

**NATIONAL INSTITUTE OF PUBLIC HEALTH AND ENVIRONMENTAL PROTECTION
P.O. BOX 1, 3720 BA BILTHOVEN, THE NETHERLANDS**

Report nr. 773001003

**GREENHOUSE GAS EMISSIONS
IN THE NETHERLANDS
1990, 1991, 1992
AND PROJECTIONS FOR 1990-2010**

**A.R. Van Amstel (ed.), R.A.W. Albers, C. Kroeze,
A.J.C.M. Matthijsen, J.G.J. Olivier and J. Spakman
September 1994**

**A background report for the National Communication of the Netherlands
for the Climate Convention**

This study was commissioned by:

The Directorate General for Environment of the Ministry of Housing, Physical Planning and Environment, The Netherlands, under the project Energy nr: 773001, and carried out by the National Institute of Public Health and Environmental Protection, Bilthoven.

ERRATUM

De kleuren van de legenda bij figuur 3.25 (bladzijde 46) zijn onjuist. De kaart moet als volgt gelezen worden.

lichtgroen:	< 25 -
geel:	25 - 50
oranje:	50 - 100
rood:	> 100
donkergroen:	bos en natuurterreinen
zwart:	stedelijk gebied

MAILING LIST

- 1 Directeur Lucht en Energie van het Directoraat-Generaal voor Milieubeheer
- 2 Directeur-Generaal Milieubeheer.
- 3 Plv. Directeur-Generaal Milieubeheer, Dr. ir. B.C.J. Zoeteman
- 4 Plv. Directeur-Generaal Milieubeheer, Mr. G.J.R. Wolters
- 5 Themacoördinator Klimaatverandering, Dr. ir. B. Metz, DGM/LE
- 6 Dr. L. Meijer, DGM/LE
- 7 Drs. J.B. Weenink, DGM/LE
- 8 Drs. J. Oude-Loohuis, DGM/LE
- 9 Drs. H. Merkus, DGM/LE
- 10 Mr. R. Hemaus, EU, Brussel
- 11 Drs. R. Culenaere, DGM/LE
- 12 Dr. J. Lenstra, DGM/LE
- 13-20 Programmaraad NWO werkgemeenschap CO₂ problematiek
- 21-25 KNAW klimaatcommissie
- 25-27 Secretariaat NOP Mondiale Luchtverontreiniging en Klimaatverandering
- 28 Drs. D. de Jager, ECOFYS
- 29 Mevr. Ir. L.J.A. Lekkerkerk, IKC Veehouderij en Milieu
- 30 Ir. R. Van Venetië, Ministerie van LNV
- 31 Mevr. Drs. H. Verhagen, Ministerie van EZ
- 32 Ir. K. Braber, NOVEM Utrecht
- 33 Ir. H. Oonk, TNO-IMET Apeldoorn
- 34 Ir. J. van der Kolk, DGM/DWB
- 35 Dr. Th. A. Kouwenaar, Min. of Foreign Affairs, DGIS, Den Haag
- 36 Mevr. M. Mulder, DGM/LE
- 37 Mevr. Ir. K. van Herwaarden, DGM/DWL
- 38 Drs. C.A. Wielenga, DGM/Afvalstoffen
- 39 Dr. Bruce Callander, IPCC WG1, Met. Off. Bracknell
- 40 Dr. K. Blok, ECOFYS
- 41 Dr. Pak Sum Low, UNEP, GEF Unit, Nairobi
- 42 Mr. P. Schwengels, OECD, Paris
- 43 Ms. J. Ellis, IEA, Paris
- 44 Mrs. J. Corfee-Morlot, OECD, Paris
- 45 Dr. J. Swager, INC, Geneva
- 46 Mr. P. Usher, UNEP, Nairobi, Kenia
- 47 Dr. Buruhani S. Nyenzi, Dar-es-Salaam, Tanzania
- 48 Dr. J. Penman, Department of the Environment, UK
- 49 Dr. K.E. Joerss, Umweltbundesamt, Berlin, Germany
- 50 Drs. J. Feenstra, Free University, Institute for Environmental Studies, Amsterdam
- 51 Drs. E. Lammers, Free University, Institute for Environmental Studies, Amsterdam
- 52 Prof. dr. ir. P. Vellinga, Free University, Institute for Environmental Studies, Amsterdam
- 53 Dr. M. Price, Environmental Change Unit, Oxford, UK
- 54 Mr. C. Ebert, ICF Inc. Washington, USA
- 55 Mr. M. Gibbs, ICF Inc. Universal City, USA
- 56 Dr. G. McInnes, European Env. Agency, Task Force Emissions EC, Brussels
- 57 Dr. A. Rosland, State Pollution Control Authority, Norway
- 58 Dr. A. Jaques, Environment Canada
- 59 Dr. E. Aitchison, ETSU Harwell, UK
- 60 Dr. D. Ahuja, Global Environmental Facility, Washington, USA
- 61 Dr. A.D. Bhide, National Research Institute, Solid Waste Division, Nagpur, India

- 62 Dr. P. Coors, NV. Nederlandse Gasunie, Groningen
63 Ir. A.J. Elshout, KEMA, Arnhem
64 Dr. Richard Grant, Air Emissions Task Force, Shell, Netherlands
65 Dr. M. Howden, Bureau of Rural Resources, Australia
66 Dr. K. Hogan, USEPA, Washington
67 Ing. P. Ruardi, DGM/DWB
68 Prof. K. Minami, Japan
69 Mrs. M. Lexmond, Agricultural University, Wageningen
70 Dr.ir. G. Zeeman, Agricultural University, Wageningen
71 Dr. T. Hedlund, Sweden
72 Dr. Luiz Gylvan Meira Filho, National Space Research Institute, Brazil
73 Dra. Raisa M. Ruiz C., Panama
74 Ms. Elizabeth Culqui Diaz, Peru
75 Dr. P.A.J. Ratnasiri, Sri Lanka
76 Ms. Susan Subak, USA
77 Dr. A.P.M. Baede, KNMI, de Bilt
78 Dr. J.J.M. Berdowski, TNO, Delft
79 Prof.dr.ir. N. van Breemen, Agricultural University, Wageningen
80 Dr. G. Heil, Resource Analysis, Delft
81 Dr.Ir. Y. van der Honing, IVVO, Lelystad
82 Prof.dr. L. Hordijk, Agricultural University, Wageningen
83 Drs. Herman Snoep, Min. EZ, Den Haag
84 Dr. D. Lashof, NRDC, Washington, USA
85 Prof.dr. L. Reijnders, Univ. Amsterdam
86 E. Rodenburg, WRI, Washington, USA
87 Michael Short UNEP, Nairobi
88 P. de Wildt, KNMI, De Bilt
89 Ir. J.I. Walpot, TNO-IMET, Apeldoorn
90 Dr. C. Evers, Ministerie VROM, Emissieregistratie
91 Drs. Tom Kolkena, Min. EZ, Den Haag
92 Ir.J.R. Ybema, ESC-ECN, Petten
93 Drs. E. Zonneveld, CBS, Voorburg
94 Dr. A. Arquit-Niederburger, Switzerland
95 Dr. N. Kilde, Denmark
96 Ms. Jane Leggett, USA
97 Dr. W. DeBruyn, VITO, Belgium
98 Dr. J. Lelieveld, Agricultural University Wageningen
99 Dr. P. Leffelaar, Agricultural University Wageningen
100 Dr. A.P. Mitra, National Physics Laboratory, India
101 Dr. P. Reiniger, CEC, Brussels
102 Stichting Natuur en Milieu, Utrecht
- 103 Depot van Nederlandse Publicaties en Nederlandse Bibliografie
- 104 Directie RIVM
105 Dr. R. van Aalst
106 Dr. L.H.J.M. Janssen
107 Ir. D. Beker
108 Ir. J. Olivier
109 Ir. R.A.W. Albers
110 Ir. A.H.M. Bresser

- 111 Drs. J. Ros
112 Ir. N.D. van Egmond
113 Ir. F. Langeweg
114 Prof.dr. J. Rotmans
115 Dr. J. Alcamo
116 Drs. G.J.B. van den Born
117 Ir. G.J.J. Kreileman
118 Dr. R. Leemans
119 Drs. R.J.M. Maas
120 Dr. H.J.M. de Vries
121 Dr. R. Thomas
122 Ir. N.J.P. Hoogervorst
123 Dr.Ir. R.J. Swart
124 Ir. K.W. van der Hoek
125 Dr. M. Krol
126 Dr. C.Kroeze
127 Drs. A.C. Matthijsen
128 Ir. J. Spakman
129 Prof. dr. W. Turkenburg
130 Dolf Gielen ECN
131 Pim Kieskamp ECN
132 O. van Hilten ECN
133 M. van Schaaik, CPB
134 W. Groot, CPB
135 Bas van Esch, MTV
136 Dr. Tamas Palvolgyi, Hongarije
- 137 Bureau Voorlichting en Public Relations
138-141 Bibliotheek RIVM (2x BIB, MTV, LAE)
142 Bureau Projecten- en Rapportenregistratie
143-200 Reserve-exemplaren

CONTENTS

Mailing list	I
Contents	VII
List of figures and tables	XI
SUMMARY	XIII
SAMENVATTING	XV

