Netherlands for the emission base year 2003 and all short-term abatement scenarios used in this study.

It is very difficult to distinguish between S0 and the effects of the short-term scenarios S1, S2, S4 and Sint, whereas S00 shows a clear decrease in the peak ozone values during daytime and enhanced values at night-time. Notice that the peak reduction at 12 July is substantially lower than at 13 July. A large number of all precursors emitted during 11 July in the Netherlands are still present in the night time boundary layer well above the surface; the next morning they are mixed downward again, leading to relatively high ozone levels despite the absence of precursor emissions in the Netherlands. After roughly a day all precursors emitted on 11 July are transported across the Dutch border and the emission reductions take full effect.

In short we conclude that short-term measures imposed during ozone episodes result on average in a small net-increase of the ozone maxima. As mentioned before, it should be realised that as a result of a premature estimate of the exceedance of the threshold level the results for 2003 are somewhat overestimated. In the next section we will focus on the variations on a grid cell and inner-grid cell scale.

When the above results are translated into more policy-related instruments like AOT40 (the cumulative exceedance of 80 μg/m^3), exceedance the information level (= 180 μg/m^3) or exceedance of the guideline value for human health (= 120 μg/m^3; mean value over an 8-hour period) the effects of short-term measures are very small. In this context it is more meaningful to show the effects of permanent measures. As an example we calculated the sum of excess hourly averaged ozone concentrations above 180 μg/m^3 and the AOT40 for each case year. All 21 grid cells in the Netherlands were weighted with the population per grid cell and we summed the results for all three smog episodes. Relative to 1995 the estimated exceedance of 180 μg/m^3 dropped to 32% and 2%, and AOT40 values dropped to 93% and 73% for 2003 and 2010, respectively. Consequently, a considerable reduction of ozone concentrations takes place in the course of time due to permanent reduction measures.

3.3 Variability at grid- and inner grid-cell scales

The results presented in the previous section concerned averaged values for 21 grid cells. In order to better understand the variability of the results across the Netherlands and the model results themselves we will now study the various kinds of variability between and within grid cells. We can distinguish two kinds of variability between grid cells: the variation in ozone maxima and the variation in the changes in ozone maxima due to the imposed short-term measures. EUROS also offers the possibility of using local grid refinement, which, for the moment allows a grid-cell size of about 15 x 15 km for O_3 calculations. This feature is still in its experimental stage and needs further validation so that its results will therefore solely be used for a qualitative study of the inner-grid-cell variability on the scale of the largest Dutch cities (e.g., Amsterdam and the Rijnmond region, including Rotterdam). The emissions used in the refined model version are also grid refined within the local grid refined area (see map in Appendix H). Since this is a qualitative study, it suffices to present results for one scenario only.

First, we will present non-refined and refined results for smog episode 2 in the year 2003 in Figures 3, 4, 5 and 6 and study the ground level ozone maxima and the scenario ratio S4/S0 of the 95-percentile values. Second, we will present non-refined results for the scenario ratios S00/S0 and Sint/S0 of the 95-percentile values.

In Figure 3 the variation in maximum ozone concentration over the Netherlands is plotted, and minimum and maximum values are shown. In the middle of the Netherlands, where the majority of inhabitants, cities, industry and traffic are present, the concentrations are fairly

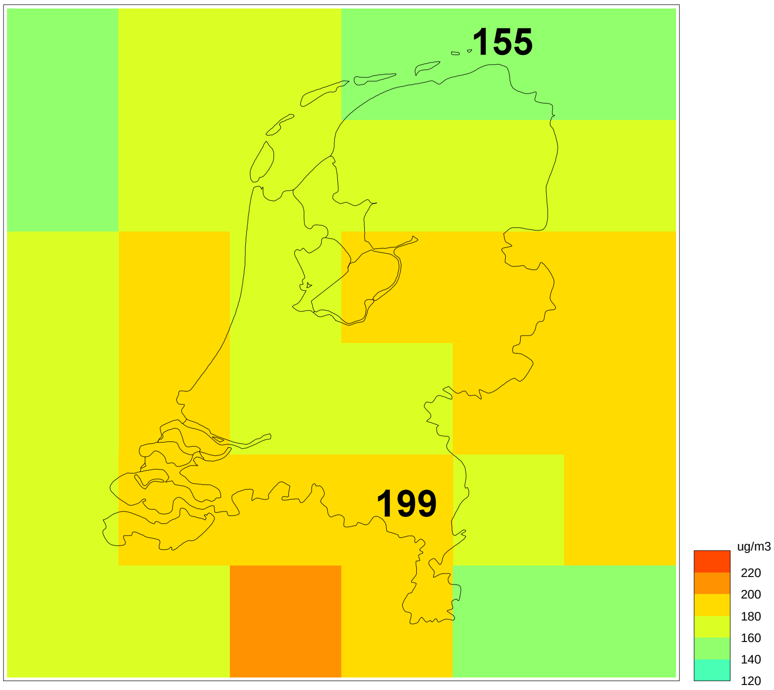


Figure 3. Maximum ozone concentrations in the Netherlands during smog episode 2 for S0 2003 emissions. The borders of the Netherlands are plotted, while the locations of cities with more than 100,000 inhabitants are visualised. Minimum and maximum values are given in the specific grid cells

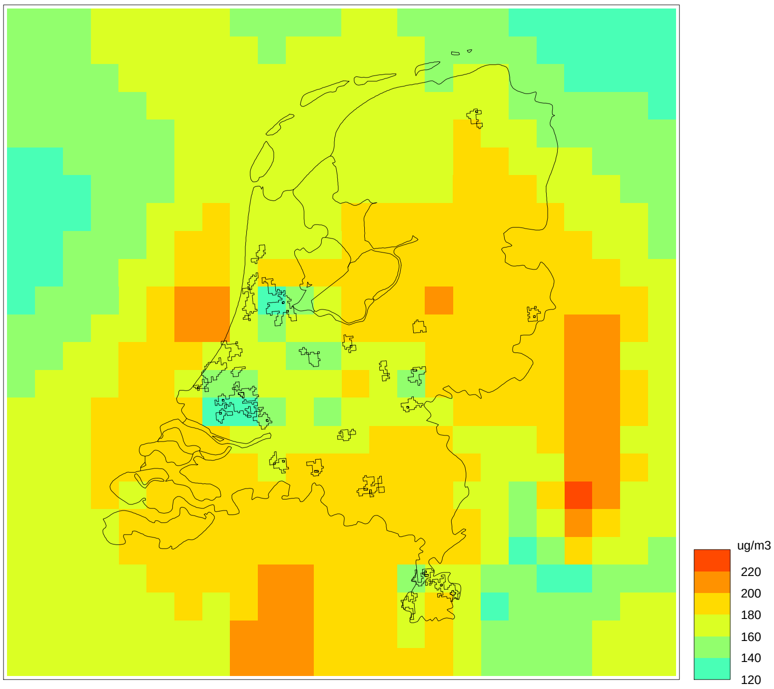


Figure 4. Maximum ozone concentrations from a grid refined model run during smog episode 2 for S0 2003 emissions. These results should only be regarded as illustrative. The borders of the Netherlands are plotted and within these, the locations of cities with more than 100,000 inhabitants are visualised. No minima and maxima are shown since grid refined results are only used qualitatively.

