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Emissions inventories and options for control[1]
SUMMARY REPORT

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This paper summarizes the results of the NRP-project number 850019, which was named "Social Causes of the Greenhouse Effect" at its inception in 1989, but gradually shifted its emphasis towards the development and application of methodologies for emissions inventories and options for control. The authors all work at the National Institute of Public Health and Environmental Protection (RIVM).

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Summary

This report is the final summary report of the project "Social causes of the greenhouse effect; emissions inventories and options for control", funded by the National Research Programme on Global Air Pollution and Climate Change (NRP) and the Environment Directorate of the Ministry of Housing, Physical Planning and Environment. In 1990, little was known about national emissions of greenhouse gases other than carbon dioxide. Therefore, the project was started in that year to develop a national inventory of the emissions of all greenhouse gases and their causes. The objectives of the project were twofold: supporting the development of a comprehensive Dutch climate policy and the identification of gaps in knowledge about sources of greenhouse gases to support priority setting of the NRP. The report summarizes the four phases of the project. In the first phase, a first national inventory of greenhouse gas emissions was made, capturing carbon dioxide (CO_2), chlorofluorocarbons (CFCs), methane (CH_4), nitrous oxide (N_2O) and the ozone precursors carbon monoxide (CO), nitrogen oxides (NO_x) and volatile organic compounds (VOC). In the second phase, the acquired expertise was used to support the development of Guidelines for National Emissions Inventories by the joint OECD/IPCC programme through workshop organization and participation in the international planning group. In the third phase, a detailed analysis was performed of the sources of methane, its current and future emissions and the options for control. Finally, a similar analysis was performed for nitrous oxide. In these studies, it was found that policies not specifically aiming at mitigating climate change, would help to control the emissions of the non-CO_2 greenhouse gases. While for methane, national emissions would even decrease because of measures in the livestock management and waste disposal sectors, for nitrous oxide the reductions in agricultural emissions would be outweighed by increases especially in the transportation sector. The project shows that the application of more detailed information leads to differences with the Guidelines, both because of the limited number of source categories in the Guidelines and because of different, locally specific emissions factors.

Note: The emission figures in this summary report have been updated recently outside the framework of NOP in van Amstel et al (1994).

Samenvatting

Dit is het eindrapport van het project "Maatschappelijke oorzaken broeikaseffect: emissie-inventarisaties en opties voor uitworpbeperking", gefinancierd door het Nationaal Onderzoek Programma Mondiale Luchtverontreiniging en Klimaatverandering en het Directoraat Milieuhygiëne van het Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer. In 1990 was er weinig bekend over de nationale uitworp van de niet-CO_2 broeikasgassen en de oorzaken ervan. De doelstellingen van het project waren tweeledig: het ondersteunen van de ontwikkeling van een Nederlands klimaatbeleid dat met alle broeikasgassen rekening zou houden en de identificering van lacunes in de kennis omtrent de bronnen van broeikasgassen teneinde de prioriteitstelling binnen het NOP te ondersteunen. Het eindrapport vat de vier fasen van het project samen. In de eerste fase werd een eerste voorlopige inventarisatie van de uitworp van broeikasgassen gemaakt, te weten koolstofdioxide (CO_2), methaan (CH_4), distikstofoxide of lachgas (N_2O) en de ozon precursors koolstofmonoxide (CO), stikstofoxiden (NO_x) en vluchtige organische stoffen (VOS). In de tweede fase werd de opgedane kennis gebruikt om de ontwikkeling van Richtlijnen voor Nationale Uitworpinventarisaties door het gezamenlijk OESO/IPCC programma te ondersteunen, onder meer via de organisatie van een internationale workshop en de deelname aan de planningsgroep van het programma. In de derde fase werd een gedetailleerde analyse uitgevoerd van de nationale bronnen van methaan, de huidige en toekomstige uitworp, en de mogelijkheden tot beheersing van de uitworp. Tenslotte werd een vergelijkbare analyse uitgevoerd voor distikstofoxide. In deze studies werd gevonden, dat maatregelen die niet speciaal gericht zijn op het beperken van klimaatverandering, zouden helpen de uitworp van de niet-CO_2 broeikasgassen te beheersen. Terwijl voor methaan, de nationale uitworp even zouden afnemen door maatregelen in de veeteelt en afvalverwijdering, zouden voor distikstofoxide de reductie in de uitworp vanuit de landbouw meer dan gecompenseerd worden door een toename in speciaal de transportsector. Het project laat ook zien, dat de toepassing van meer gedetailleerde informatie leidt tot verschillen met de Richtlijnen, enerzijds omdat niet alle broncategorieën in de Richtlijnen zijn opgenomen en anderzijds vanwege andere locatie-specifieke emissiefactoren.
N.B. De emissiegegevens in de NOP "summary report" zijn inmiddels buiten NOP-kader geactualiseerd in Van Amstel et al (1994).

1. Introduction and background

In 1990, the first phase of the Dutch National Research Programme on Global Air Pollution and Climate Change started with a number of so-called "early start" projects. The project "Social Causes of the Greenhouse Effect" was one of these. At that time, little was known about the emissions of greenhouse gases in the Netherlands, notably those of the non-CO_2 greenhouse gases. Uncertainties included the causes, the emissions factors and the regional distribution of emissions. The main objectives of the project at that time were formulated as follows:

a) provide information for prioritizing greenhouse gas emissions research in the Netherlands
b) provide input data for global models
c) support national and international policy development

The emphasis of the project was on non-CO_2 greenhouse gases, notably methane (CH_4) and nitrous oxide (N_2O). While state-of-the-art information from international research would be used and analyzed, the focus of the project was on the Dutch emissions and their causes. Information was drawn from literature research, discussions with national and international experts, and experimental information from NRP and other projects. At the start of the project, the following products were envisaged:

a) (contribution to) preliminary inventories of emissions of methane and nitrous oxide to support NRP priority setting;
b) a report on the Dutch emissions of greenhouse gases, a.o. in support of the preparation of a "Climate Change Memorandum" of the Dutch government;
c) a contribution to the development of a global emissions data base in collaboration with the Organization of Applied Scientific Research (TNO);
d) detailed background reports on the knowledge about the non-CO_2 greenhouse gases methane and nitrous oxide[2].