1. INTRODUCTION

1.1	Climate Convention	1
1.2	Content of this document	1
1.3	Methods	1
1.4	Scenario development	2
1.5	Measures in the National Environmental Policy Plan 2 for greenhouse gas mitigation ..	3

2. CARBON DIOXIDE

2.1	Introduction	5
2.2	Emissions	5
	- Temperature correction	6
	- Feedstocks	6
	- Industrial processes	7
	- Waste incineration	7
	- Bunkers	9
	- Carbon sink by reforestation	9
	- Conclusions	10
2.3	Comparison with IPCC methodology	11
2.4	Projection base line	17
2.5	Projection additional policies	18
2.6	Conclusions	21

3. METHANE

3.1	Introduction	23
3.2	Emissions	23
	- Introduction	23
	- Oil and Gas	23
	- Enteric fermentation	25
	- Animal waste	27
	- Landfills	30
	- Wetlands	32
	- Methane uptake in forest soils	33
3.3	Comparison with IPCC methodology	33
3.4	Projection base line	34

	- Introduction	34
	- Gas	34
	- Enteric fermentation	34
	- Animal waste	37
	- Landfills	38
3.5	Projection additional policies	39
3.6	Conclusions	42

4. NITROUS OXIDE

4.1	Introduction	45
4.2	Emissions	45
	Emission factors	45
	- Energy	45
	- Transport	46
	- Industry	46
	- Waste incineration	46
	- Agricultural and non-agricultural soils	46
	- Inland and coastal surface waters	47
	- Waste water treatment	47
	- Other sources	47
	Activity levels	47
4.3	Comparison with IPCC methodology	49
4.4	Projection base line	50
4.5	Conclusions	51

5. NITROGEN OXIDES, SULFUR DIOXIDE, AMMONIA CARBON MONOXIDE AND NON-METHANE HYDROCARBONS (NMHC)

5.1	Emissions and projections	61
-----	---------------------------------	----

6. HALOCARBONS (CFCs, HCFCs, HFCs, PFCs)

6.1	Emissions	63
6.2	Projections	67
6.3	Evaluation	69

7. TOTAL GREENHOUSE GAS EMISSIONS

7.1	Global warming potentials according to IPCC	71
7.2	CO ₂ -equivalent emissions 1985-2010	73
7.3	Evaluation	75

	REFERENCES	77
--	------------------	----

	SUMMARY TABLES	81
--	----------------------	----

SUMMARY TABLES (temperature corrected) 87
ANNEX 1 93

List of figures and tables

Figure 3.1	Methane emissions in agriculture in the Netherlands	38
Figure 3.2	Fugitive methane emissions in energy in the Netherlands	40
Figure 3.3	Methane emissions from landfills in the Netherlands	42
Figure 6.1	Halocarbon use in the Netherlands under different scenarios	69
Figure 7.1	Greenhouse gas emissions in the Netherlands in CO ₂ equivalents	73
Table 2.1	Emission factors for CO ₂ used in the aggregated fuel approach	5
Table 2.2	Temperature correction in the Netherlands	6
Table 2.3	Application factors for temperature correction in different sectors	6
Table 2.4	Fuels used as feedstocks, carbon dioxide emitted during and after production and carbon dioxide stored in products	8
Table 2.5	Emissions from industrial processes and waste incineration	9
Table 2.6	Bunker emissions from the Netherlands	9
Table 2.7	Carbon storage in living biomass through forest extension in the Netherlands	10
Table 2.8	Carbon dioxide emissions in the Netherlands	12
Table 2.9	Summary of energy balances and carbon dioxide emissions for 1980 and 1985	13
Table 2.10	Summary of energy balance and carbon dioxide emissions for 1990	14
Table 2.11	Summary of energy balance and carbon dioxide emissions for 1991	15
Table 2.12	Summary of energy balance and carbon dioxide emissions for 1992	16
Table 2.13	Measures for reduction of carbon dioxide emissions in the NEPP2, to be introduced before 2000	19
Table 2.14	Emissions of carbon dioxide in the European Renaissance scenario with high energy prices	22
Table 3.1	Activity data for oil and gas in the Netherlands	25
Table 3.2	Methane emission factors for oil and gas in the Netherlands	25
Table 3.3	Methane emissions from oil and gas in the Netherlands	25
Table 3.4	Number of (pseudo)ruminants in the Netherlands	26
Table 3.5	Methane emission factors and methane emissions from (pseudo)ruminants in the Netherlands	27
Table 3.6	Manure production in the Netherlands	29
Table 3.7	Methane emission factors for animal waste in the Netherlands	29
Table 3.8	Methane emissions from manure in the Netherlands	30
Table 3.9	Total landfilled waste, total organic carbon and total methane emission and recovery	31
Table 3.10	Methane emissions change in the Netherlands from drainage of wetlands between 1950 and 1990	32
Table 3.11	Methane uptake in forest soils in the Netherlands	33
Table 3.12	Number of ruminants under scenarios	36
Table 3.13	Methane emission of enteric fermentation under scenarios	36
Table 3.14	Manure production under scenario	37
Table 3.15	Methane emissions from animal waste under scenario	37
Table 3.16	Methane emissions from landfills according to different scenarios	41
Table 3.17	Summary of methane emissions in the Netherlands, with and without additional policies	43
Table 4.1	Dutch N ₂ O emissions for the period 1980 to 2015	52
Table 4.2	Emission factors for N ₂ O as used for fossil fuels	53
Table 4.3	Emission factors for N ₂ O as used for transport	53
Table 4.4	Energy use excluding transport and related N ₂ O emissions	54
Table 4.5	Vehicle-kilometers driven and related N ₂ O emissions	55
Table 4.6	Nitric acid production and related N ₂ O emissions	56
Table 4.7	Incineration of waste and related N ₂ O emissions	56
Table 4.8	Agricultural land use, nitrogen input and related soil emissions of N ₂ O	57
Table 4.9	Nitrogen loading to surface waters and related N ₂ O emissions	58
Table 4.10	Waste water treatment plants, nitrogen-influent, nitrogen-removal and related N ₂ O emissions	58
Table 4.11	Summary of N ₂ O emissions from the Netherlands	59
Table 4.12	Comparison of emission estimation methods for 1990 for nitrous oxide in the Netherlands	59
Table 5.1	Emissions of NO _x , SO ₂ and NH ₃ per sector	61
Table 5.2	Carbon monoxide emissions	62
Table 5.3	Emissions and projections of non-methane hydrocarbons	62
Table 6.1	Use of halocarbons in the Netherlands and total global warming of potential emissions	63

Table 6.2	Estimated use of halocarbons for different applications in the Netherlands in 1986	64
Table 6.3	Estimated use of halocarbons for different applications in the Netherlands in 1990	64
Table 6.4	Primary aluminum production and emissions of CF ₄ and C ₂ F ₆	66
Table 6.5	Dutch use of halocarbons under different scenarios	68
Table 7.1	Global warming potentials according to IPCC	72
Table 7.2	Summary of emissions, aims and scenarios for greenhouse gases	74

SUMMARY

The United Nations Framework Convention on Climate Change (UNFCCC) was ratified by the Netherlands in December 1993. One of the obligations is to provide a National Communication on greenhouse gas emissions, projections and programmes to reduce these emissions.

This background report was written at the request of the Dutch Ministry of Housing, Physical Planning and Environment as a background report for the first Dutch National Communication for the Framework Convention on Climate Change. It documents the methodologies, both for estimating greenhouse gas emissions and sinks, and for projections. For the most important greenhouse gases, it gives estimates for 1980, 1985, 1990, 1991 and 1992, and projections of possible future emissions in 2000 and 2010 under two scenarios. The short-term aim of the Convention is stabilization of emissions between 1990 and 2000. Therefore 1990 was chosen as the base year for emission estimation and 2000 as the base year for evaluation. The projections are based on the analysis for the National Environmental Outlook 3, the Second Environmental Policy Plan and the Second Memorandum on Energy Conservation.

Emissions were estimated using internationally agreed IPCC methodology as well as methodology used in the Netherlands. The differences between the methods are explicitly explained. Carbon dioxide emissions were estimated with and without a temperature correction. The original Dutch policy method estimates emissions including feedstock use. For methane and nitrous oxide emissions, Dutch emission factors were applied instead of IPCC defaults. As more sources were found for nitrous oxide in the Netherlands, the Dutch emission was higher than when strictly applying IPCC methodology.

Carbon dioxide emissions increased from 174 to 177 Mton CO₂ (net emissions, temperature corrected) between 1990 and 1992. The Second National Environmental Policy Plan (NEPP-2) was formulated to reduce environmental problems in the Netherlands. In addition to the NEPP-2, energy policy was formulated in the Second Memorandum on Energy Conservation (SMEC). Measures were formulated to reduce emissions of greenhouse gases. The aim for reducing carbon dioxide was 3-5% between 1990 and 2000. This aim was based on emissions including feedstock use (184 Mton in 1989/1990). Projections throughout this report were based on the European Renaissance scenario, with a high energy-price development. A contrasting scenario was the Global Shift, with a low energy-price development. Scenario calculations show that a 3% reduction of carbon dioxide emissions between 1990 and 2000 (from 184 to 179 Mton) is within reach. Reductions are dependent on real oil price developments and the growth of the economy. In the scenarios, the NEPP-2 set of measures, including an energy levy, will reduce emissions by 12-13 Mton in 2000 compared to the baseline emission in 2000 of 189-192 Mton (189-192 to 177-179 Mton).