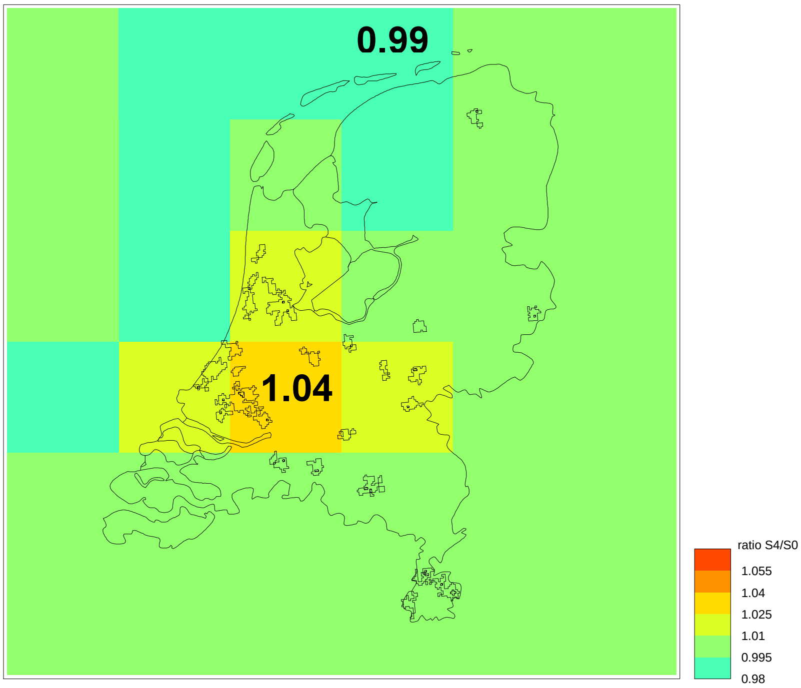


Figure 5. Ratios of the 95-percentile ozone concentrations results of scenarios S4 and S0 (i.e., S4/S0) for emissions in the year 2003 during smog episode 2. The borders of the Netherlands are plotted and within these, the locations of cities with more than 100,000 inhabitants are visualised. Maximum and minimum values are given in the specific grid cells.

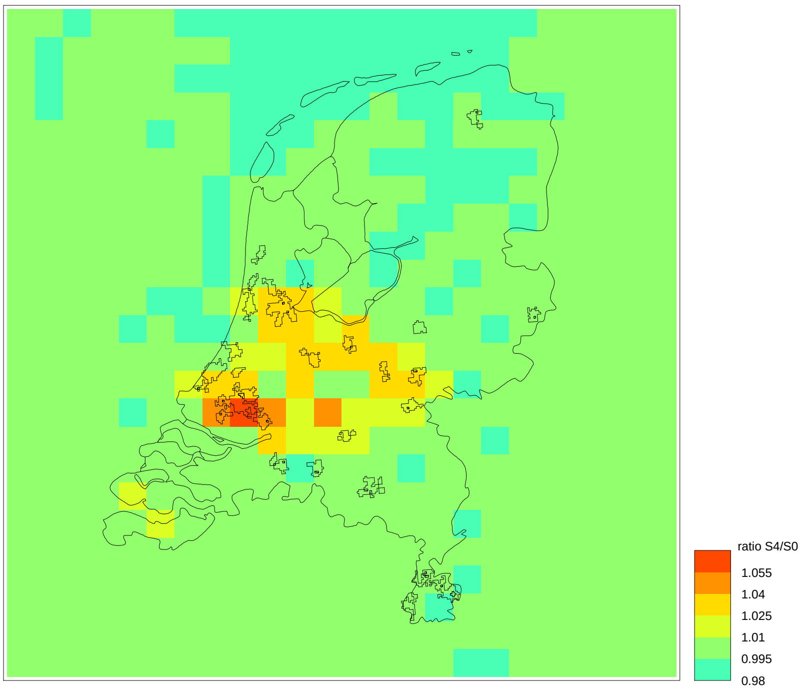


Figure 6. Ratios of the 95-percentile grid refined ozone concentrations results of scenarios S4 and S0 (i.e., S4/S0) for emissions in the year 2003 during smog episode 2. These results should only be regarded as illustrative. The borders of the Netherlands are plotted and within these, the locations of cities with more than 100,000 inhabitants are visualised. No minima and maxima are shown since grid refined results are only used qualitatively.

low due to the NO titration effect (Appendix A). In line with this the surrounding cells with more rural characteristics show markedly higher concentrations (southern and eastern part of the Netherlands). In the far north-western and northern part of the map the precursor load of the air is lower so that the ozone peaks are lower too. In Figure 4, the grid-refined counterpart of Figure 3 is shown with all the above noted features identified on city scale (15 x 15 km). The most populated and industrialised parts of the Netherlands (in the middle of the figure), with large cities such as Amsterdam and Rotterdam and the surrounding Rijnmond area are nicely identified by their low ozone concentrations (dark and light blue colours). On the leeside (recalling the prevailing south-easterly or easterly winds) of these areas, we observe much higher ozone concentrations over parts of the North Sea; this is in qualitative agreement with the review given in Appendix A.

Figure 5 shows the ratio of 95-percentile ozone concentrations from scenario S4 and S0 (i.e., S4/S0) without grid refinement. The centre of the Netherlands has the highest grid-cell values (maximum 1.04), whereas the rest of the Netherlands shows values between 0.993 and 1 (for 1995 the results for the S4 scenario vary from 1.08 to 0.985). The results presented in Table 4 appear therefore to be dominated by the increment of ozone maxima in the most industrialised and inhabited part of the Netherlands due to reduced NO titration (56% of the Dutch population lives within the four cells with values above 1). The refined results in Figure 6 confirm this and illustrate that the highest cell values are related mainly to highly industrialised and populated areas, e.g. the Rijnmond area around Rotterdam. Most other cells show a small decrease in 95-percentile values due to short-term measures.

Figure 7 shows the ratio of 95-percentile ozone concentrations in scenarios S00 and S0 (i.e., S00/S0) without grid refinement. As already observed in our previous results, the ozone maxima in the highly industrialised and populated Rijnmond area are increased, along with one cell due south-west of it. Several other cells, especially in the northern half of the Netherlands, show a substantial decrease of ozone maxima, with a maximum value of -14%. Obviously these are only small effects compared with the enormous effort taken; i.e., there are no precursor emissions in the Netherlands. Figure 8 shows the ratios for the scenarios Sint and S0 (i.e., S00/S0). We used the same scaling as in Figure 5 for the ratio S4/S0, which makes it easy to compare both results. In the Rijnmond area we observe comparatively increased values of the ozone maxima. In contrast to the results for scenario S4 in Figure 5, the southern and eastern parts of the Netherlands now show a large number of cells with decreased ozone maxima. Although the effects are small, they nevertheless indicate the importance of advection for these parts. The cell with the highest value is found in Germany and is highly industrialised and populated (includes, for example, Cologne and Dusseldorf) showing clearly the effects of reduced NO titration.

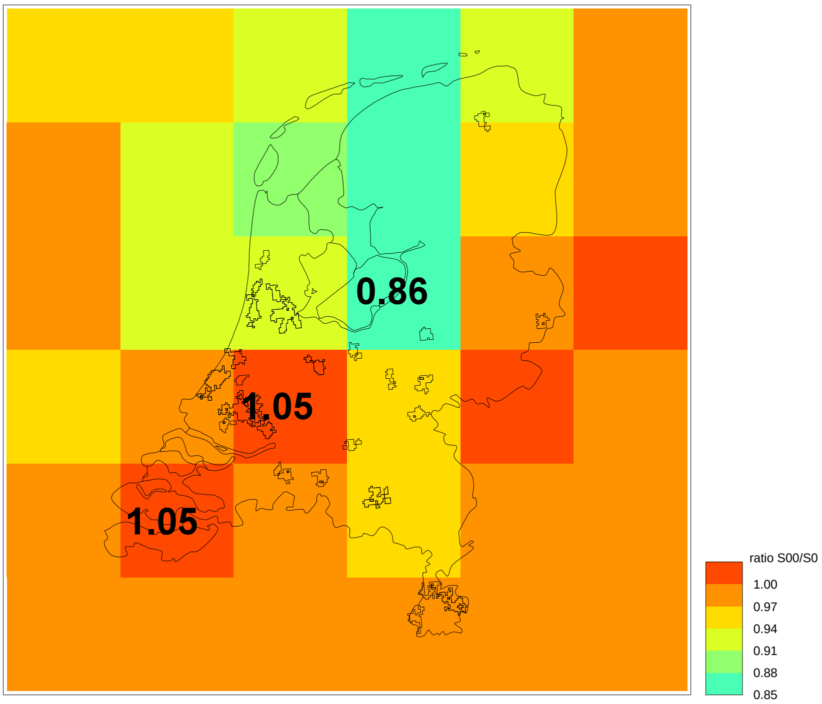


Figure 7. Ratios of the 95-percentile ozone concentration in scenarios S00 and S0 (i.e., S00/S0) for emissions in the year 2003 during smog episode 2. The borders of the Netherlands are plotted and within these, the locations of cities with more than 100,000 inhabitants are visualised. Maximum and minimum values are given in the specific grid cells.