The contribution under a) was made by participation of project staff to small NRP expert groups that helped setting the research agenda for theme B (emissions) of the NRP and subsequently through chanelling information via the NRP Programming Group to other projects. The contribution under c) was later shifted to a large extent to another NRP project, focusing on the development of the global emissions database EDGAR (Olivier et al., 1994). The methodologies and emissions factors from the current project however, were and are applied in the EDGAR project. Originally not planned, in the project much effort was given to support the development of Guidelines for National Emissions Inventories by the joint IPCC/OECD programme within the context of the activities of the Science Working Group of the Intergovernmental Panel on Climate Change (IPCC). Consequently, the emphasis of the current summary report is on b) and c), with a small section on the work for the IPCC/OECD

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[2] Proposals to extend the project to prepare similar background documents for other non-CO_2 greenhouse gases were not funded by NRP, but currently a study on HFCs is underway, supported by the Dutch Environment Ministry.

programme. We refer to the products of the project listed in the reference list for more detailed lists of relevant literature.

2. National inventory

In 1990, a first inventory of current and future emissions of greenhouse gases in the Netherlands was performed (figure 1). In this inventory, data from the international literature and expert opinions were used to arrive at estimates of national emissions (van den Born et al., 1991). Because of the relatively small area of the Netherlands, emissions from industry, energy consumption and transport generally dominate over land-related natural and agricultural emissions (Table 1). Table 2 shows the projected greenhouse gas emissions for existing and potential additional policies.

Table 1: Greenhouse gas emissions in the Netherlands in 1989/1990 (in weight and CO_2 equivalent for a time horizon of 100 and 20 years) as assessed in 1990 (van den Born et al., 1991)

	Emission average (kton)	CO_2 equivalent time horizon 100 yr (kton CO_2 equiv.)	CO_2 equivalent time horizon 20 yr (kton CO_2 equiv.)
CO_2	182,000	182,000	182,000
CFCs *	21	48,700	51,200
CH_4	960	19,000	59,100
N_2O	40	11,600	10,800
NO_X	560	22,400	84,000
CO	1,100	2,200	6,700
VOC	490	4,900	14,700

* including halons, CCl_4, methylchloroform, HFCs and HCFCs.

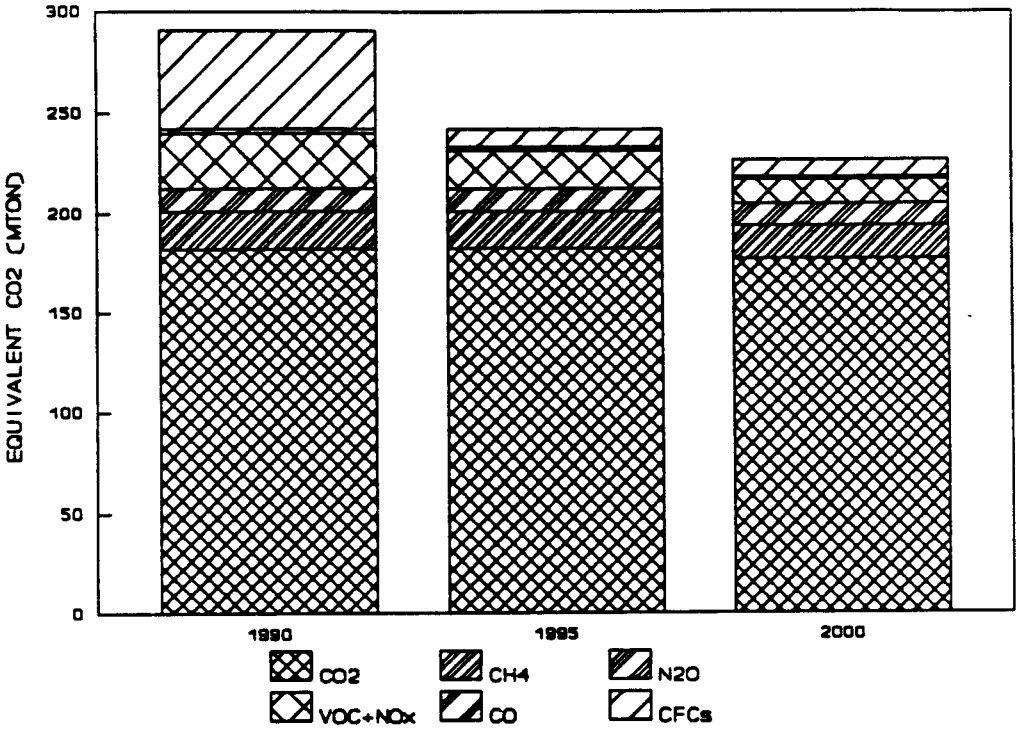
Table 2: Projected future greenhouse gas emissions in the Netherlands in 1990 - 2000 under existing policies and additional policies (in kton CO_2 eq./year and a time horizon of 100 years).

Trace gases		Existing policies		Additional response policies		
	1990	1995	2000	1990	1995	2000
CO_2	182,000	182,000	177,000	182,000	170,000	150,000
CFCs *	48,800	8,800	8,300	48,800	8,800	7,200
CH_4	19,000	18,700	16,800	19,000	16,800	12,000
N_2O	11,600	11,500	11,300	11,600	10,500	9,300
NO_X	22,400	15,700	9,800	22,400	14,900	8,900
CO	2,200	1,600	1,000	2,200	1,400	800
VOC	4,900	3,600	2,400	4,900	3,600	2,300