Carbon dioxide emissions are steadily increasing with the growth of the economy. As no additional policy measures have yet been formulated for the years after 2000, the emissions in 2010 show a large increase.

Methane emissions peaked in 1991 to 1090 kton. In 1990 and 1992 they were 1070 kton (rounded off). According to scenario calculations the aim of 10% methane reduction between 1990 and 2000 will be realized. Under the assumption that all policies will be a success, scenario calculations even show that methane emissions are decreasing by more than 25% between 1990 and 2000. Emissions will be mainly reduced because of policies to reduce waste, landfilling, manure surpluses and ammonia deposition. Methane from waste can be recovered as an energy source. Further reductions are possible, especially with advanced techniques in waste gas recovery.

Nitrous oxide emissions were stable in 1990 to 1992 at a level of about 60 kton for each year. The aim is to stabilize nitrous oxide emissions between 1990 and 2000. Scenario calculations show that it will be difficult to realize this aim, especially because of the introduction and aging of the 3-way catalytic convertors in cars. Emissions are expected to be 62 kton in 2000.

Policies are in place for the reduction of the gases that have an indirect warming effect like CO, NO_x and NMVOC; the agreed reductions will not be reached without additional policies.

In 2030, HCFCs will be phased out to conform to the Copenhagen amendment of the Montreal Protocol. According to scenario calculations, the contribution of HFCs to potential global warming in the Netherlands in 2000 is small but increasing. If unchecked the contribution in 2010 will be relatively large. The HFCs are substitutes for the ozone depleting substances like CFCs and HCFCs. HFCs have no ozone depleting effects but a relatively large global warming potential. Policy on HFCs will need consideration in the near future.

More attention is needed for the other trace gases showing relatively high global warming potentials, for example, the PFCs. Small emissions already have large effects (3×10^9 kg equivalent carbon dioxide emissions) in a small country like the Netherlands.

SAMENVATTING

Het klimaatverdrag werd door Nederland in December 1993 geratificeerd. Het verdrag is op 21 maart 1994 officieel van kracht geworden. Eén van de verplichtingen die de overheid daarmee op zich heeft genomen is een nationaal overzicht te maken van de uitstoot van broeikasgassen in het basisjaar 1990. Tevens dienen projecties te worden gegeven voor het jaar 2000. Eveneens dient Nederland een overzicht te geven van de maatregelen om deze uitstoot te verminderen. Ook over andere jaren in het verleden of de toekomst kan gerapporteerd worden. Deze rapportage heet een National Communication in de termen van het verdrag.

Dit rapport werd geschreven op verzoek van het Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieu als een achtergrondrapport voor het eerste Nationaal Overzicht ten behoeve van het Klimaatverdrag. Het documenteert de gebruikte methoden, zowel voor de emissie berekeningen als voor de projecties. Voor de belangrijkste broeikasgassen worden schattingen gegeven voor 1980, 1985, 1990, 1991 en 1992, en projecties voor 2000 en 2010 onder twee scenario's. Het eerste doel van het Klimaatverdrag is de stabilisering van emissies in 2000 op het niveau van 1990. Daarom is 1990 als basisjaar gekozen voor de emissie berekeningen en 2000 als basisjaar voor de projecties. Projecties zijn gebaseerd op de Derde Nationale Milieuverkenning, het Tweede Nationaal Milieubeleidsplan, en de aanvullende nota Energiebesparing.

Internationaal overeengekomen methoden van de IPCC zijn gebruikt voor de berekeningen. Nederlandse methoden zijn gebruikt waar deze beter geacht werden. De verschillen worden expliciet aangegeven. De emissies van kooldioxide zijn met en zonder temperatuurcorrectie voor weersomstandigheden gegeven. In de oorspronkelijke Nederlandse methode gehanteerd in het NMP werden emissies berekend inclusief potentiële emissies uit brandstoffen gebruikt als grondstof. Voor methaan en lachgas emissies zijn Nederlandse emissiefactoren gebruikt. Aangezien bij lachgas meer bronnen voor emissies gevonden werden dan behandeld in de IPCC Guidelines, zijn onze schattingen mogelijk om die reden hoger dan in andere landen die strikt de IPCC Guidelines gebruiken¹.

De kooldioxide uitworp nam tussen 1990 en 1992 toe van 174 tot 177 Mton CO₂ (netto uitworp, gecorrigeerd voor temperatuur). In het tweede Nationaal Milieubeleidsplan en de tweede Nota Energiebesparing zijn maatregelen geformuleerd om de uitstoot van broeikasgassen te reduceren. Het doel voor CO₂ is 3-5% vermindering tussen 1990 en 2000. Dit is van 184 naar 173-177 Mton (inclusief feedstock emissies, gecorrigeerd voor temperatuur). Of, in IPCC termen van 174 naar 160-164 Mton (exclusief feedstocks, gecorrigeerd voor temperatuur).

Projecties in dit rapport zijn gebaseerd op het European Renaissance scenario met een hoge energieprijzontwikkeling. Een contrasterend scenario was het Global Shift scenario met een lage energieprijzontwikkeling. Scenarioberekeningen tonen dat een reductie van bijna 3% tussen 1990 en 2000 (van 184 naar 179) haalbaar is. De werkelijke reductie is afhankelijk van de ontwikkeling van de economie en de energieprijzen. De emissies na 2000 tonen een stijging met de groei van de economie, omdat nog geen beleid na 2000 is geformuleerd.

Methaan emissies vertonen een piek van 1090 kton in 1991. Uit scenario berekeningen blijkt dat het doel van 10% reductie tussen 1990 en 2000 zal worden gehaald. Als al het milieubeleid succesvol is dan tonen scenario berekeningen dat zelfs een reductie van 25% tussen 1990 en 2000

¹ Het is de bedoeling dat in de nabije toekomst RIVM, CBS en TNO één gemeenschappelijk Nederlands emissie-overzicht opstellen. Hierin kunnen andere methoden voor de schatting van de emissies gebruikt zijn.

mogelijk is. Emissies zullen voornamelijk afnemen door het beleid van reductie van afval en afvalstort, mestoverschotten en ammoniakemissies. Methaan uit afval kan ingezet worden als energiebron. Verdere reducties zijn mogelijk, vooral met geavanceerde technieken bij de stortgaswinning en de biogaswinning bij GFT-fermentatie.

N₂O emissies waren stabiel op 60 kton per jaar in 1990 tot 1992. Het doel is stabilisatie van deze emissies tussen 1990 en 2000. Scenario berekeningen tonen dat dit doel mogelijk moeilijk realiseerbaar is, vooral door de introductie en slijtage van de 3-weg katalysator in auto's. In 2000 wordt een uitwerp van 62 kton verwacht.

Beleid is overeengekomen voor de reductie van emissies van de gassen die vooral een indirecte broeikaswerking hebben zoals CO, NO_x en NMVOC. Extra beleid is nodig om de doelstellingen te halen.

In 2030 zullen de HCFK's uit productie genomen zijn volgens afspraken in Kopenhagen bij het Montreal Protocol. HFK's worden ingezet als vervangers voor CFK's en HCFK's. Volgens scenario berekeningen is de bijdrage van HFK's aan de potentiële opwarming in 2000 in Nederland nog klein. De bijdrage in 2010 zal relatief groot zijn tenzij maatregelen genomen worden. HFK's hebben geen ozonaantastende werking maar wel een relatief groot potentieel broeikas effect. Een HFK beleid is nog niet vastgesteld.

Meer aandacht is nodig voor andere sporegassen met een relatief hoge potentiële broeikaswerking, bijvoorbeeld de PFCs (polyfluorinated carbon compounds). Kleine hoeveelheden hebben al grote effecten door de extreem hoge atmosferische verblijftijden en Global Warming Potentials van deze stoffen.

1. INTRODUCTION

1.1 Climate Convention

The Framework Convention on Climate Change came officially into force on 21 March 1994 after the ratification by 50 parties. The official National Communications are due by 21 September 1994 for the Annex 1 countries, i.e. the OECD countries, and the Eastern European countries whose economies are in transition from a planned to a market economy. In these Communications countries will report on their national net anthropogenic emissions of greenhouse gases. Countries will also report on the policy measures they have taken to reduce emissions. In order to present an international review of their policy programme at the first Conference of Parties in Berlin in Spring 1995, countries will make projections of emissions with and without the measures they have taken to stabilize emissions in 2000 at the 1990 levels. The Parties will then decide whether the programmes are sufficient to meet the stabilization objective.

1.2 Content of this document

This document describes the emissions of greenhouse gases in the Netherlands for the years 1990 - 1992 and gives projections for the emissions up to the year 2010. The projections are based on the analysis for the National Environmental Outlook 3, the Dutch Second National Environmental Policy Plan and the Second Memorandum on Energy Conservation, carried out by the RIVM in cooperation with a number of other institutes (RIVM, 1993a; RIVM, 1993b; RIVM, 1994).

In this document the following greenhouse gases are covered: CO₂, CH₄, N₂O, NO_x, CO, NMHC, CFCs, HCFCs and HFCs. The CFCs and HCFCs are covered in the Montreal Protocol and amendments but are also reported here because of their global warming potential.