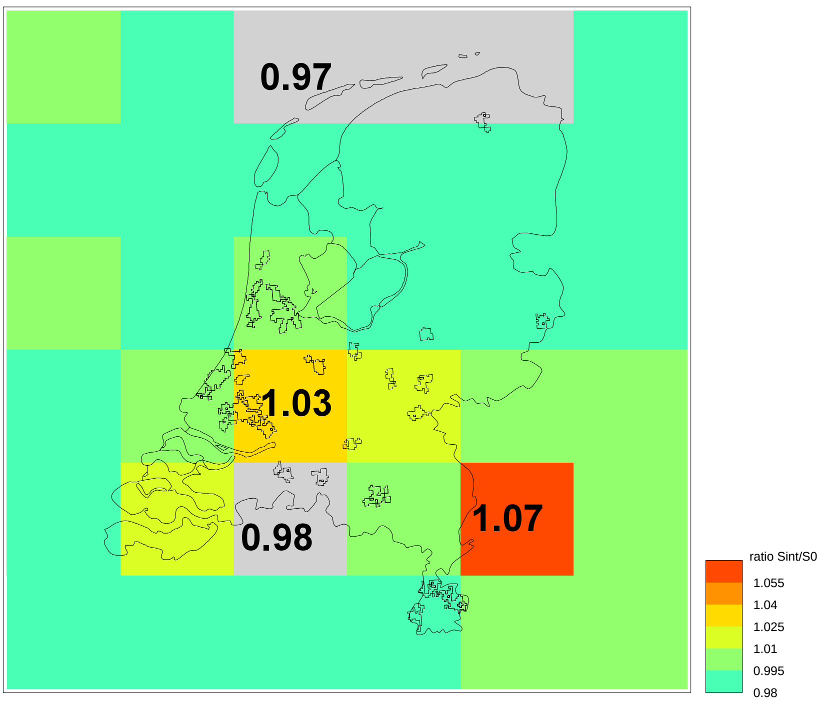


Figure 8. Ratios of the 95-percentile ozone concentration in scenarios Sint and S0 (i.e., Sint/S0) for emissions in the year 2003 during smog episode 2. The borders of the Netherlands are plotted and within these, the locations of cities with more than 100,000 inhabitants are visualised. Maximum and minimum values are given in the specific grid cells.

In short, at a grid-cell scale in the highly industrialised and populated western part of the Netherlands, which experiences the lowest ozone maxima, we observe an increase in the ozone maxima due to short-term measures. This is the consequence of reducing the NO_x emissions, i.e. the titration effect is reduced. This effect clearly dominates the weighted averaged results for the Netherlands, as presented in Tables 4 and 5. For the larger part of the Netherlands (being much less populated and industrialised) we only observe small variations in the ozone maxima (between -1% and +1%). In addition, it should be noted that the latter part of the Netherlands often experiences the highest ozone maxima (in the south-east). The effects of the scenarios S00 and Sint are small too, but nevertheless, indicate that advection plays a crucial role in the southern and eastern part of the Netherlands.

4. Social cost effectiveness of short-term abatement measures

An estimate of cost efficiency for the short-term abatement measures imposed in our model study (see Table 1) appears not to be possible within a certain degree of accuracy. However it is possible to gain some insight in cost efficiency by using the results from a study on speed reductions on motorways in the Netherlands conducted by project developer IVVS (Binsbergen et al., 1995). The former study calculated social costs for applying a nation wide speed limit of 90 km/hr instead of the regular 100 or 120 km/hr. A cost benefit analysis showed that, according to IVVS, the speed limits would lead to a profit of about EUR 800 million per year (including e.g. travel time, fuel usage, emissions, road casualties). It is obvious that the reduction of road casualties dominates this figure. Incidentally the lower average speed reduces the total length of traffic-jams which stimulates a more free circulation of traffic.

In translating these results to our short-term scenarios one should account for the short-term at which these scenarios are proclaimed, e.g. no more then one or two days in advance. This will raise the costs unpredictably. Experiences with acceptance of short-term measures during field experiments at a local scale performed in Germany showed that the population is willing to accept restrictions to achieve better air quality (see e.g. Bruckmann and Wichmann-Fiebig, 1997; Moussiopoulos et al., 1997). On the other hand, experiences in Germany with its ozone law (in effect from 1995 until 1999, triggering short-term measures at the alert level and including large-scale driving bans) show that the monitoring of upholding selective driving bans is very laborious and not very efficient. The not-in-my-backyard syndrome definitely will play a role here. If we consider the costs then scenario S2 will probably lead to extra costs due to an increased use of public transport as an alternative to the car and scenario S3 will lead to extra costs because of e.g. non-deliverance of products.

5. Discussion and conclusions

In this report we studied the effects of short-term measures during three summer smog episodes in the year 1994 using the air quality model EUROS and two different emission base years, i.e. 1995 and 2003. The year 2003 was chosen as a reference to the year in which the new ozone Directive, and consequently possible short-term measures will take effect. The scenario for 2010 was used a reference for permanent measures. It appears that on average the short-term measures tend to slightly increase the 95-percentile values (a representative of ozone maxima) in 1995 and 2003. Studying the variations at a grid-cell level shows that the ozone maxima mainly increase in highly industrialised and populated areas (e.g. the Rijnmond area around Rotterdam) possibly as a result of reduced NO titration. In contrast, a large part of the Netherlands (the south and east), usually having the highest ozone maxima shows only little or no variation of ozone maxima. This indicates that advection of air pollution is an important contributor to the high ozone maxima in these parts of the Netherlands. An international scenario that imposes short-term measures at the same rate to the Netherlands, Belgium, Luxembourg and Rhineland-Westphalia (Germany) did not improve the average results significantly. However, this was the only scenario that revealed reduced ozone maxima in the south and east, pointing to the significance of advected air pollution in these areas. As a sensitivity test we also imposed a hypothetical scenario that prescribed no precursor emissions in the Netherlands. The averaged results only show a small reduction of ozon maxima. The inner-cell variability is fairly large and shows a sunstantial increase in the ozone burden in and around the Rijnmond region (95 percentile values increased about +15%) and a substantial reduction to the north of this region (values dropped about –10%). Nonetheless, compared to the unrealistic effort taken, the changes are relatively small.

Our simulations suggest that photochemical pollution in the Netherlands is dominated by a transboundary phenomenon, meaning that advection of air with a high ozone and precursor load is the factor mainly determining the extent of the ozone burden. The results obtained from our model calculations strongly suggest that the ozone burden in the Netherlands cannot be reduced significantly by imposing short-term reduction strategies within the Netherlands alone or with inclusion of surrounding areas. In this light the 10% minimum effectiveness targeted in the Ozonen Position Paper for reducing peak ozone levels will probably not be met by means of short-term abatement measures in the Netherlands. It should be noted that the emission reductions due to permanent measures in the near future will even further reduce the effects of short-term measures.