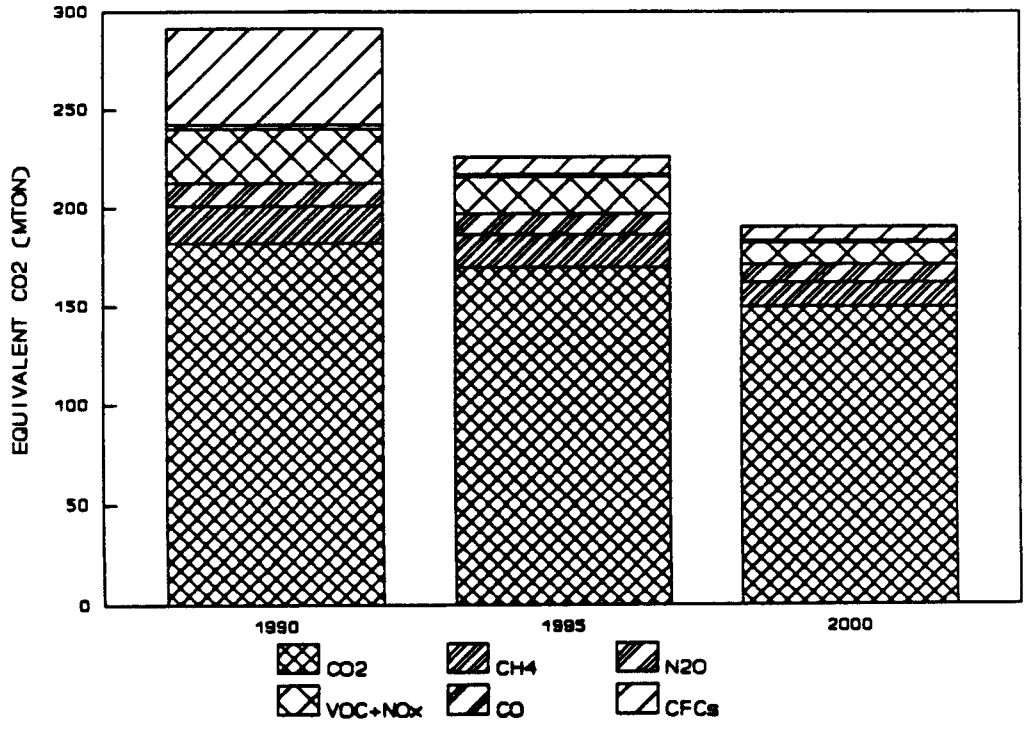
* including halons, CCl_4, Methylchloroform, HFCs and HCFCs.

Figure 1: Projected future greenhouse gas emisisons for a time horizon of 100 years under existing (A) and additional (B) policies, as assessed in 1990: direct effect, CFCs and precursors of ozone

(A)



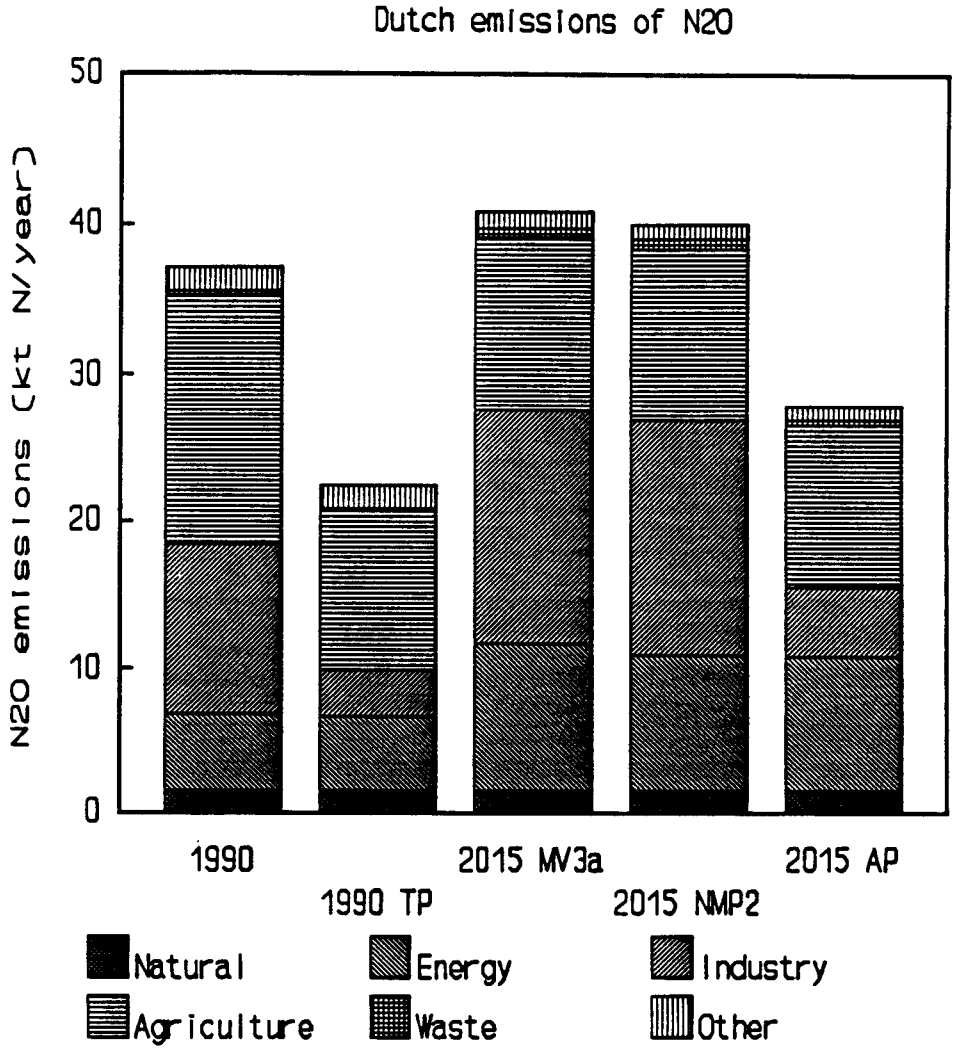
(B)



Carbon dioxide

As a result of policies at that time (1990), emissions of carbon dioxide were estimated to be reduced slightly, consistent with the 3-5 % government target. This government target is consistent with the IPCC Accelerated Policies scenario, *provided that further reductions are achieved thereafter.* This scenario is believed to be consistent with a preliminary "climate target" set at 0.1 degree per decade for global mean temperature change. Since the scenario leads to stabilization of carbon dioxide concentrations at levels well below doubling, it was used as a preliminary basis for the current ultimate objective of the climate convention. Options for further reduction of carbon dioxide emissions would be found primarily in energy conservation, reduction of demand and efficiency improvements, followed by a shift to non-fossil fuels. Because of the small size of the Netherlands, sequestration by afforestation programmes can only play a minor, albeit psychologically important role. Research to determine the carbon budget for the Netherlands more precisely was suggested to provide useful information for further action. This was pursued separately in the NRP (Nabuurs and Mohren, 1993). Additional, technologically feasible measures in the energy sector were suggested to achieve at least another 20 % reduction, but the cost-effectiveness of these measures was concluded to be subject to controversy, as it indeed still is.