This document is written at the request of the Directorate of Environment as a background report for the National Communication. Emission estimates from this document are the same as in the National Communication, with the exception of projections of emissions for carbon dioxide for 2000 and beyond. The carbon dioxide scenario projections in this document can be considered as a sensitivity analysis of the carbon dioxide scenario in the National Communication. Some differences occur in the baseline, as in this document measures taken before 1 January 1995 are considered baseline measures adopted in the First Environmental Policy Plan. The reason for this is the evaluation cycle by RIVM of the First and Second Environmental Policy Plans. The projections in this report are based on the evaluation of the additional measures proposed in the Second Environmental Policy Plan (RIVM, 1993a; 1993b and 1994).

1.3 Methods

In this document the IPCC methodology for estimating greenhouse gas emissions will be followed, with the exception of projections of carbon dioxide emissions for 2000 and beyond. However, information is given for calculating projections according to IPCC methods. The IPCC methodology is documented in three volumes: Reporting Instructions, a Workbook and a Reference Manual (IPCC, 1994). Next to the IPCC methods, emissions are calculated according to methods developed in the Netherlands. If differences occur, they are described explicitly.

For carbon dioxide, energy balances in an aggregated fuel approach are used. Apparent energy consumption in solid, liquid and gas fuels is multiplied by an aggregated emission factor based on the average carbon content of the fuel. This approach is fairly robust; uncertainty is about 2%. Feedstocks are used to produce monomers, solvents, plastics, bitumen and other products

containing carbon that potentially emitted after the lifetimes of these compounds. In this report is estimated which part of the non-energy use of fossil fuels is directly emitted during the production process, which part is emitted during use of the products and which part is actually stored in products. No account has been taken of import and export of products. As many products (e.g. solvents and monomers) are exported, part of the stored carbon will be emitted during waste incineration in other countries. Mineral emissions, like carbon dioxide from cement, iron and glass production, are estimated. Carbon storage in forest extension is reported as a sink. Bunker emissions are given separately.

For methane, nitrous oxide and the indirect greenhouse gases like nitrogen oxides, carbon monoxide and non-methane hydrocarbons, activity data (like the energy produced, the number of car kilometres travelled, the number of cows, the amount of fertilizer applied to the soil, the amount of waste landfilled) are used for the country for a particular year and multiplied by an appropriate emission factor based on experimental data. In some cases experimental data are lacking, then default emission factors based on extrapolations of experimental results elsewhere are used. For the CFCs, HCFCs and HFCs data on the actual use are reported.

1.4 Scenario development

The baseline scenario adopted in this report is called the European Renaissance, with high real energy prices in 2000. Here, the effects of all adopted policy measures per 1 January 1995 are included. A contrasting scenario is Global Shift, with low real energy prices. In the high price path real oil prices in 2000 are 45% higher than in 1990. In the low price path the oil price in 2000 equals that of 1990. Only in carbon dioxide projections are differences visible; this is because carbon dioxide emissions are price and growth sensitive. The scenarios are from the *National Environmental Outlook 3* (NEO3) report of the National Institute of Public Health and Environmental Protection (RIVM) to make projections on the state of the environment. At the request of the Dutch Government RIVM reported on the effectiveness of the National Environmental Policy Plan 2 (NEPP-2) to reach environmental goals for 2000 that were formulated and approved by Parliament. In NEPP-2 a set of measures were formulated beyond those of the earlier NEPP and NEPP-plus. The additional policies scenario in this report is based on this set of measures.

Measures adopted by Parliament up to 1 January 1995 and included in the Baseline scenario are reported. This is different from the Guidelines for projections in National Communications, as adopted in Berlin by the International Negotiating Committee 9th Session, where all measures from 1990 are included in the base line. In the Dutch National Communication report all measures dating from 1990 will be included.

The European Renaissance and Global Shift scenarios are based on a long-term scenario study on the world economy, "Scanning the Future" (CPB, 1992), carried out by the Central Planning Bureau. To study the effects of these different paths of growth for the Netherlands, the scenarios were further extended to include Dutch socioeconomic developments ("Nederland in Drievoud"). Several features of the two scenarios, i.e. Global Shift and European Renaissance, used in the RIVM studies, will be given here.

Global Shift (GS)

In this scenario the core of the world's economic activity shifts to the Asia-Pacific region. Europe loses ground in important industrial sectors and stagnation is a result. Only after 2000 does a gradual economic improvement take place. Migration from Africa and Eastern Europe to Western Europe takes place as a result of the failure to financially support development of the first two

regions. Environmental policies fail to halt pollution. In Western Europe and the Asian-Pacific region only local problems are addressed. In Africa and Eastern Europe negative trends continue. BNP growth in the Netherlands is 1.5%

European Renaissance (ER)

Western Europe develops prosperously in this scenario. The European integration is a success. The European Monetary Union will be completed before the end of the century, when the American economy will be faced with a recession. The central European states will be assisted by the European Community's financial and technical support. The former Soviet Union is faced with stagnation, but some republics, especially those near Western Europe, will recover quickly. The European Energy Charter will play an important role in this respect. Energy savings will take place in these countries. Increased earnings from the exports of energy, especially gas, will be used for investments in infrastructure and capital goods.

Great improvement will get underway in the USA in about the first half of the next decade, when international cooperation will increase. BNP growth in the Netherlands in this scenario is 2.7%

1.5 Measures in the Second National Environmental Policy Plan for greenhouse gas mitigation

In *National Environmental Outlook 3* (RIVM, 1993a) environmental measures that will be adopted by parliament before 1 January 1995 are evaluated. In the National Environmental Policy Plan 2 (NEPP-2) new measures are formulated. In the RIVM report "Effect of measures of the Second Environmental Policy Plan" (RIVM, 1993b) expected emission reductions from the new proposed measures are estimated. Different sets of measures are distinguished into the following categories:

1. Baseline. Including all measures to be adopted by Parliament before 1 January 1995. Considered the baseline projection.
2. Additional policies. Measures from National Environmental Policy Plan 2 (NEPP-2) to be either directly effectuated or implemented in consultation with the economic sector representatives during the planning period 1995-1998.
3. Additional policies under study. Measures under consideration, not included in the National Communication.

Measures from the first category are used to construct the Baseline. Measures from the second category are taken into account when projecting the effects of measures to reduce the greenhouse gas emissions. The effects of these measures are considered in the Additional policies scenario. Measures from the third category are considered as "additional policies under study", and, where relevant, are indicated separately in scenario outcomes.

The outcomes have no prognostic value. Scenarios are used to assess "what could happen if certain policy measures are taken". Important uncertainties in the outcomes are economic developments and developments in real energy prices.

2. CARBON DIOXIDE

2.1 Introduction

The increase of greenhouse gas concentrations in the atmosphere may lead to an increase in the global average temperature on Earth. Carbon dioxide is the most important greenhouse gas. About 50% of the extra radiative forcing in the eighties was caused by the increase of carbon dioxide. The most important anthropogenic source of carbon dioxide is the combustion of fossil fuels. The total emission of CO₂ from the combustion of fossil fuels is estimated through historic records of fossil fuel production and use. In the Netherlands the fossil fuel production and use is recorded by the Central Bureau of Statistics and published in the yearly Dutch Energy Statistics. Another anthropogenic source of carbon dioxide is cement production. In the Netherlands this is a small source. Preindustrial atmospheric concentrations were 280 ppmv. The concentration was 315 ppmv when measurements started at Mauna Loa in 1958 and the rate of increase was 0.6 ppmv per year. The growth rate of atmospheric concentrations has increased steadily since that time. It was 1.6 ppmv per year during the eighties. In 1992, the growth rate was falling back to 0.6 ppmv per year. At that time the concentration had grown to 355 ppmv. The reason for this anomalous growth rate is unclear, but may be due to anomalous weather conditions affecting ecosystems and ocean waters.

2.2 Emissions

Emissions are calculated from the energy balances of the Netherlands for 1980, 1985, 1990, 1991 and 1992. Emission factors have been agreed on in coordination with the Central Bureau of Statistics, TNO Emission registration, Energy Research Foundation in Petten, National Institute of Public Health and Environmental Protection, Ministry of Economic Affairs, Directorate General for Energy and the Ministry of Housing, Physical Planning and Environment. Emissions are estimated using the aggregated fuel approach, with emission factors for solid, liquid and gas fuels and multiplying these by the apparent consumption of solid, liquid and gas fuels. Emission factors used in the aggregated approach are given in Table 2.1. More detailed emission factors for a detailed fuel approach are given in Annex 1; these factors are used in National Environmental Outlook 3 (RIVM, 1993) for detailed calculations within economic sectors.

Table 2.1 Emission factors for CO₂ used in the aggregated fuel approach

Fuel type	Emission factor kg CO ₂ /GJ
Natural gas	56
Oil and oil products	73
Coal	94

Summaries of energy balances and estimated CO₂ emissions are given both corrected and uncorrected for temperature. In the following section more detail is given on temperature correction, feedstock use, industrial process emissions, waste incineration, calculating carbon storage from forest extension and bunker emissions.

Temperature correction

Almost all space heating in the Netherlands is by natural gas burning devices. Therefore the outdoor temperature has a direct effect on the use of gas. As consequence, deviations from "normal" temperatures result in perturbations of the trend in energy use. This perturbation can be as much as 5% of the total energy consumption in the Netherlands, as was the case in the relatively warm year of 1990. In order to analyze the policy effects and visualize the trend in CO₂ emission in the Netherlands, the consumption of natural gas must be corrected for temperature effects.