Permanent reductions of precursor emissions in all Member States appears to be the only effective way to obtain a substantial reduction of ozone peak concentrations. Regional concentration fields of ozone are dominated by long-range transport even under conditions with low wind speeds. As a consequence, measures to prevent high ambient ozone concentrations have to be taken simultaneously on a large (European) scale. The proposed structural reduction measures in 2010 will lead to a reduction of ozon precursors in the EU of 21(17)% VOC(NO_x) and 30(25)% VOC(NO_x) relative to 1995. Based on these emissions we found that in 2010 in the Netherlands (for the periode from may to july) the exceedance of the information level (= 180 $\mu g/m^3$) drops 90%, the guideline value for human health (= 120 $\mu g/m^3$ mean over an 8 hr period) drops 30%, and AOT40 (accumulation over threshold of 80 $\mu g/m^3$ during daylight hours) drops 25% relative to 1995.

We emphasize that our model results are generally in good agreement with several earlier model studies performed in the Netherlands (De Leeuw, 1984; De Leeuw, 1987; Van den Hout et al., 1985; Van den Hout en De Leeuw, 1987) and more recent German results from field studies and model calculations (e.g. Bruckmann and Wichmann-Fiebig, 1997; Motz et al., 1997). In view of this agreement we feel that, despite the inevitable presence of model uncertainties, our results and conclusions are validated firmly.

References

Becker, K.H.: 2000. Prozeßstudien zur Oxidantienbildung und Oxidationskapazität: Kurzüberzicht. Institut für Physikalische Chemie, Bergische Universität GH, Wuppertal, Germany.

Binsbergen, A.J., G.D. van Goeverden, R.G.M.M. Vermijs: 1995. Mag het ietsje minder snel?; Berekening van maatschappelijke kosten en baten van snelheidsverlaging voor het personenautoverkeer. Technische Universiteit Delft, Delft (commissioned by Projectbureau IVVS)

BMU (Bundesministerium für Umwelt Naturschutz und Reaktorsicherheit): 2000. The Federal Government of Germany's immediate programme for the reduction of ozone pollution. Bundestagsdrucksache 14/3609, Berlin.

Borrell, P., P. Builtjes, P. Grennfelt, Ø. Hov, R. van Aalst, D. Fowler, G. Megie, N. Moussiopoulos, P. Warneck, A. Volz-Thomas and R. Wayne: 1995. Photo-oxidants, Acidification and Tools; Policy Applications of EUROTRAC Results, EUROTRAC ISS, Garmisch-Partenkirchen, Germany.

Bruckmann, P. and M. Wichmann-Fiebig: 1997. The efficiency of short-term actions to abate summer smog: Results from field studies and model calculations. EUROTRAC Newsletter, 19, 2-9.

Commissie van de Europese gemeenschappen: 1997. Voorstel voor een dochterrichtlijn voor SO_2, NO_X, zwevende deeltjes en lood.

Crutzen, P.J.: 1995. Introductory lecture. Overview of tropospheric chemistry: developments during the past quarter century and a look ahead., Faraday Discuss., 100, 1-21.

Cuvelier, C. and P. Thunis: 1998. Influence of NO_X/VOC emission reduction on ozone levels in the Mediterranean area. Joint Research Centre, Ispra, Italy.

Delobbe, L., J. Matthijsen and F.J. Sauter: 2001. Evaluation of mixing height representations in the EUROS model. Report 711002001, Institute of Public Health and Environmental Protection (RIVM), Bilthoven, The Netherlands.

Derwent, H.G. and A.M. Hough:1987. The impact of emission reduction scenarios on photochemical Ozone and other pollutants formed downwind of London. AERE Report R-12859, HMSO, London.

Derwent, R.G. and T.J. Davies: 1994. Modelling the impact of NO_X or hydrocarbon control on photochemical ozone in Europe. Atmosph. Environm., 28(12), 2039-2052.

Diederen, H.S.M.A., R. Guicherit, L.F. Heidema, J.C.T. Hollander en K.D. van den Hout: 1981. Rapport ter afsluiting van het oxidantiaproject. Rapport IMG-TNO G 1095, Delft.

Doesburg, M.J. van: 1995. Evaluatie van de zomersmogsituatie in 1994. Report 722101020, Institute of Public Health and Environmental Protection (RIVM), Bilthoven, The Netherlands. *(in Dutch)*

Duncan, B.N. and W.L. Chameides: 1998. Effects of urban emission control strategies on the export of ozone and ozone precursors from the urban atmosphere to the tropospere. J. Geofys. Res., 103 (D21), 28159-28179.

EC: 1999. Ad-Hoc Working Group on Ozone Directive and Reduction Strategy Development, Ozone Position Paper. Office for Official Publications of the European Communities, Luxembourg.

EC: 2001. Environment 2010: Our Future, Our Choise. 6^{th} EU Environment Action Programme (6^{th} EAP). Office for Official Publications of the European Communities, ISBN 92-894-0261-X, Luxembourg.

Finzi, G., C. Silibello and M. Volta: 1998. Evaluation of urban pollution abatement strategies by a photochemical dispersion model. Proc. 5^{th} International conference on harmonisation within atmospheric dispersion modelling for regulatory purposes, Rhodes.

Geiβ, H., M. Memmesheimer, D. Kley, H. Jakobs, A. Ebel and H. Hass: 1996. Nested simulation of summer smog episode with the EURAD model: The role of the VOC/NO_X ratio of anthropogenic emission sources. In: Borrell, P.M., P. Borrell, T. Cvitaš, K. Kelly, and W. Seiler (eds.), Proceedings of EUROTRAC symposium ’96, Vol 1, 497-502.

Haagen-Smit, A.: 1952. Chemistry and physiology of Loa Angeles smog. Ind. Eng. Chem., 44, 1342-1346.

Hout, K.D. van den et al.: 1985. Koolwaterstoffen in relatie tot de luchtkwaliteit (3e basisdocument koolwaterstoffen). Rapport CMP 85/03 CMO-TNO, Delft.

Hout, K.D. van den and F.A.A.M. de Leeuw: 1987. Modelberekeningen met het MPA-trajectoriënmodel van episoden met fotochemische luchtverontreiniging. In: Ozon, fysische en chemische veranderingen in de atmosfeer en de gevolgen, 92, Kluwer, Deventer.

Jacobs, C.M.J. and W.A.J. van Pul: 1996. Long-range atmospheric transport of persistant Organic Pollutants, I: Description of surface-atmosphere exchange modules and implementation in EUROS. Report 722401013, National Institute of Public Health and Environmental Protection (RIVM), Bilthoven, The Netherlands. (*In Dutch)*

Krüger, B.C., J.Kübler and A. Clappier: 1998. Ozone control strategy calculations for the Geneva area. In: Borrell, P.M., P. Borrell, K. Kelly, T. Cvitaš and W. Seiler (eds.), Proceedings of EUROTRAC symposium '98, Vol 2, 826-830.

Leeuw, F.A.A.M. de: 1984. Schattingen van de effecten van een reductie in NO_x emissies op oxidantniveau's. Report 228216031, National Institute of Public Health and Environmental Protection (RIVM), Bilthoven, The Netherlands. (*In Dutch)*

Leeuw, F.A.A.M. de: 1987. Fenomenologie, trends en bronnen van ozon. In: Ozon, fysische en chemische veranderingen in de atmosfeer en de gevolgen, 40, Kluwer, Deventer.

Leeuw, F.A.A.M de, R. Sluyter R, P. van Breugel, and F. Bogman: 2001. Air pollution by ozone in Europe in 1999 and the summary of 2000. Topic Report no. 1/2001. European Topic Centre on Air Quality EEA, Copenhagen.

Leeuw, F.A.A.M de and E.D.G. Van Zantvoort: 1997. Exceedance of ozone threshold values in the European Community in 1996. ETC/AQ, Bilthoven, The Netherlands.

LFU: 1998. Kurtzzeitmassnahmen zur Reduzierung der Ozonevorläuferstoffe in der Europäischen Union und der USA. Landesanstalt für Umweltschutz Baden-Würtenberg, Karlruhe, Duitsland.

Loon, M. van: 1996. Numerical methods in smog prediction. Ph. D. thesis, Universiteit van Amsterdam, Amsterdam.