Figure 2: Methane emissions 1988-2000 accoording to van den Born et al. (1991) and 1990-2015 according to van Amstel et al. (1993): A = current policies and B = additional policies



Methane

As most important sources of methane in the Netherlands, cattle, landfills, gas distribution and the production of oil and natural gas were identified. Because of policies in the areas of waste disposal, livestock management and distribution of natural gas, emissions of methane were estimated to decrease by approximately 10 % by 2000 as compared to 1990. Again, this development is consistent with the assumptions of the IPCC Accelerated Policies scenario, provided that the emissions controls would be continued after 2000 and other countries would achieve similar reductions. Stabilization of the global methane concentration could eventually require reductions of global methane emissions of 0 to 30 %, dependent on the emissions of other gases, notably carbon monoxide. This finding has recently be confirmed by the 1994 IPCC special report on radiative forcing. Additional measures for the reduction of methane emissions are integrated measures in the waste sector (recovery of gas from landfills, prohibition of dumping of waste containing organic material), diminishing of methane emissions per animal and reduction of cattle population, further promotion of biogas from animal waste and storage measures of animal waste, earlier renewal of the oldest cast iron distribution networks, prohibition of the venting of associated, uneconomic volumes of gas (gas production, drinking water production and waste water treatment plants) and on increase in level of maintenance of especially residential gas devices. These measures would lead to a reduction of about 30 % of 1990 levels by 2000. These findings were used by the Dutch government to adopt a methane emissions control target of 10 % of 1990 emissions by 2000 and to develop a plan to guarantee that this target would be met, especially in the waste sector. The 1991 report recommended additional research to corroborate the findings with respect to notably emissions from livestock, animal waste systems, organic soils, and industrial emissions from exploration and exploitation of natural gas and oil. These recommendations were taken into account in the further development of the NRP research programme.

Nitrous oxide

As major Dutch sources of nitrous oxide the following were identified: grassland (both on organic and mineral soils), agricultural lands, transportation, and - surprisingly - coastal and inland waters and waste water treatment plants. The source strengths were found to be extremely uncertain and therefore more research would be necessary to better quantify the emissions level and to evaluate response options. Through the year 2000, emissions reductions of nitrous oxide because of planned reduction of fertilizer application were estimated to be balanced by emissions increases because of the introduction of three-way catalysts in transport. Here one Dutch environment policy, reduction of ammonia and nitrogen oxide for acidification abatement, is counteracted by another environment policy, introducing threeway catalysts to abate transport emissions of carbon monoxide, nitrogen oxide and volatile organic compounds for reasons of photochemical smog and acidification. Additional measures to reduce the emissions of nitrous oxide by maybe up to 20 % of 1990 levels would be primarily in the area of decreasing the nitrogen loads on soils and waters. The assessment of the 1991 report could be improved by additional field experiments addressing the particular Dutch situation, specifically nitrous oxide fluxes in grassland and other agricultural systems, coastal and inland water systems, waste water treatment plants and automobiles with catalytic

converters. Many of these recommendations were taken up by the NRP (Slanina et al. (in prep.). The Dutch government introduced an emissions control target of stabilization of nitrous oxide emissions by 2000 at 1990 levels.

Halocarbons

The Netherlands' programme to phase out CFCs and reduce the associated emissions was found to effectively reduce their contribution to the enhanced greenhouse effect. On the long term it was concluded to be important that HCFCs and HFCs with a remaining (though smaller) global warming potential should be regarded as useful products only in a (short) transition period. Continuation of a further search for low or zero-GWP substitutes in an international context was found to be important. Since, the HCFCs have been regulated nationally, and internationally within the framework of the London and Copenhagen amendments of the Montreal Protocol. HFCs, which compounds have a zero-ODP but a significant GWP, cannot be controlled under the current Vienna Convention and Montreal Protocol. Unrestricted global production and use of these compounds may outweigh the effects of the CFC and HCFC controls in terms of global warming potential already in the first half of the next century. Therefore, it has been proposed to explore the possibilities for a HFC-protocol under the Framework Convention on Climate Change. A background document on HFCs is currently prepared at RIVM. At the time of publication of the first Dutch inventory, the indirect cooling effect of ozone depleting halocarbons had not yet been identified.

Ozone precursors

Carbon monoxide contributes to the enhanced greenhouse effect as precursor of ozone and carbon dioxide, and competes with methane for hydroxyl radicals (OH) in the troposhere, tehrewith enhancing methane's lifetime. Main sources are the transportation sector and industry, notably the basic metals producers. Present policies in the transportation sectorare likely to reduce emissions by 40 % in 2000. Research in this area may focus on the options for further reduction of industrial carbon monoxide emissions. Emissions of nitrogen oxides and non-methane hydrocarbons (or volatile organics compounds, VOCs) in the Netherlands contribute significantly to climate change because of their role as precursors of ozone and thebfact that the national emissions are relatively high due to intensive traffic and industrialization. It was found that the present policies to abate acidification and photochemical air pollution are also important from the point of view of climate change. The enhanced greenhouse effect thus provides another reason to pursue or even intensify these policies. Decreasing nitrogen deposition also limits nitrous oxide emissions from soils and surface waters. Decreasing emissions of non-methane hydrocarbons not only reduce ozone production, but are also assumed (depending on NO_x-concentrations) to increase the atmospheric sink of methane. Additional research aiming at better quantification of the present and future role of these gases for the problem of global climate change was recommended. It is currently being pursued further at RIVM, amongst others by further developing and applying the MOGUNTIA 3D model of atmospheric chemistry **ref**.