The temperature dependency for space heating is expressed and quantified in terms of degree days over one year. This indicative number is calculated with the formula $\sum_i (18-T_i)$, where i is any day during the year having an averaged temperature, T_i , below 18°C. A 30-year moving average can be calculated for this climate indicator. The moving average for the Netherlands is given in Table 2.2. The correction factor for the use of natural gas is proportional to the ratio of the "30-year normal" and the "actual" value of the degree days over one year.

Table 2.2 Temperature correction (°C)*days in the Netherlands

Year	Actual °C*days	30-year moving average °C*days
1990	2677	3214
1991	3163	3201
1992	2831	3206

The correction factor is only applied to that part of the gas consumption used for space heating. These factors are given in Table 2.3 for the various economic sectors.

Table 2.3. Application factors for temperature correction (%) in different sectors

Households	85.0
Trade/services	82.5
Agriculture	82.5
Small industries	50.0
Large industries	10.0
Energy	5.0

Feedstocks

Feedstocks are fossil fuels used for the manufacturing of products e.g. plastics, monomers and solvents. In the energy statistics the amount of fossil fuels that are feeded in these processes is given. Finally, all embedded carbon dioxide will end up in the atmosphere. Part of the carbon dioxide from the feedstocks is directly lost during the manufacturing process, part is emitted as the products are used (e.g. methanol or carbon electrodes) and part is stored for a longer period of time, only to be released after waste incineration. An effort has been made to estimate these

different amounts. Although the Netherlands is a net importer of plastics no corrections have been made for imports.

In the year 1990 feedstocks covered about 412 PJ of fossil energy carriers, mainly oil and natural gas, with a potential CO₂ emission of about 28.6 Mton. From this amount it is estimated that about 8.0 Mton is emitted directly (e.g. in fertilizer production and monomers) and another 6.8 Mton indirectly during the use of products. Thus about 14.8 Mton must be regarded as actual emissions from feedstocks. About 13.8 Mton is stored in products, e.g. bitumen and monomers. In Table 2.4 an overview is given of emissions during the process, and during product use and storage of carbon dioxide in various products.

In 1990 direct emissions during the processes mainly concerned monomers (4.0 Mton) and the release of carbon during fertilizer production (3.7 Mton). In fertilizer production the hydrogen from the feedstock is used and the carbon is released, except for a small amount used in urea production. Emissions after production result from monomers and solvents (5.2 Mton), C electrodes (0.4 Mton), lubricants (0.4 Mton) and various products (0.8 Mton). The remaining 45% of the feedstock related CO₂ must be seen as being stored in the products (10.8 Mton in monomers, 1.5 Mton in bitumen and 1.5 Mton in various products). In the case of waste incineration these will be emitted later.

Industrial processes

Mineral carbon dioxide emissions from limestone used in cement manufacturing have been documented for some years (OECD, 1991). Smaller industrial applications where limestone is converted to CO₂ include: steel production, glass manufacture and flue-gas desulfurization.

In 1990 Portland cement production was responsible for 0.8 Mton carbon dioxide emission (see Table 2.5). This is calculated from a production of 1 Mton lime, with an emission factor of 0.8 ton/ton of pure lime (Smit, 1993). Process emissions from steel production in 1990 from 0.9 Mton lime addition and the same emission factor were 0.7 Mton carbon dioxide emission (Annema et al., 1992). Flue-gas desulfurization leads to a CO₂ emission of 0.15 Mton (Okken et al., 1993) and glass manufacture to an emission of 0.2 Mton. Calculated from 1 Mton glass produced, times 25% lime addition, times the emission factor of 0.8 ton CO₂/ton pure lime (Loos, 1992). A total mineral emission of 1.85 Mton CO₂ is estimated. Probably in the ceramic industry there are mineral carbon dioxide emissions as well; the exact magnitude is unknown.

Waste incineration

The total amount of carbon dioxide from the incineration of synthetics in 1990 is estimated at 0.9 Mton (De Jager and Blok, 1993). This estimate is based on a careful analysis of waste streams and the amount of fossil carbon in these waste streams.

Table 2.4 Fuels used in the Netherlands as feedstocks, carbon dioxide emitted during and after production, and carbon dioxide stored in products

	Fuel and products	PJ input	Emissions during process (Mton CO ₂)	Emissions after production (Mton CO ₂)	Carbon dioxide storage (Mton CO ₂)	Total (Mton CO ₂)
1980	Coal and coke	2		0.09	0.09	0.18
	Natural gas (fertilizer)	43	2.4			2.4
	Natural gas (other)					
	Bitumen/petrocokes	17			1.2	1.2
	Lubricants	5		0.4		0.4
	Other	166	2.4	3.1	6.6	12.1
	TOTAL	233	4.8	3.6	7.9	16.3
1985	Coal and coke	10		0.3	0.7	1.0
	Natural gas (fertilizer)	65	3.6			3.6
	Natural gas (other)	23	0.3	0.3	0.7	1.3
	Bitumen	22			1.6	1.6
	Lubricants	6		0.4		0.4
	Other	258	3.8	4.7	10.3	18.8
	TOTAL	384	7.7	5.7	13.3	26.7
1990	Coal and coke industry	4.7		0.4		0.4
	Coal (other)	6.5			0.6	0.6
	Natural gas (fertilizer)	65.7	3.7			3.7
	Natural gas (other)	29.6	0.3	0.4	0.9	1.6
	Bitumen	19.9			1.5	1.5
	Lubricants	5.4		0.4		0.4
	Petrocokes	5.8		0.4		0.4
	Solvents	4.1		0.3		0.3
	Monomers	269.8	4.0	4.9	10.8	19.7
TOTAL	411.5	8.0	6.8	13.8	28.6	
1991	Coal and cokes industry	4.4		0.4		0.4
	Coal (other)	5.8			0.5	0.5
	Natural gas (fertilizer)	74.0	4.1			4.1
	Natural gas (other)	28.1	0.3	0.4	0.9	1.6
	Bitumen	16.9			1.2	1.2
	Lubricants	7.3		0.5		0.5
	Petrocokes	5.8		0.4		0.4
	Solvents	4.1		0.3		0.3
	Monomers	281.2	4.1	5.1	11.3	20.5
TOTAL	427.6	8.5	7.1	13.9	29.5	
1992	Coal and cokes industry	4.1		0.4		0.4
	Coal (other)	5.9			0.6	0.6
	Natural gas (fertilizer)	75.2	4.2			4.2
	Natural gas (other)	26.0	0.3	0.4	0.8	1.5
	Bitumen	17.3			1.3	1.3
	Lubricants	6.1		0.4		0.4
	Petrocokes	5.8		0.4		0.4
	Solvents	4.1		0.3		0.3
	Monomers	258.4	3.8	4.7	10.4	18.9
TOTAL	402.9	8.3	6.6	13.1	28.0	

Table 2.5 Emissions in 1990 from industrial processes and waste incineration

	Activity level	Emission factor CO ₂	Emission CO ₂
Portland cement	1 Mton lime	0.8 ton/ton pure lime	0.8 Mton
Iron and steel production	0.9 Mton lime addition	0.8 ton/ton pure lime	0.7 Mton
Flue gas desulfurization	0.2 Mton lime addition	0.8 ton/ton pure lime	0.15 Mton
Glass manufacture	0.25 Mton lime addition	0.8 ton/ton pure lime	0.2 Mton
Subtotal			1.85 Mton
Waste incineration	3413 kton incinerated with 888 kton carbon content	27% carbon is fossil carbon	0.9 Mton
TOTAL			2.8 Mton

Bunkers

Air and marine bunkers also contribute to the emission of anthropogenic carbon dioxide. For the Netherlands these are (according to the definition of the "General trade system") about 540 PJ for the years 1990-1992. Most of these emissions are outside the Netherlands. Results are listed below. Differences with Eurostat carbon dioxide emission calculations for the Netherlands may be related, among other things, to the treatment of air bunkers. The emission factor used is 77 kg CO₂/PJ for marine bunkers and 73 kg/PJ for aviation bunkers.

Table 2.6. Bunker emissions from the Netherlands

Year	Marine bunkers		Aviation bunkers		Total bunkers	
	PJ	CO ₂ [Mton]	PJ	CO ₂ [Mton]	PJ	CO ₂ [Mton]
1990	466	35.9	61	4.5	527	40.4
1991	476	36.7	68	5.0	544	41.7
1992	478	36.8	81	5.9	559	42.7

Carbon sink through reforestation

In forestry, CO₂ is sequestered by the growth of the biomass, increases in stable humus in the soils, and the accumulation of dead organic material and litter on the ground. A study has been done where the increase of standing biomass and material in and on the soils is calculated from growth tables for different tree species in combination with results from carbon modelling (Mohren and Klein Goldewijck, 1990). One of their conclusions was that the standing biomass in the Netherlands was 50% more than earlier estimates. Recently, a study has become available on carbon fixation through forestation activities (Nabuurs and Mohren, 1993). This study assessed the potential of carbon fixation of selected forest types on the basis of a dynamic model of the carbon

cycle. The maximum CO₂ storage in the living biomass in temperate forests is 5.5 to 9.0 ton CO₂ ha⁻¹ a⁻¹ (Nabuurs and Mohren, 1993).