MEDCAPHOT-TRACE: 1998. The Mediterranean campaign of photochemical traces transport and chemical evolution (MEDCAPHOT-TRACE). Atmosph. Environm., 21(2), special issue.

Motz, G., A. Hartmann and E. Plinke: 1997. Action program and control concept for ozone (summersmog). Prognos AG, Basel.

Moussiopoulos, N., P.Sahm, R. Hunz, T. Vögele, CH. Schneider and CH. Kessler: 1997. High-Resolution simulations of the wind flow and the ozone formation during the Heilbronn ozone Experiment. Atm. Environm., 31(19), 3177-3186.

Moussiopoulos, N., Sahm, P., Tourlou, P.M., Friedrich, R. Wickert, B., Reis, S. and Simpson, D.: 1998. Technical Expertise in the Context of the Commission's Communication on an Ozone Strategy. Report nr B4-3040/98/000052/MAR/D3

Moussiopoulos, N., P. Sahm, P.M. Tourlou, T. Nitis, A.K. Azad and S. Papalexiou: 1999. Tropospheric ozone and urban air quality. In: Friedrich, R. and S. Reis (eds.), Tropospheric ozone abatement: developing efficient strategies for reduction of ozone procursor emissions in Europe.

NEC: 1999. Proposal for a directive of the European parliament and of the council on national emission ceilings for certain atmospheric pollutants. COM 99(125). Brussels.

RIVM: 1999. Luchtkwaliteit: jaaroverzicht 1997. Report 725301001. Institute of Public Health and Environmental Protection (RIVM), Bilthoven, The Netherlands. (*InDutch)*

RIVM: 2000. Nationale Milieuverkenning 5, 2000-2030 (MV5). Samson H.D. Tjeenk Willink, Alphen aan de Rijn.

RIVM: 2001a. Luchtkwaliteit: jaaroverzicht 1998 en 1999. Report 725301006. Institute of Public Health and Environmental Protection (RIVM), Bilthoven, The Netherlands. (*InDutch)*

RIVM: 2001b. Milieubalans 2001. Samson H.D. Tjeenk Willink, Alphen aan de Rijn.

Rombout, P.J.A., H.C. Eerens and F.A.A.M. de Leeuw: 1989. Analyse van het gezondheidsrisico van stadsbewoners door blootstelling aan luchtverontreiniging tijdens zomersmogperioden en het effect van verkeersbepalende maatregelen. Report 678902001, Institute of Public Health and Environmental Protection (RIVM), Bilthoven, The Netherlands. *(inDutch)*

Sillman, S: 1999. The relation between ozone, NO_x and hydrocarbons in urbanand polluted rural environments. Atm. Environm., 33, 1821-1845.

Simpson, D., K. Olendrzynski, A. Semb, E. Storen, and S. Unger: 1997. Photochemical oxidant modelling in Europe: multi-annual modelling and source-receptor relationships. EMEP/CCC-Report 3/97, DNMI, Oslo, Norway.

Touloumi G, K. Katsouyanni and D. Zmirou: 1997. Short-term effects of ambient oxidant exposure on mortality: a combined analysis within the APHEA project. Am. J. Epidemiol., 146, 177-85.

UBA (Umweltbundesamt): 2001. Hintergrundinformation: Sommersmog. Berlin.

Vanderstraeten, P., F. Willette and G. Dumont: 1996. Working day versus non-working day ambient ozone concentrations in Brussels and in Belgian. In: Borrell, P.M., P. Borrell, K. Kelly, T. Cvitaš and W. Seiler (eds.), Proceedings of EUROTRAC symposium ’96, Vol 1, 899-903.

VROM: 1991. Smogregeling 1991. Den Haag.

VROM: 2001. Smogregeling 2001. Den Haag.

Appendix A A brief overview of O_3-NO_x-VOC chemistry

The central features of the relationship between ozone, NO_x and VOC are illustrated by the ozone production isopleth's in Figure 9 (based on Fig. 1 in Sillman, 1999). The rate of ozone production (the arrow indicates increasing values) is plotted as a function of NO_x and VOC concentrations.

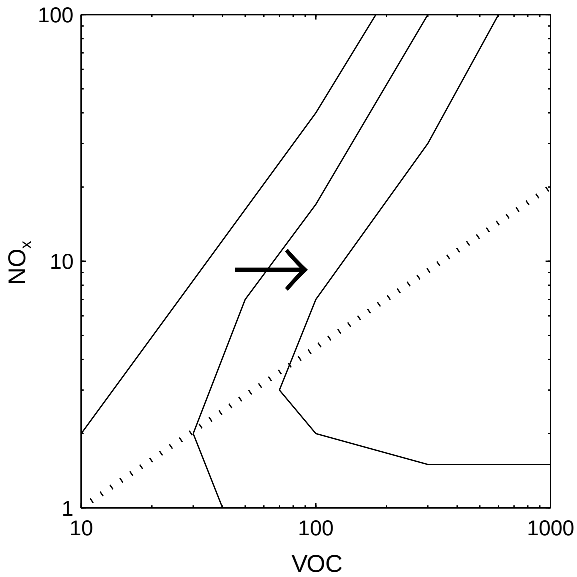


Figure 9. The qualitative behaviour of the ozone-NO_x-VOC chemistry as approximated from Fig. 1 in Sillman (1999). The isopleth's give the rate of ozone production (solid lines) as a function of VOC and NO_x for mean summer daytime meteorology and clear skies. The arrow indicates increasing ozone production. The dotted line represents a devide between the VOC saturated (below) and a NO_x saturated (above).

As is obvious from Figure 9 the process of ozone formation is highly non-linear in relation to NO_x and VOC concentrations. When NO_x is low, the rate of ozone production mainly increases with increasing NO_x (the VOC saturated regime). As NO_x further increases the rate of increase in ozone formation slows, reaching a local maximum (the dotted line) and eventually the ozone formation decreases (the NO_x saturated regime). The latter regime will e.g. be observed for scenario S1 (1995, Table 2) in industrialised areas of our model. NO_x decreases by about 8%, whereas VOC emissions remain about constant, comparable to vertically downward travel in Figure 9 above the dotted line, hence ozone production increases.

Besides the aforementioned O_3-NO_x-VOC sensitivity we also have to consider the photostationary balance

$$NO_2 + O_2 \leftrightarrow NO + O_3$$

that takes place at a substantially shorter time scale than ozone production and is therefore of more importance to local ozone concentrations in case of e.g. high local NO emissions in urban areas. Under such conditions ozone is rapidly removed due to a shift in the photostationary balance. Hence, the ozone concentration rapidly decreases and becomes relatively low in areas where this so-called NO titration (as it is also referred to in this report) takes place. Our results on the grid and inner-grid cell scale clearly show that in the industrialised parts of the Netherlands this process controlls the ozone concentrations (see Figures 3 and 5). Further downwind of urban centres the direct NO-sink becomes less important since the precursor emissions are small and a new balance is obtained in the air mass while it ages and evolutes to a VOC saturated regime (Sillman, 1999). The ozone production process takes over, and as a result, increases the ozone concentration.

Appendix B Emissions in the Netherlands for the years 1995, 2003 and 2010

Table 6 shows the emission levels for the years 1995 and 2010 as described in MV5. For the year 2003 there is no specific information at hand and we estimated these figures from the emissions of year 2000 and 2005 used as background information in RIVM (2001b). The transport sector, of major importance for our short-term abatement reductions, is subdivided into its most important contributors. Notice that passenger car emissions are reduced substantially whereas shipping traffic emissions increase in the course of time. As a consequence, short-term abatement measures imposed solely on road traffic will have a decrease in efficieny in the course of time.

Table 6. Emissions of NO_x and VOC in the Netherlands for a variety of different sectors in the years 1995, 2003 and 2010 based on MV5 (RIVM, 2000) scenarios. Values are given in the dimension [kton per year].