3. Support of the joint IPCC/OECD Programme on Guidelines for National Emissions Inventories

The expertise acquired with the first national inventory was used to support the joint IPCC/OECD Programme on Guidelines for National Emissions Inventories. Amongst others, an international workshop was organized in support of the IPCC process (van Amstel, 1993a and 1994). More than 100 particants from about 30 countries discussed methods for emissions inventories and options for control for 10 source categories: methane from oil and gas, methane from coal mining, methane from ruminants, methane from animal waste, methane from landfills and sewage treatment, methane from combustion and industry, methane from rice production and wetlands, methane from biomass burning, nitrous oxide from agricultural soils and nitrous oxide from combustion and industry (Van Amstel and Swart, 1994).

Methods for the estimation of CO_2 emissions are relatively straightforward and results are robust, and uncertainties are rather political that scientific (e.g. how marine and aviation bunkers and carbon embodied in traded products should be accounted for). This is not the case for methane and nitrous oxide. Methods are still in an early stage of development, notably for nitrous oxide. Part of the reason for the large uncertainties is due to the difficulty of translating local measurements of a limited periodicity and duration into emissions estimates for larger areas (countries) or larger time frames (years). The complexity of processes in biogenic production in soils or in fysio-chemical formation in combustion devices determines this difficulty: extrapolation of local emissions results is hampered by the dependance on local climate, soil, and management conditions.

Another basic difficulty in making national inventories is the absence of data, notably in non-industrialized countries. Therefore, in the Amersfoort workshop much attention was paid to the development of different levels of reporting, dependent on the availability of data. It was concluded that emission factors derived from studies in industrialized countries, can often not be translated to other environmental conditions, countries or continents.

Also, RIVM participated actively in the International Liaison Group supporting the Programme. Jointly with the Institute for Environmental Studies of the Amsterdam Free University, RIVM staff helped the implementation of regional workshops, and performed an in-depth study for OECD to compare submissions of national inventories (van Amstel, 1993b). The Programme has led to the adoption of the Guidelines in 1994 in support of the commitment of national inventories for signatory countries, laid down in the United Nations Framework Convention on Climate Change.

The focus of the Netherlands policy and research, notably this project, on the non-CO_2 greenhouse gases, has also led to the organization of an international Symposium "Non-CO_2 Greenhouse Gases: Why and How to Control?". The ideas developed in this project have to a large extent influenced the structure and contents of the Symposium and its Conference Statement, which was drafted and edited by a small committee including staff of the project (appendix 1).

4. Methane emissions reductions: a side-effect of waste disposal and agricultural policies

Background and objectives

A background study on methane updated the 1991 estimate of national emissions, applying new information on methane sources (van Amstel et al., 1993). This new information included:

- o the development of the draft Guidelines for National Inventories of Greenhouse Gases by the IPCC, coordinated by the OECD Environment Directorate;
- o preliminary results of experimental research projects of the NRP, notably on methane from landfills;
- o new scenarios, developed for the global and national economy and energy systems by the Central Planning Bureau and the Energy Study Centre of the Netherlands Energy Research Foundation;
- o new scientific information about the current and future emissions of methane and its radiative effect, a.o. published by the IPCC in its 1992 Supplement;
- o new insights into the effectiveness of related national policies.

The specific objectives of the methane study were:

- o to test the IPCC methodology on 1990 data, to further refine the emissions estimates,
- o to assess the effects of curent policies in more detail, and
- o to assess the needs of additional policies in reaching the government 10 % reduction target.

Methane sources

The most important of the methane sources in the Netherlands were confirmed to be landfills, cattle, manure and the exploration, transport and distribution of oil and gas (table 3). Wetlands are a natural source of methane, diminished since the beginning of the century by land reclamation and the lowering of the groundwater table for agriculture, as well as by the accompanying dessication of natural wetlands. Incomplete combustion of wood and fossil fuels is a relatively small source. While the previous report estimated emissions "around 1990", the new report produced estimates of a historical time series over the years 1989-1992 and further extended the future scenarios beyond 2000 up to 2015, using scenarios from the third National Environmental Outlook (figure 2).

Evaluating the IPCC/OECD Guidelines

In van Amstel et al. (1993), the emissions of methane were determined both by applying the draft version of the IPCC/OECD Guidelines for National Emissions Inventories and by using more detailed information on the situation in the Netherlands. Even for a developed country as the Netherlands the application of the draft Guidelines for estimating the emissions from the production of oil and gas appeared to be difficult, primarily because of the absence of sufficient information about the number of wells in operation and the composition of the oil/gas mixture. A national method, which makes use of emissions factors expressed as volume percentages, is recommended. However, in the future a distinction between onshore

and offshore emissions factors would be necessary. Also, a better distinction between old and new gas distribution networks would improve the estimates from the energy sector. For the emissions from cattle, the Guidelines resulted to be very complicated, while a more simple calculation method provided basically the same results. This was not true for animal waste, where the IPCC methodology suggested seven times higher emissions than orginally estimated. While this was probably due to overestimates of emission factors by IPCC for the European situation, the earlier Dutch inventory may have underestimated this source. Thus, local experiments should decide on appropriate factors. Because of the first results of experimental NRP research in the area of landfill emissions, this source was significantly increased, due to higher estimates of rates of decomposition of organic material in Dutch landfills.

Will the government emissions control target be achieved?

The government emissions control target, set at a 10 % reduction of the 1990 emissions by 2000, was estimated to be reached only if the planned measures to reduce landfilled waste, acid deposition and the manure surplus would be fully effective. While the relative reduction would remain as estimated by 1991, the absolute emissions levels were upgraded considerably. Notably, potential emissions from manure were found to be considerably higher than estimated in the 1991 report. Additional policies for up to 30 % methane emissions reductions were found to be feasible in the recovery of landfill gas and in the utilization of vented gas on North Sea platforms. The latter would include the obligatory flaring of waste gas, increased use of associated gas, and early replacement of old distribution pipes. Collaboration with industry should be initiated to confirm the assessment and evaluate the technical and economic feasibility of the options. By means of a programme to collect and handle garden, fruit and kitchen waste (GFK) separately, and to enhace recovery from landfills and from separately collected GFK waste, additional reductions can be achieved, with the additional benefits of saving fossil fuels and limiting related carbon dioxide emissions.