In this section results from these studies are used to estimate the net increase of CO₂ in biomass from increases in permanent and temporary forest area in the Netherlands. No assessment is made of stock increases. Information on forest area development is derived from a recent evaluation of forestry policies (Ministry of Agriculture, Nature Management and Fisheries, 1992). In the Netherlands subsidies are available for reforestation of agricultural area. Normally after clearcutting, there is an obligation to replant the trees. An exception has been made to this rule in these agricultural areas to stimulate farmers to set aside some of their property for trees.

Actually about 1500 ha a⁻¹ are planted to increase the forested area. Of these about 500 ha a⁻¹ are without a replanting obligation, and 1000 ha a⁻¹ are with a replanting obligation. An autonomous decrease in the forest acreage of 300 ha a⁻¹ has been noted in the years since 1977.

The net CO₂ storage is calculated as mean storage per year over a 30-year growing period up to harvest of the trees. Table 2.7 gives the net increment and carbon storage. From 1977 to 1991, 2800 ha of temporary forest was planted. This kind of forest consists of fast growing poplar trees. The net storage is 25,000 ton CO₂ a⁻¹ if calculated over a 30-year rotation period. Since 1977 about 13,000 ha of permanent forest has been planted. Under the assumption that half of it consists of oak trees and half of Douglas fir, with a rotation period of 30 years, the storage of carbon dioxide can be calculated.

Since 1977 about 300 ha a⁻¹ has disappeared. We assume that half consisted of Scotch pine and half of oak trees. Then 600 ton a⁻¹ of carbon dioxide storage in Scotch pine disappeared and 750 ton a⁻¹ of storage in oak trees. Net storage is 0.12 Mton CO₂ a⁻¹.

Table 2.7. Carbon storage in living biomass through forest extension in the Netherlands

	Average volume increment of standing biomass (m ³)	Carbon storage standing biomass (ton CO ₂ /ha/yr)	Area increase between 1977 and 1991 (ha)	Carbon storage (Mton a ⁻¹)
Poplar	18	9	2800	0.03
Oak	9	5	6850	0.03
Douglas fir	17	9	7000	0.06
TOTAL				0.12

Conclusions

Resulting net actual carbon dioxide emissions in the Netherlands for 1980, 1985, 1990, 1991 and 1992 are summarized in Table 2.8. Details are given in Tables 2.9 through 2.12. For 1990 it is calculated that about 412 PJ of fossil fuels was used as a feedstock, with a potential CO₂ emission of 28.6 million tons. It is estimated that about 8 Mton of the feedstock use is directly oxidated during the processes, and 6.8 Mton is emitted after production. About 13.8 Mton is stored in

products, like monomers and bitumen. About an extra 40 Mton is emitted from bunker fuels, of which about 4.5 Mton is from aviation bunkers and 35.5 Mton from international marine bunkers. Most of the bunker emissions are outside the Netherlands. Small emissions are found in industrial processes: 0.8 Mton from Portland cement production. (Part of the cement production is from steel slag; in this production process no emissions of carbon dioxide are found. During steel production some carbon dioxide is, of course, emitted because chalk is added in the process. It is estimated that 0.7 Mton is emitted from this process.) Emissions from flue-gas desulfurization and glass production are 0.15 and 0.2 Mton, respectively. After temperature correction, the carbon dioxide emission (including feedstocks) in the Netherlands in 1990, 1991 and 1992 were 185.0, 185.6 and 186.8 million tons, respectively. Correcting for feedstock use, and emissions and storage in products, mineral emissions and waste incineration, the resulting CO₂ emissions in 1990, 1991 and 1992 were 174.0, 174.4 and 176.6 million tons, respectively (see Table 2.8).

2.3 Comparison with IPCC methodology

IPCC top-down methodology has been applied. For carbon dioxide from combustion, temperature-corrected figures are given as well. In the IPCC methodology feedstock use is separated out after calculation of emissions by the use of a fraction storage. Extra detail is given concerning actual emissions from feedstock use in the Netherlands. Emissions during processes, product use and actual longer term storage in products are estimated separately. Some differences have been noticed between IPCC defaults and the Netherlands in emission factors in the detailed fuel approach. These differences will be evaluated in the near future.

Table 2.8. Carbon dioxide emissions in the Netherlands¹

Year	Uncorrected for temperature effects							
	a. Feedstock included (million ton CO ₂)	b. Feedstocks excluded	c. Potential from feedstocks	d. Actual from feedstocks	e. Mineral emission waste incineration	f*. Net actual emission	g. Air bunkers	h. Marine bunkers
1980	173.2	156.9	16.3	8.3	2.0	167.2	2.8	30.2
1985	163.6	136.9	26.7	13.5	2.0	152.4	3.5	28.2
1990	178.7	148.9	28.6	14.8	2.8	167.6	4.5	35.9
1991	185.2	154.5	29.6	15.6	2.8	174.0	5.0	36.7
1992	182.3	154.8	27.9	14.9	2.8	172.1	5.9	36.8
	Corrected for temperature							
1980	172.5	156.2	16.3	8.3	2.0	166.5	2.8	30.2
1985	160.8	134.1	26.7	13.5	2.0	149.6	3.5	28.2
1990	185.0	155.3	28.6	14.8	2.8	174.0	4.5	35.9
1991	185.6	154.9	29.6	15.6	2.8	174.4	5.0	36.7
1992	186.8	159.3	27.9	14.9	2.8	176.6	5.9	36.8

- * = National net actual emission of carbon dioxide applying IPCC methods
a = Potential emission, feedstocks included. Including a statistical difference between supply and demand statistics.
b = Emission, feedstocks excluded
c = Potential emission from feedstocks
d = Actual emission from feedstocks during processes and from solvents and other product use
e = Mineral emissions from cement, glass, flue gas desulfurization, steel slag and emissions from waste incineration
f= Net national total carbon dioxide emission, calculated from a-c+d+e.

Storage from feedstocks use (Mton): 8.0 (1980), 13.2 (1985), 13.8 (1990), 13.9 (1991), 13.1 (1992)

¹ Emissions reported to CORINAIR are different from these values. Emissions after production as in table 2.4 are not reported to CORINAIR.

Table 2.9. Summary of energy balance and carbon dioxide emissions for 1980 and 1985

1980		Uncorr. Gas PJ	Corr. Gas PJ	Uncorr. CO ₂ Mton	Corr. CO ₂ Mton	Oil PJ	CO ₂ Mton	Coal PJ	CO ₂ Mton	Total PJ	Total Mton
A Fuel combustion activities											
1	Energy and transformation industry	211	211	11.8	11.8	364	26.6	90	8.5	665	46.9
2	Industry	393	392	22.0	21.9	376	27.4	72	6.8	841	56.1
3	Transport	0	0	0	0	322	23.5	0	0	322	23.4
4	Commercial/Institutional	134	132	7.5	7.4						
5	Residential	415	408	23.2	22.8	52	3.8	2	0.2	469	26.8
6	Agriculture/Forestry	114	112	6.4	6.3						
7	Other(4+6)	248	244	13.9	13.7	74	5.4	1	0.1	323	19.2
Total incl. feedstocks uncorr.		1267	1255	70.9	70.3	1188	86.7	165	15.5	2620	173.2
Total corrected for temperature						1188	86.7	165	15.5	2608	172.5
Marine bunkers										396	30.2
Air bunkers										39	2.8
Mineral emissions and waste											2.0
1985											
A Fuel combustion activities											
1	Energy and transformation industry	328	326	18.4	18.3	121	8.8	164	15.4	611	42.5
2	Industry	414	405	23.2	22.7	278	20.3	93	8.7	776	51.7
3	Transport	0	0	0	0	322	23.5	0	0	322	23.5
4	Commercial/Institutional	119	112	6.7	6.3	83	6.1	8	0.8	203	13.2
5	Residential	424	397	23.7	22.2	16	1.2	1	0.1	414	23.5
6	Agriculture/Forestry	92	86	5.2	4.8	22	1.6	0	0	108	6.4
Total incl. feedstocks uncorr.		1376	1326	77.1	74.3	842	61.5	266	25.1	2485	163.6
Total corrected for temperature						842	61.5	266	25.1	2435	160.8
Marine bunkers										371	28.2
Air bunkers										48	3.5
Mineral emissions and waste											2.0