	MV5 1995		**2003**		**MV5 2010**	
	NO_X	**VOC**	**NO_X**	**VOC**	**NO_X**	**VOC**
Industry (including refineries)	78	96	51	69	51	64
Energy	58	26	43	21	24	9
Building	1	20	1	19	1	11
Traffic: passenger cars	113	103	64	56	20	27
Traffic: delivery vans	14	8	19	5	7	1
Traffic: lorries	76	9	59	5	41	3
Traffic: busses	9	2	5	1	3	0
Traffic: railway	2	0	1	0	2	0
Traffic: shipping	53	3	50	2	62	5
Traffic: other	43	28	39	21	25	15
Rural	9	2	9	2	9	2
Processing of waste	3	2	2	2	2	2
Services (abbreviated as HDO in Dutch)	6	32	7	20	8	19
Consumers	25	37	21	30	15	31
Nature	16	3	16	3	16	3
Total emission in [kton per year]	**506**	**371**	**387**	**256**	**286**	**192**

In Table 7 the VOC emissions are given as a result of transshipment activities for several sectors and three case years. It should be noted that the values for the sector Services has a rather large range of uncertainty.

Table 7. VOC emissions in [kton per year] as a result of transshipment activities for several sectors and case years.*

	2000	**2003**	**2010**
Refineries	0.8	0.8	0.9
Services (abbreviated as HDO in Dutch)	2.4 - 3.6	2.5 - 3.7	2.6 - 3.9
Chemical industry	0.2	0.2	0.2
Total [kton per year]	**3.4 – 4.6**	**3.5 – 4.7**	**3.7 – 4.8**

* this information was provided by Bart Wesselink and Marian van Schijndel, LAE, RIVM.

Appendix C Overview of the short-term abatement measures in 1995 and 2010

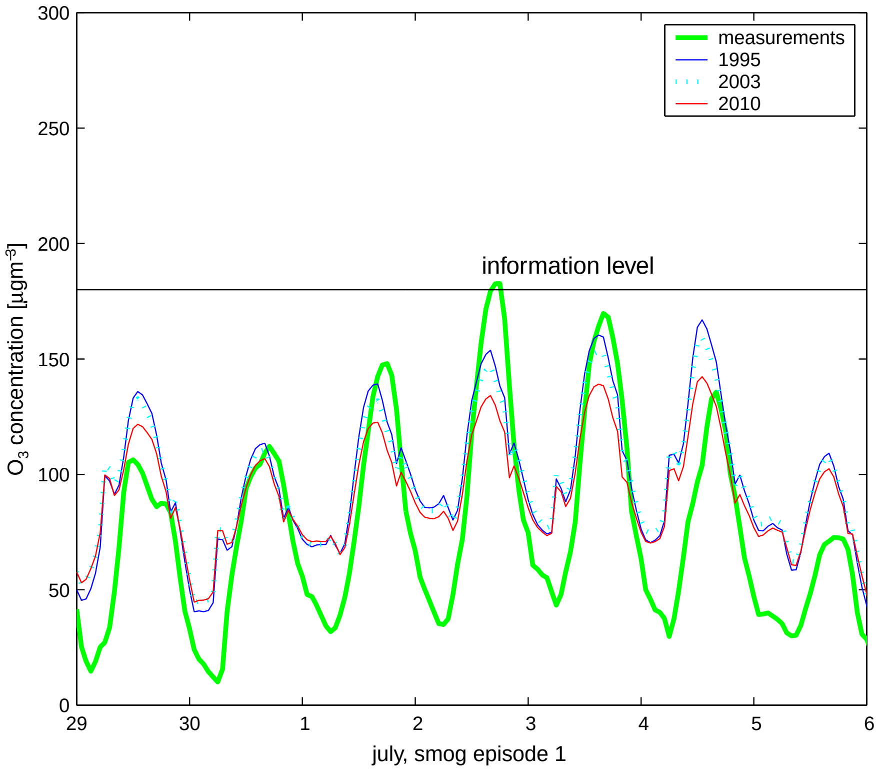
Table 8. Comprehensive overview of road traffic emissions for 1995 and 2010 considering the short-term abatement scenarios S1, S2 and S3 imposed in our model study.*

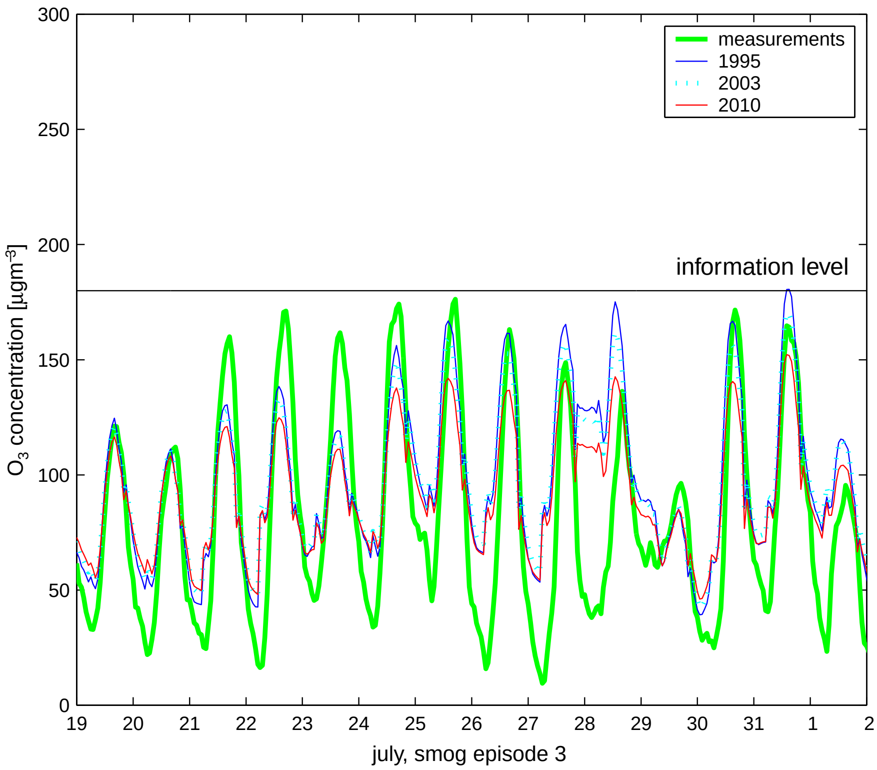
	Emissions								
1995	**NO_X (kton)**					**VOC (kton)**			
	city	rural	motorway	total		city	rural	motorway	total
passenger car	24	27	58	108		38	15	16	70
delivery van	9	5	5	20		5	2	1	7
lorry	5	10	20	34		1	1	2	4
tractor	9	7	23	40		2	1	2	5
bus	3	2	3	8		1	0	0	2
other	2	1	0	3		10	3	2	15
total road traffic	52	52	109	213		58	22	23	103
2010-EC	**NO_X (kton)**					**VOC (kton)**			
	city	rural	motorway	total		city	rural	motorway	total
passenger car	4	5	10	19		9	4	4	17
delivery van	5	2	3	10		1	0	0	1
lorry	3	5	11	19		0	0	1	2
tractor	5	4	12	20		1	0	0	1
bus	1	1	1	3		0	0	0	0
other	1	0	0	2		4	1	1	6
total road traffic	18	17	36	72		15	6	6	27
S1: motorway speed limit: cars 80 km/hr, delivery vans and trucks 60 km/hr									
1995	**NO_X (kton)**					**VOC (kton)**			
	city	rural	motorway	total		city	rural	motorway	total
passenger car	24	27	44	95		38	15	16	70
delivery van	9	5	4	18		5	2	1	7
lorry	5	10	19	33		1	1	2	5
tractor	9	7	22	39		2	1	2	5
bus	3	2	3	8		1	0	0	2
other	2	1	0	3		10	3	2	15
total road traffic	52	52	92	195		58	22	24	104
effect of measure on emission	0%	0%	-16%	-8%		0%	0%	4%	1%
2010-EC	**NO_X (kton)**					**VOC (kton)**			
	city	rural	motorway	total		city	rural	motorway	total
passenger car	4	5	8	17		9	4	4	17
delivery van	5	2	2	9		1	0	0	1
lorry	3	5	10	18		0	0	1	2
tractor	5	4	11	20		1	0	1	1
bus	1	1	1	3		0	0	0	0
other	1	0	0	2		4	1	1	6
total road traffic	18	17	32	68		15	6	6	27