Further measures to reduce cattle numbers (e.g. smaller milk quota) for reasons other than climate change were found to have a large secondary effect on methane emissions.Decreases in the dairy cattle herd are expected to be partially compensated by increases in the beef cattle herd size. Current plans in the European Union (e.g. the McSharry plan) will have an effect on animal rations. Increase of roughage, which tends to increase the emissions per animal, are expected and breeding will increase the milk production per animal. As these animals need more food the methane emisison per animal will increase. The net effect of these trends howver is a decreasing methane emission.

Can global methane concentrations be stabilized?

A rough analysis of global emissions and options for control suggests that the implementation of promising options for methane control may make stabilization of concentrations in the atmosphere, as stipulated by the ultimate objective of the climate convention, feasible. These findings were further confirmed by model calculations with the IMAGE-model and by a model comparison exercise for the 1992 Supplement publication of the first IPCC Assessment. Global emissions reduction levels of 10-20 % were estimated to be sufficient to stabilize atmospheric concentrations of methane at 1990 levels, depending on similar control for other reactive gases, such as carbon monoxide, non-methane hydrocabrons and nitrogen compounds.

Positive temperature feedbacks on wetland methane emissions caused by climatic changes may interfere with this assessment. In addition to directly addressing the sources of methane, its atmospheric sink can be influenced by controlling the emissions of different pollutatsn, thus enhancing the oxidizing capacity of the atmosphere. The Dutch control policy is consistent with the objective, albeit that the small size of the country and its emissions can not make more than a marginal contribution to global methane control.

5. Nitrous oxide: losses at different places of the nitrogen cycle makes control difficult

Background and objectives

The study on nitrous oxide (Kroeze, 1994) had similar objectives of that on methane (see section above): 1) to evaluate the IPCC methodology using 1990 data, 2) to further refine the emissions estimates, 3) to assess the effects of current policies in more detail, and 4) to assess the needs of additional policies in reaching the government stabilization target. Also, the new information available for nitrous oxide was of the same type as quoted above for methane.

Updating the national inventory and evaluating the IPCC/OECD Guidelines

A comparison was made between the IPCC Guidelines and the application of a more detailed methodology, taking recent experimental data from the Netherlands into account. The detailed method, an update of the methodology of the 1991 report, led to considerably higher emissions estimates (13 - 70 Gg N/yr, central estimate 37 Gg N) than in the 1991 report (6 - 38 Gg N/yr, central estimate 17 Gg N/yr). The reasons were: 1) higher local emission factors were used for key sources and 2) in the IPCC Guidelines some sources appeared not to be taken into account (figure 3). These latter sources include emissions of N_2O from nitrogen leaching from soils, other N loading to surface waters, wastewater treatment, atmospheric deposition of NO_x and non-agricultural NH_3, manure in stables, atmospheric formation and use in anaesthesia. Both methods now took into account the industrial emissions from nitric acid production, a source not identified yet in the Netherlands in 1990 by van den Born et al.[3]. According to the analysis, 95 % of the Dutch nitrous oxide emissions are anthropogenic, due to the high intensity of agricultural activity (45 %), industry (31 %) and transport (10 %) per unit of area in the small country. Because of a more complete coverage of all sources and the application of locally specific emissions factors, the detailed national method is applied for further determination of Dutch nitrous oxide emissions.

Will the government emissions control target be achieved?

Currently, no specific nitrous oxide reduction policies have been developed to achieve the government goal of stabilizing emissions, primarily because stabilization was expected to be autonomous. Kroeze (1994) however shows that emissions reductions from soils, as caused by decreasing nitrogen deposition and fertilizer application, will probably be outweighed by expected emissions increases from especially the transport sector: emissions by 2000, 2010 and 2015 emissions are estimated to be 1 %, 6 % and 10 % higher than in 1990.

Future scenarios of transport do not only show increasing car numbers and mileages, but also include increasing numbers of aged three-way catalysts, which have high specific emissions factors. Therefore, the government target of emissions stabilization can only be achieved by additional control measures. The options considered have the potential to reduce total 1990 emissions of N_2O from the Netherlands by about 40% (as compared with 20 % in the earlier report by van den Born et al.), if nothing else would change (figure 4). The technical

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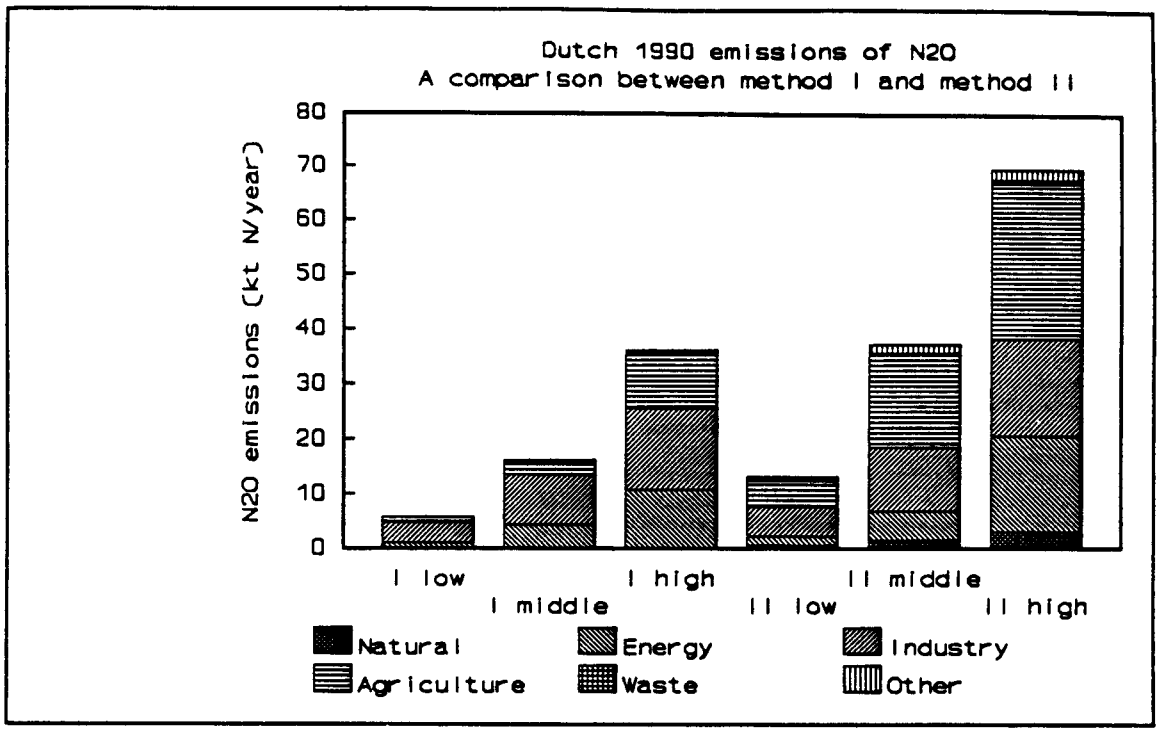
[3] Adipic acid, another industrial source of nitrous oxide is not produced in the Netherlands.