Table 2.10. Summary of energy balance and carbon dioxide emissions for 1990

Not corr. for temp.	Gas PJ	CO2 Mton	Oil PJ	CO2 Mton	Coal PJ	CO2 Mton	Total PJ	Total CO2 Mton
Energy and transformation	278	15.6	152	11.1	263	24.7	693	51.4
industry								
Industry	334	18.7	83	6.1	92	8.6	509	33.4
Transport	0	0.0	368	26.9	0	0.0	368	26.9
Comm./Inst.	141	7.9	20	1.5	2	0.2	163	9.5
Residential	329	18.4	10	0.7	0	0.0	339	19.2
Agricult./Forestry	126	7.1	21	1.5	0	0.0	147	8.6
Total excl. feedst.	1208	67.6	654	47.7	357	33.6	2219	148.9
Feedst.	95	5.3	305	22.3	11	1.0	411	28.6
Total	1303	73.0	959	70.0	368	34.6	2630	177.6
Statistical differences	-13	-0.7	16	1.2	7	0.7	10	1.1
Apparent consumption								178.7
Total incl. actual from feedst.								164.8
Total incl. mineral and waste								167.6
Air bunkers								4.5
Marine bunkers								35.9
Corrected for temp.								
Energy and transformation	281	15.7	152	11.1	263	24.7	696	51.6
industry								
Industry	346	19.4	83	6.1	92	8.6	521	34.1
Transport	0	0.0	368	26.9	0	0.0	368	26.9
Comm./Inst.	164	9.2	20.5	1.5	2	0.2	186.5	10.9
Residential	384	21.5	10	0.7	0.5	0.0	394.5	22.3
Agricult./Forestry	146	8.2	20.5	1.5	0	0.0	166.5	9.7
Total excl. feedst.	1321	74.0	654	47.7	357.5	33.6	2332.5	155.3
Feedst.	95	5.3	305	22.3	11	1.0	411	28.6
Total	1416	79.3	959	70.0	368.5	34.6	2743.5	183.9
Statistical differences	-13	-0.7	16	1.2	7	0.7	10	1.1
Apparent consumption								185.0
Total incl. actual from feedst.								171.2
Total incl. mineral and waste								174.0
Air bunkers								4.5
Marine bunkers								35.9

Table 2.11 Summary of energy balance and carbon dioxide emissions for 1991

Not corrected for temp.	Gas	CO ₂	Oil	CO ₂	Coal	CO ₂	Total	Total CO ₂
	PJ	Mton	PJ	Mton	PJ	Mton	PJ	Mton
Energy and trans.	327	18.3	163	11.9	241	22.7	731	52.9
Industry	339	19.0	73	5.3	85	8.0	497	32.3
Transport	0	0.0	369	26.9	0	0.0	369	26.9
Comm./Inst.	173	9.7	21	1.5	1	0.1	195	11.3
Residential	373	20.9	10	0.7	1	0.1	384	21.7
Agricult./Forestry	142	8.0	20	1.5	0	0.0	162	9.4
Total excl. feedst.	1354	75.8	656	47.9	328	30.8	2338	154.5
Feedst.	102	5.7	315	23.0	10	0.9	427	29.6
Total	1456	81.5	971	70.9	338	31.8	2765	184.2
Statistical differences	-14	-0.8	25	1.8	0	0.0	11	1.0
Apparent consumption								185.2
Total incl. actual from feedst.								171.2
Total incl. mineral and waste								174.0
Air bunkers								5
Marine bunkers								36.7
Corrected for temp.	Gas	CO ₂	Oil	CO ₂	Coal	CO ₂	Total	Total CO ₂
	PJ	Mton	PJ	Mton	PJ	Mton	PJ	Mton
Energy and trans.	327	18.3	163	11.9	241	22.7	731	52.9
Industry	340	19.0	73	5.3	85	8.0	498	32.4
Transport	0	0.0	369	26.9	0	0.0	369	26.9
Comm./Inst.	174	9.7	21	1.5	1	0.1	196	11.4
Residential	377	21.1	10	0.7	1	0.1	388	21.9
Agricult./Forestry	143	8.0	20	1.5	0	0.0	163	9.5
Total excl. feedst.	1361	76.2	656	47.9	328	30.8	2345	154.9
Feedst.	102	5.7	315	23.0	10	0.9	427	29.6
Total	1463	81.9	971	70.9	338	31.8	2772	184.6
Statistical differences	-14	-0.8	25	1.8	0	0.0	11	1.0
Apparent consumption								185.6
Total incl. actual from feedst.								171.6
Total incl. mineral and waste								174.4
Air bunkers								5
Marine bunkers								36.7

Table 2.12 Summary of energy balance and carbon dioxide emissions for 1992

Not corrected for temp.	Gas	CO ₂	Oil	CO ₂	Coal	CO ₂	Total	Total CO ₂
	PJ	Mton	PJ	Mton	PJ	Mton	PJ	Mton
Energy and trans.	342	19.2	157	11.5	240	22.6	739	53.2
Industry	336	18.8	102	7.4	85	8.0	523	34.3
Transport	0	0.0	384	28.0	0	0.0	384	28.0
Comm./Inst.	162	9.1	20	1.5	0.5	0.0	182.5	10.6
Residential	335	18.8	9	0.7	0.5	0.0	344.5	19.5
Agricult./Forestry	141	7.9	19	1.4	0	0.0	160	9.3
Total excl. feedst.	1316	73.7	691	50.4	326	30.6	2333	154.8
Feedst.	101	5.7	292	21.3	10	0.9	403	27.9
Total	1417	79.4	983	71.8	336	31.6	2736	182.7
Statistical differences	-20	-1.1	15	1.1	-4	-0.4	-9	-0.4
Apparent consumption								182.3
Total incl. actual from feedst.								169.3
Total incl. mineral and waste								172.1
Air bunkers								5.9
Marine bunkers								36.8
Corrected for temp.	Gas	CO ₂	Oil	CO ₂	Coal	CO ₂	Total	Total CO ₂
	PJ	Mton	PJ	Mton	PJ	Mton	PJ	Mton
Energy and trans.	344	19.3	157	11.5	240	22.6	741	53.3
Industry	345	19.3	102	7.4	85	8.0	532	34.8
Transport	0	0.0	384	28.0	0	0.0	384	28.0
Comm./Inst.	178	10.0	20	1.5	1	0.1	199	11.5
Residential	372	20.8	9	0.7	1	0.1	382	21.6
Agricult./Forestry	156	8.7	19	1.4	0	0.0	175	10.1
Total excl. feedst.	1395	78.1	691	50.4	327	30.7	2413	159.3
Feedst.	101	5.7	292	21.3	10	0.9	403	27.9
Total	1496	83.8	983	71.8	337	31.7	2816	187.2
Statistical differences	-20	-1.1	15	1.1	-4	-0.4	-9	-0.4
Apparent consumption								186.8
Total incl. actual from feedst.								173.8
Total incl. mineral and waste								176.6
Air bunkers								5.9
Marine bunkers								36.8

2.4 Baseline projection

Two baseline projections are constructed for CO₂ based on the two economic scenarios as described in section 1.4. The one scenario is characterized by a relatively high economic growth and relatively high energy prices (European Renaissance), the other has a lower economic growth and relatively low energy prices (Global Shift). The energy consumption in the scenarios depends on the economic growth, the energy prices and the government policy as formulated in the First National Environmental Policy Plan and the related Memorandum on Energy Conservation, both presented in 1990. In GS (low) it is assumed that the real energy prices in 2000 are about the same as in 1990. In ER (high) the real energy prices in 2000 are 45% higher than in 1990. In the Memorandum on Energy Conservation an autonomous energy saving of about 1% per year was postulated. The outcome of the baseline calculations, which includes a number of policy measures, was an energy efficiency improvement of 1.0 to 1.6% per year between 1990-2000.

In industry an energy efficiency improvement (excluding feedstock) of 10% is anticipated in 1995 and another 10% in 2000. Because of increasing energy prices in ER (high) an autonomous energy improvement of 15% is assumed for combustion in industry. Insulation programmes in housing lead to a reduction in energy used for heating. In GS (low) it is assumed that 1.9% per year can be saved on heating. The energy used in transport is affected by an increase in volume of traffic and an increase in fuel economy. In ER (high) it is assumed that the resulting energy used in transport in 2000 will be 3% lower than in 1990. In agriculture a strong increase in horticulture in greenhouses is assumed. Despite the increase in energy efficiency, energy use is expected to rise 20 to 25% between 1990 and 2000. In the energy sector an increase of decentralized combined thermal and power plants with a corresponding increase in energy efficiency is assumed. The energy use will therefore decrease by 15% between 1990 and 2000.

Because of a shift from coal to natural gas, an increase of the amount of fossil fuel replaced by waste incineration and reusables, the increase in CO₂ emissions is 0.4% slower than the growth of the total national energy use.

The outcome of the scenarios is strongly related to the energy prices. In *Environmental Outlook 3* (RIVM, 1993) it is shown that in a situation with low economic growth and a large increase in the price of energy (GS with relatively high energy prices), the emissions will be 1% lower in 2000 compared to 1990. With the exception of a small extra levy on petrol and diesel, no energy tax increases are assumed in these scenarios. After 2000, the emissions of carbon dioxide increase by 0.9 to 1.3% per year in the Global Shift scenario (with low energy prices) because of a continuing growth in consumption and production. In the European Renaissance scenario, with its high energy prices, the increase is 1.1 to 1.6% per year.

The aim for the carbon dioxide emission reductions according to the First National Environmental Policy Plan Plus is a 3 to 5% reduction in 2000 with respect to 1989/90. The aim set is 173-177 Mton CO₂ in 2000. In the Netherlands the aim is formulated for the total emissions, including feedstock use and excluding bunker and mineral emissions. No effort is made to reformulate aims and projections to conform with the IPCC methodology, where carbon dioxide emissions are calculated with actual emissions from feedstock use. Earlier it was stated that feedstock use in 1990 is estimated at 28.6 Mton CO₂ potential emissions. About 14.8 Mton is actually released during the processes or after production. About 3 Mton is released from mineral emissions and waste incineration. So about 11 Mton should be subtracted from the 1990 figures mentioned in this section. Actual emissions from feedstock use in 2000 are assumed 16 Mton and 19 Mton in 2010. So for the figures for 2000, 13 Mton may be subtracted and for the 2010 figures, 16 Mton may be subtracted.