effect of measure on emission	0%	0%	-11%	-6%		0%	0%	4%	1%
S2: driving ban for cars without catalytic converters									
1995	**NO_X (kton)**					**VOC (kton)**			
	city	rural	motorway	total		city	rural	motorway	total
passenger car	11	10	19	39		21	4	4	29
delivery van	9	5	5	20		5	2	1	7
lorry	5	10	20	34		1	1	2	4
tractor	9	7	23	40		2	1	2	5
bus	3	2	3	8		1	0	0	2
other	2	1	0	3		10	3	2	15
total road traffic	39	34	70	143		41	11	11	62
effect of measure on emission	-25%	-33%	-36%	-33%		-29%	-51%	-53%	-39%
2010-EC : no effects on NO_x and VOC									
S3: driving ban for lorries and tractors within urban centres									
1995	**NO_X (kton)**					**VOC (kton)**			
	city	rural	motorway	total		city	rural	motorway	total
passenger car	24	27	58	108		38	15	16	70
delivery van	9	5	5	20		5	2	1	7
lorry	0	10	20	30		0	1	2	3
tractor	0	7	23	30		0	1	2	2
bus	3	2	3	8		1	0	0	2
other	2	1	0	3		10	3	2	15
total road traffic	38	52	109	198		55	22	23	99
effect of measure on emission	-27%	0%	0%	-7%		-6%	0%	0%	-3%
2010-EC	**NO_X (kton)**					**VOC (kton)**			
	city	rural	motorway	total		city	rural	motorway	total
passenger car	4	5	10	19		9	4	4	17
delivery van	5	2	3	10		1	0	0	1
lorry	0	5	11	16		0	0	1	1
tractor	0	4	12	15		0	0	0	1
bus	1	1	1	3		0	0	0	0
other	1	0	0	2		4	1	1	6
total road traffic	11	17	36	65		14	6	6	26
effect of measure on emission	-40%	0%	0%	-10%		-7%	0%	0%	-2%

* This information was provided by Robert van den Brink, LAE, RIVM.

Appendix D Time series for smog episodes 1 and 3





Figures 10 and 11. Averaged time series of ozone concentrations for smog episode 1 and 3 (Figure 10 and 11, respectively) with emissions from base years 1995, 2003 and 2010 (MV5; RIVM, 2000). The information level is indicated by the solid horizontal line. The average consists of 15 time series calculated for 15 different locations in the Netherlands at measurement level. In thick solid green a time series of measurements is shown being an average for the same locations in the year 1994.

Appendix E Grid cells in the EUROS model

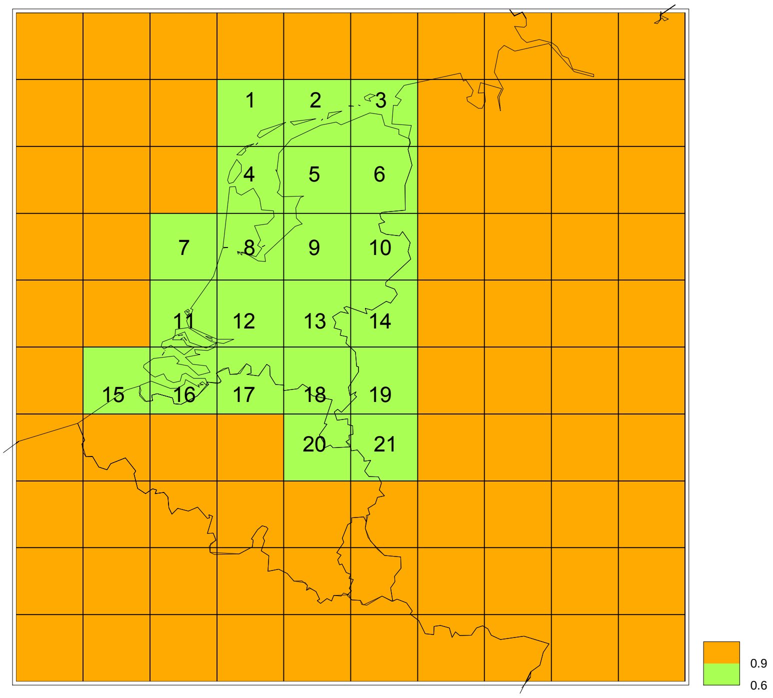


Figure 12. Map of the Netherlands and its bourdering areas as represented in EUROS showing the 21 grid cells (green colour, values are arbitrary) that were used in section 3 to establish average values of 95-percentile values for the Netherlans. The grid cell numbers are the same as in Appendix F.

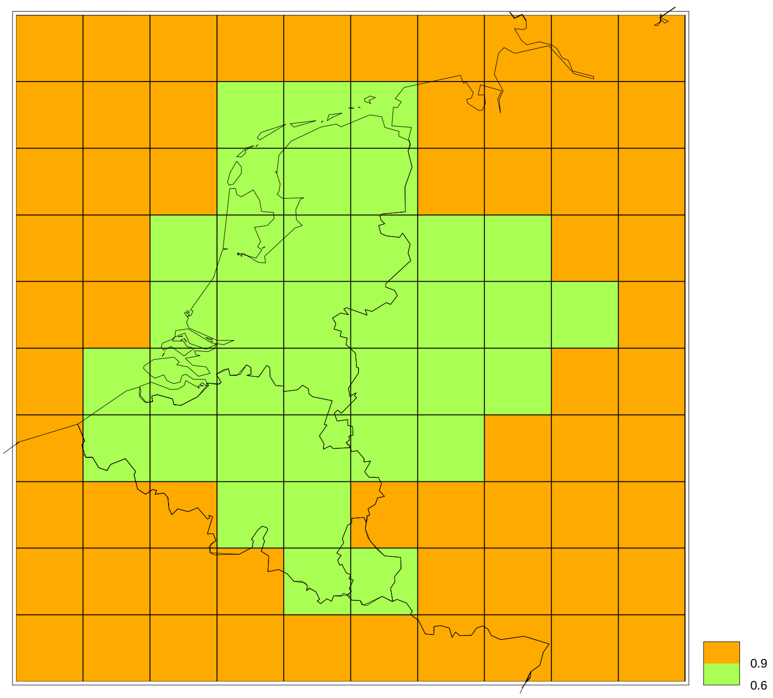


Figure 13. Map of the Netherlands and its bordering areas as represented in EUROS showing the grid cells with reduced emissions for NO_x and VOC emissions (green colour, values are arbitrary) in the international short-term scenario Sint.

Appendix F Grid-cell statistics for the Netherlands

Tabe 9. Dutch surface areas within the 21 grid cells covering the Netherlands and the time evolution of the number of citizens within all grid cells. The number of the grid cells are conform those in Appendix E.

grid cell number	Dutch surface area with grid cell [km^2]	number of citizens 1995	2003	2010
1	100	5792	5678	5564
2	1003	124148	129866	135584
3	1159	276448	277980,5	279513
4	959	198887	203376,5	207866
5	3514	619305	654544	689783
6	3195	628302	658419	688536
7	15	30452	30256,5	30061
8	2684	2620887	2777771	2934655
9	3358	988280	1075507,5	1162735
10	2644	766752	795952,5	825153
11	1300	1342079	1384672,5	1427266
12	3649	2886414	2994273,5	3102133
13	3437	1706480	1796274	1886068
14	976	232522	242591,5	252661
15	138	15081	15207,5	15334
16	1800	435471	444070	452669
17	1440	708850	745474	782098
18	2773	1077266	1124927,5	1172589
19	215	110116	115077	120038
20	619	577377	585799	594221
21	27	51742	51489,5	51237
Total	35007	15402651	16109208	16815764

Appendix G Model results weighted with the area of Dutch territory within a grid cell

Table 10. Results for all three smog episodes of averaged 95 percentile values of hourly ozone concentrations for all 21 grid cells in overlapping parts of the Netherlands for the years 1995 and 2010. Before calculating the average, the value for each grid cell was weighted with the area of Dutch territory within a grid cell.