potentials of these options to reduce N_2O emissions have been estimated for emissions from stationary combustion (15%), industry (70%), agriculture (35%) and waste (50%). Most of the options formulated for agriculture are included in *National Environmental Policy Plan 2* (NMP-2).

Figure 3: Dutch 1990 emissions according to method I (IPCC methodology) and method II (update of the National Environmental Outlook 3)

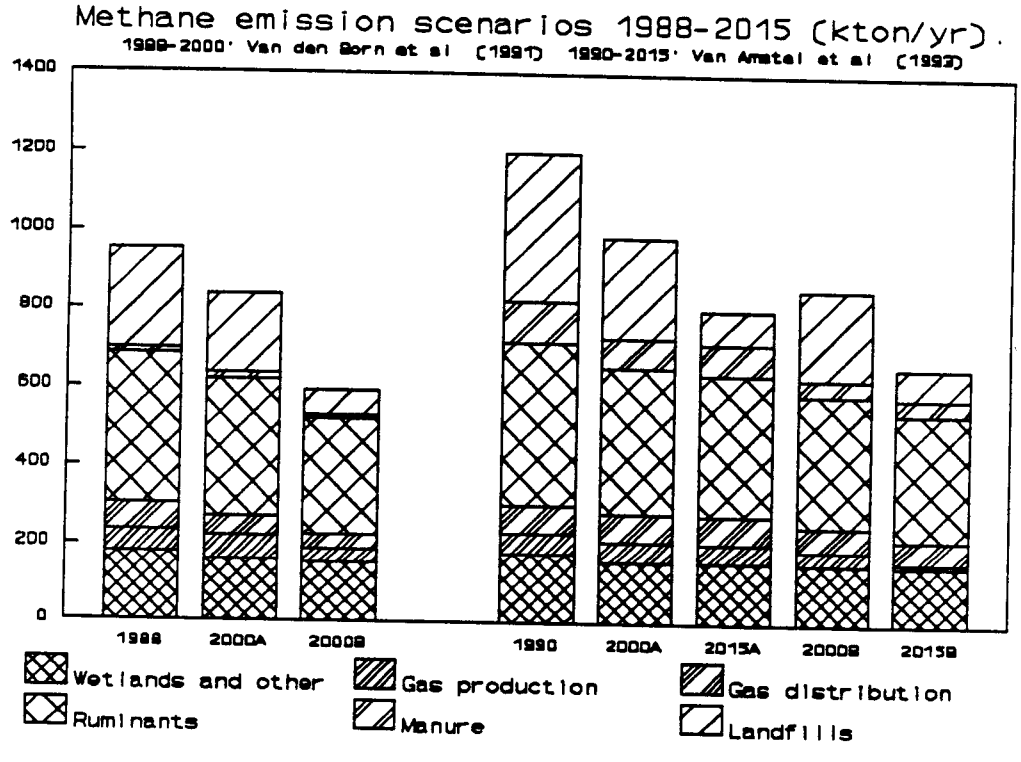


Before 2000, technological options to reduce Dutch emissions include:

(1) a catalytic reduction step in nitric acid production;
(2) improved fertilzer-N use efficiency by, e.g. the use of slow-release fertilizers;
(3) improved combustion of municipal solid waste and sewage treatment, and
(4) improved combustion in power plants.

However, the implementation of a such a catalytic converter may not be achieved by 2000. Conceivable technologies that will not be implementable before 2000 include a number of promising options, such as low NOx engines in vehicles, electric vehicles, NOx reduction with low N_2O formation in stationary combustion and development of modified combustors.

Figure 4: Total Dutch emissions of N_2O in 1990, the theoretical potential (TP) to reduce 1990 emissions (if nothing else would change) and the 2015 projections based on current policy (MV3a), National Environmental Policy Plan 2 (NMP-2) and additional policy (AP)



Implementation of *National Environmental Policy Plan 2* (NMP-2) is expected to prevent less than 1 Gg N_2O-N emissions from 2000 onwards. This is not sufficient for a stabilization at the 1990 level after 2000. The additional policy options could reduce next century's emissions by another 11 - 12 Gg N y^{-1}, so that 28 Gg N y^{-1} is emitted by 2015 (figure 4). The effect of additional policies is dominated by the catalytic N_2O reduction in nitric acid production which still has to be developed. Without this catalytic reduction step, a stabilization of Dutch N_2O emissions after the year 2000 would seem difficult. The Dutch emission in the additional policy projections is about 25% below the 1990 emission. To achieve a much further reduction, which could be needed to stabilize CO_2-equivalent concentrations at a level well below doubling of the pre-industrial concentrations, the development of yet unavailable or unknown technologies, or a reduction in the use of energy, mobility and the use of fertilizers is needed.

Can global nitrous oxide concentrations be stabilized?