O_3 [µg/m³]	S0 1995	S1 1995	S2 1995	S4 1995	S00 1995	Sint 1995	S0 2010
Episode 1	165	167 (+1%)	167 (+1%)	169 (+2%)	160 (-3%)	166 (+1%)	144 (-13%)
Episode 2	174	175 (+1%)	175 (+1%)	176 (+1%)	169 (-3%)	175 (+1%)	148 (-15%)
Episode 3	168	169 (+1%)	170 (+1%)	172 (+2%)	165 (-2%)	167 (+1%)	143 (-15%)

Differences between the emission reduction scenarios and the base year 1995 referred to as S0 are given in parentheses.

Table 11. Results for all three smog episodes of averaged 95 percentile values of hourly ozone concentrations for all 21 grid cells in overlapping parts of the Netherlands for the years 2003 and 2010. Before calculating the average, the value for each cell was weighted with the area of Dutch territory within a grid cell.

O_3 [µg/m³]	S0 2003	S1 2003	S2 2003	S4 2003	S00 2003	Sint 2003	S0 2010
Episode 1	158	159 (+1%)	158 (+0%)	159 (+1%)	148 (-6%)	157 (-1%)	144 (-9%)
Episode 2	164	164 (+0%)	164 (+0%)	165 (+1%)	156 (-5%)	164 (+0%)	148 (-10%)
Episode 3	159	160 (+1%)	159 (+0%)	160 (+1%)	153 (-4%)	157 (-1%)	143 (-10%)

Differences between the emission reduction scenarios and the case year 2003 referred to as S0 are given in parentheses.

Appendix H The local grid refined field within the EUROS grid

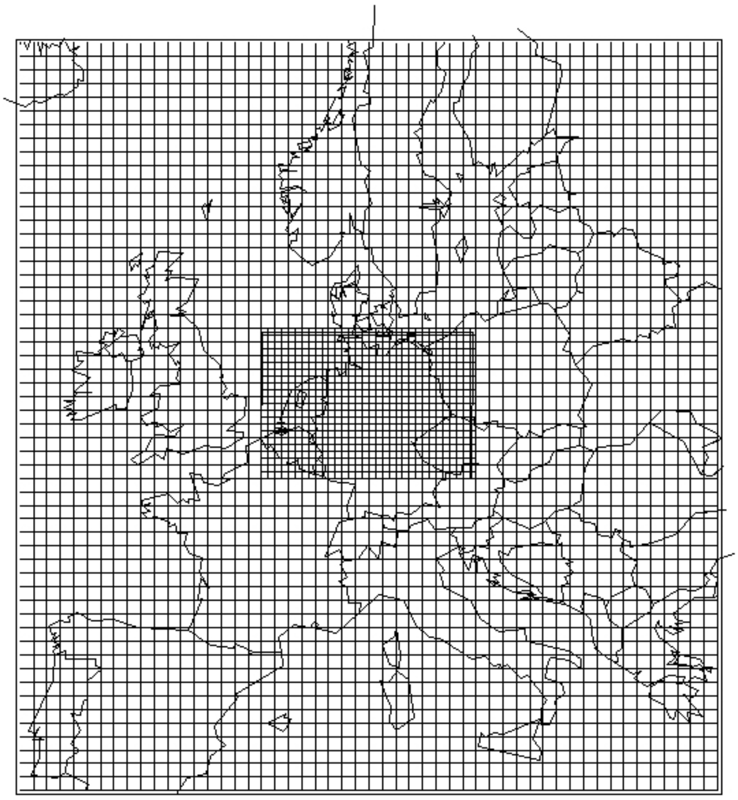


Figure 14. The local grid refined field (the refined part in the middle of the Figure) as it was applied within the basic EUROS grid to study inner-grid cell variability on the scale of the largest Dutch cities in section 3.3.

Appendix I Mailing list

1 Directeur-generaal Milieubeheer, Ir. J. van der Vlist (VROM/DGM)
2 Plv. Directeur-generaal Milieubeheer, Dr.ir. B.C.J. Zoeteman (VROM/DGM)
3 Ir A.P.M. Blom (VROM/DGM/KvI)
4 Ir. J.A. Herremans (VROM/DGM/KvI)
5 Drs. C.J. Sliggers (VROM/DGM/KvI)
6 Drs. P.L. Hofmeijer (VROM/DGM/KvI)
7 Drs. K. Sanders (VROM/DGM/KvI)
8 E. Dame (VROM/DGM/KvI)
9 Dr. K.R. Krijgsheld (VROM/DGM/KvI)
10 Drs. R. Braakenburg (V&W/S&C)
11 Prof. Dr. ir. P.J.H. Builtjes (TNO-MEP)
12 Dr. M.G.M. Roemer (TNO-MEP)
13 Dr. M. van Loon (TNO-MEP)
14 C. van der Kooij (DCMR Milieudienst Rijnmond)
15 B. Leurs (CE, Delft)
16 Dr. G. Dumont (IRCEL/CELINE, Brussel, België)
17 F. Fierens (IRCEL/CELINE, Brussel, België)
18 Dr. C. Mensink (VITO, Mol, België)
19 Prof. Dr. P. Bruckmann (Landesumweltamt NRW, Essen, Germany)
20 Dr. W.D. Garber (Umweltbundesambt, Berlin, Germany)
21 Dr. A. Graff (UBA, Berlin, Germany)
22 Dr. M. Williams (Ministry of Environment, London, UK)
23 Depot Nederlandse Publikaties en Nederlandse Bibliografie
24 Directie RIVM
25 Prof. Ir. N.D. van Egmond
26 Ir. F. Langeweg (SV)
27 Dr. J. Hoekstra (LAE)
28 Drs. R.J.M. Maas (MNV)
29 Dr. A. Opperhuizen (LEO)
30 Dr. Ir. E. Lebret (LBM)
31 Dr. Ir. D. van Lith (LLO)
32 Drs. F. Bogman (LLO)
33 Ir. H.S.M.A. Diederen (LLO)
34 Drs. H.C. Eerens (LLO)
35 Ir. P. Hammingh (LLO)
36 Dr. F.A.A.M. de Leeuw (LLO)
37 Dr. J. Matthijsen (LLO)
38 Dr. ir. W.A.J. van Pul (LLO)
39 Ir. F.J. Sauter (LLO)

40 Ir. R.J.M. Folkert (LLO)
41 Drs. K. van Velze (LLO)
42 Ing. W. de Vries (LLO)
43 Ing. E.S. de Waal (LLO)
44 Ir. R.A.W. Albers (LLO)
45 Dr. ir. J.R.M. Alkemade (LBG)
46 Ir. P.H. Fischer (LBM)
47 Dr. ir. E. Buringh (LEO)
48 Dr. L. van Bree (LEO)
49 Drs. J.A. Annema (LAE)
50 Ir. R.M.M. van den Brink (LAE)
51 Dr. M.W. van Schijndel (LAE)
52 Ir. L.G. Wesselink (LAE)
53 Ing. M. Marra (LBM)
55-60 SBD/Voorlichting & Public Relations
61 Bureau Rapportenregistratie
62 Bibliotheek RIVM
63 Bibliotheek LLO
64-73 Bureau Rapportenbeheer
74-95 Reserve exemplaren