Globally, the linkage between nitrous oxide emissions and food production as well as the long atmospheric lifetime make stabilization of atmospheric concentrations unlikely for some time to come. Global anthropogenic emissions of N_2O would have to be reduced by 80 % to achieve stabilization of concentrations at low enough levels to limit future warming to 0.1° degree per decade, providing also other greenhouse gas concentrations are stabilized in accordance with the ultimate objective of the Climate Convention and the Dutch Climaet Memorandum.

Which research priorities can be derived from the study?

To decrease the large uncertainties in the emissions estimates, particularly more research is recommended in the following five areas:

1) measurements of nitrous oxide production in nitric acid plants and other industrial facilities,
2) further investigation of N_2O production in vehicles,
3) monitoring of N_2O emissions from Ducth soils, including different types of agricultural soils and management types,
4) investigating N_2O fluxes from Dutch surface waters and ground waters, and
5) investigation of atmospheric formation of N_2O and
6) the effect of global warming on N_2O emissions.

The historical depth and breadth of Dutch research in the area of nitrogen chemistry in soils and air makes these recommendations particularly relevant for the further programming of Dutch global change research.

6. Conclusions and recommendations for further work

The project has facilitated the development of the national capabilities to comply with the requirement of the Framework Convention on Climate Change that countries should regularly report about their emissions of greenhouse gases and national policies. The methodologies developed and applied in the project, will be used for future national National Environmental Outlooks and national communications to comply with the requirements of the Convention[4]. The project has laid out the special circumstances that govern the emissions of greenhouse gas emissions in the Netherlands: because of the high intensity of population and economic activities - including intensive agriculture, industry, transport - the vast majority of emissions are of anthropogenic origin. The implementation of policies in areas other than climate policies - notably the prevention, disposal and treatment of solid waste and manure and the abatement of acidifying nitrogen emissions - has a counteracting effect on the tendency of growing non-CO_2 emissions that would result from the growth of economic activities. For methane this implies that emissions can even be reduced significantly with currently available technologies, without necessarily decreasing the volume of the activities. Evidently, volume measures will further decrease emissions. For nitrous oxide, emissions reductions will probably require further volume measures in addition to the development and demonstration of currently not available technological options. Taking into account the inevitable growth of emissions of the greenhouse gas emissions in the developing countries, such emissions reductions can be associated with the commitments of the Climate Convention, which has stabilization of GHG concentrations as its ultimate objective and clearly articulates the responsibility of the industrialized countries to take the lead in responding to and mitigating climate change. The options reviewed in this project demonstrate that particularly the non-CO_2 greenhouse gases - with the exception of N_2O - offer challenging and interesting possibilities to demonstrate the feasibility of stabilizing atmospheric concentrations of greenhouse gases.

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[4] The work, initiated in the project described above, is currently proceeding outside the context of the National Research Programme. A background study on HFCs is carried out, similar to the ones on methane and nitrous oxide described above. The objective of this study is to explore the potential future contribution of HFCs to the enhanced greenhouse effect and the national and international options for limitations, for example through a HFC-protocol within the framework of the Framework Convention on Climate Change. The work is also used for the national communication to the Climate Convetion (van Amstel et al., 1994).

7. Selected publications (full references contained in these reports):

Amstel. A.R., van, R.J. Swart, M.S. Krol, J.P. Beck, A.F. Bouwman and K.W. van der Woerd: "Methane: the Other Greenhouse Gas Research and policy in the Netherlands", report no. 481507001, RIVM, Bilthoven, 1993

Amstel, A.R. van (ed.): "Proceedings International IPCC Workshop on Methane and Nitrous Oxide: Methods in National Inventories and Options for Control", RIVM, Bilthoven, 1993a

Amstel, A.R. van: "Transparency of National Emissions Inventories", in: van Amstel, A.R. (ed.): "Proceedings International Workshop on Methane and Nitrous Oxide: Methods in National Inventories and Options for Control", RIVM, Bilthoven, 1993

Amstel, A.R. van and R.J. Swart: "Methane and Nitrous Oxide: an Introduction", in *Fertilizer research*, vol. 37, pp. 213-225, 1994

Amstel, A.R., R.A.W. Albers, C. Kroeze, A.C. Matthijsen, J.G.J. Olivier and J. Spakman: "Greenhouse Gas Emissions in the Netherlands 1990, 1991, 1992 and Projections for 1990-2010", report nr. 773001003, RIVM, Bilthoven, 1994

Amstel, A.R.: "Methane emissions and control in the Netherlands", in: J. van Ham, L. Janssen and R.J. Swart (eds.): "Non-CO_2 Greenhouse Gases: Why and How to Control?", pp. 515-525, Kluwer, 1994

Bouwman, A.F., G.J. van den Born and R.J. Swart: "Landuse-related Sources of CO_2, CH_4 and N_2O: Current Global Emissions and Projections for the Period 1990-2100", report no. 222901004, RIVM, Bilthoven, 1992

Born, G.J. van den, A.F. Bouwman, J.G.J. Olivier and R.J. Swart: "The Emissions of Greenhouse Gases in the Netherlands", report no. 222901003, RIVM, Bilthoven, 1991

Kroeze, C.: "Nitrous Oxide: Emissions Inventory and Options for Control in the Netherlands", report no. 773001004, RIVM, Bilthoven, 1994

Nabuurs, G.J. and G.M.J. Mohren: "Carbon fixation through forestation activities", Agricultural University, Wageningen, and Stichting FACE, Arnhem, the Netherlands, 1993

Olivier, J.G.J.: " Inventory of Aircraft Emissions: a Review of Literature", RIVM-report no. 736301008, Bilthoven, 1991

Olivier, J.G.J., A.F. Bouwman and C.W.M. van der Maas: "Emissions Database for Global Atmospheric Research (EDGAR)", in: J. van Ham, L.J.H.M. Janssen and R.J. Swart: "Non-CO_2 Greenhouse Gases: Why and How to Control?", Kluwer, 1994

Slanina, J., J. Berdowski and A.F. Bouwman: "Deelassessment rapport NOP I Thema B", NOP, Bilthoven, 1994 (in preparation)

Swart, R.J., A.F. Bouwman, J.G.J. Olivier and G.J. van den Born: "Inventory of Greenhouse Gas Emissions in the Netherlands", Ambio, vol. 22, no. 8, 1993