2.5 Projection of additional policies, ER(high) and GS(low)

In the Second National Environmental Policy Plan extra measures are proposed to bring the aim of CO₂ within reach. Related to this NEPP-2 the Memorandum on Energy Conservation was updated. No changes have been made to the aim for carbon dioxide reductions as formulated in the First Environmental Policy Plan. The aim for the carbon dioxide emission reductions according to the Second National Environmental Policy Plan is a 3 to 5% reduction in 2000 with respect to 1989/90.

The most important contribution to the emission reduction in 2000 will be extra energy saving. In ER (high) about 10 Mton can be saved with these measures, excluding an energy tax, and 13 Mton, including an energy tax. A sensitivity analysis showed that with these additional measures in ER (high) an extra energy saving of 0.5% per year is possible. In ER (high) this is 2.1% per year in the period 1990-2000. Most energy can be saved in the residential and commercial sectors with insulation of existing buildings. Important energy saving takes place with the increase in use of combined heat and power. The contribution of the extra measures in transport and waste management to emission reduction of CO₂ is relatively small. At the moment, the same applies for fuel shifts and the use of renewable energy sources.

After introduction of measures before 2000, as formulated in the Second National Environment Programme, the emissions for 2000 in the European Renaissance scenario with high energy prices will be 182 Mton. The emissions will be 179 Mton in the Global Shift scenario, with low energy prices for 2000. In both cases the target of 173-177 Mton will not be reached. In Table 2.13 an overview of measures introduced before 2000 is given. For the period between 2000 and 2010, CO₂ emissions increase to 214 Mton, a 15% increase compared with 2000. No national aim has been formulated for 2010. Industrialized countries together have decided that after 2000 their emissions would decrease with 1-2% per year. To give an impression of the possibilities for CO₂ emission reduction after 2000, a few technical scenario calculations have been made for the Second Memorandum on Energy Conservation. No analyses have been made of the possible implementation of the policies used.

Energy-saving seems to be the most important and cheapest option for emission reduction after 2000. The reduction possible with a technical package of measures (with costs lower than Dfl.100 per ton CO₂ reduction) is 16 Mton CO₂ in 2010 (from 219 to 203 Mton). The total yearly savings (after depreciation) of this package is Dfl. 1.7 billion. Another package of measures (costs per ton CO₂ reduction between Dfl. 100 and 200 per ton CO₂) can save another 16 Mton in 2010 (down from 203 to 187 Mton). The total net yearly costs (after depreciation) of this package are Dfl. 0.2 billion. In the transportation sector an extra reduction of 3 Mton CO₂ in 2010 is possible.

On the supply side measures may be: increasing nuclear energy, increased carbon dioxide removal in coal power plants and industry, the increase in combined thermal and power, and renewable energy. A reduction of 20-27 Mton CO₂ is possible in 2010. Costs of measures are lower than Dfl. 200 per ton CO₂ reduction (depreciation). Total yearly net costs of these measures are Dfl. 0.5 to 1.5 billion. These scenarios are described in a technical report (RIVM, 1994).

Description of measures of NEPP 2 and MEC 2

Measures are described with effects on carbon dioxide emissions in 2000 compared to the reference scenario, which is the European Renaissance with high energy prices. Net yearly costs are defined as the capital costs of investments (depreciation and interest) and operational costs (costs for personnel, energy, overhead, raw materials and maintenance). Possible savings (energy

savings, savings in raw materials, maintenance etc.) are subtracted. Depreciation is calculated over the technical lifetime of installations at an interest rate of 5.25%. The measures can often be introduced with net gains. In that case costs are expressed with a negative sign in the table. This cost calculation is used for macroeconomic analyses. On a microeconomic level energy consumers will use different cost calculations based on a higher internal interest or shorter pay-back times. The consequences are that the net yearly costs as presented here give a more optimistic view on the costs than companies and consumers experience as individuals.

Long Term Agreements with industry

Signed agreements between government and industry on savings and energy efficiency over a longer time period. will be incorporated in the environmental permits. Because it was assumed in the European Renaissance scenario that the contracts would be totally effective, no effect is seen, while in Global Shift this measure does have effects.

Extension of Long Term Agreements to covering 90% of industry

Through this measure energy savings and efficiency will be agreed with new sectors in industry. The effect in 2000 is a reduction of 0.4 Mton CO₂ compared to the base scenario. Costs and savings balance at Dfl. 41 million per year.

Extension of Action Plans to the remaining 10% of industry.

Innovations and savings in the 10% energy use in industry not covered by negotiations will lead to 5% extra savings in 2000, or 0.1 Mton carbon dioxide emissions.

Table 2.13 Measures for reduction of carbon dioxide emissions in the additional policies to be introduced before 2000 and effects in European Renaissance scenario (high prices)

Sector	Measure	Effect (10 ⁹ kg)	Costs (Dfl.x 10 ⁶)	Introduction
Industry	Long term Agreements with industry	0	-	before 2000
	Extension of LTA to 90% of industry	0.4	-41	before 2000
	Extension of Action Plans to remaining 10% of industry	0.1	-8	before 2000
	Fuel shift from coal to gas	0.3	0	before 2000
Agriculture	Negotiations with greenhouse horticulture sector to increase efficiency to 30%	0.7	-48	before 2000
	Negotiations with other agricultural sectors to increase efficiency to 30%	0.2	<0	before 2000
Transport	Speed limit to 80 km h ⁻¹ for heavy duty trucks and buses	0.3	-160	before 2000
	Control of actual speed limit of 120 km h ⁻¹ for passenger cars	0	pm	before 2000
	Control of actual speed limit of 120 km h ⁻¹ for light duty trucks	0	pm	before 2000
	More efficient cars	0.1	<0	before 2000
Electricity	Biomass power plant	0.6	18	before 2000
	Carbon dioxide removal	0.5	38	before 2000
	Combined heat and power	1.3	-420	before 2000
Refineries	Energy saving in refineries and energy production	0.6	-40	before 2000
Residential	Energy saving in appliances	0.5	-110	per 1-1-1997
	Energy saving in warm water	0.1	0	per 1-1-1996
	Energy saving in heating	0.1	-4	per 1-1-1996
Services	34% energy saving in heating and lighting in new offices	0.3	-54	per 1-1-1997
Waste	Extra landfill gas recovery	0.1	-	per 1-1-1994
Forestry	Reforestation	0.3	0	before 2000
Taxes	National energy levy	3	pm	1995

Fuel shift from coal to gas

Total coal use in industry is 111 PJ in 2000; 100 PJ is used as raw material or in energy

transformation. Coal use for burning in 2000 is 11 PJ. Part of this amount can be shifted to gas. Reduction of carbon dioxide emission in 2000 is 0.3 Mton, with zero costs.

Negotiations with greenhouse horticulture sector to increase energy efficiency to 30%
In current talks between government and the sector an efficiency improvement to 23% between 1991 and 2000 has been agreed on. A 32% increase in efforts gives an extra 0.7 Mton reduction of emissions. Savings are Dfl. 48 million, assuming that prices for gas in horticulture will increase from 19 Dutch cents per m³ in 1994 to 40 Dutch cents per m³.

Negotiations with other agricultural sectors to increase energy efficiency to 30%.
If all agricultural sectors commit themselves to energy efficiency improvements from the actual 10% to 30% in 2000, an extra reduction of 0.2 Mton without costs is possible.

Taxes to reduce NOx emissions, 1995-2000
If a tax is introduced passenger car use will be reduced by 0.3% with a resulting carbon dioxide reduction of 0.4 Mton. No costs by definition.

Speed limit to 80 km h⁻¹ for heavy duty trucks and buses
Speed limitators have already been introduced. Only trucks smaller than 12 ton will have to be equipped. Cost is Dfl. 1600 for each of these trucks. Fuel savings are 10%, savings for tyres are 34%. An emission reduction in of 0.3 Mton will be reached in 2000 with Dfl. 160 million savings.

Control of the actual speed limit
In NEPP-2 calculations it is assumed that 100% control will not be reached. Therefore a reduction is not expected. If 100% control is assumed before 2000, a reduction of about 0.35 Mton CO₂ is possible.

More efficient cars
Through European legislation and financial stimuli new cars will be more efficient than assumed in the baseline scenario: 1% in 1996, 1997, 1998, and 2, 3 and 4% in 1999, 2000 and 2001-2010, respectively. This gives a reduction of 0.1 Mton CO₂.

Biomass power plant
Three points are important. First, technical know-how, for the use of this energy source has to be developed. Second, a large group of farmers must be found willing to devote their land to this crop for a long period of time (12 years or more). Third, infrastructure is needed to transport this fuel to a power plant. If investments are made, a 0.6 Mton carbon dioxide reduction is possible in 2000.

Carbon dioxide removal
Technical knowledge for the removal of carbon dioxide from flue gases is available. Less experience exists with the storage, for example, in gas fields. For storage, energy is needed to bring the carbon dioxide under pressure. A pilot project is assumed to show a removal of 0.5 Mton in 2000.

Combined thermal and power plant
This measure assumes an extension of combined heat and power to 8000 MegaWatt in 2000, when an emission reduction of 1.3 Mton is possible.

Energy-saving in refineries and energy production
In 2000, energy saving measures in refineries, and in oil and gas production, can reduce emissions by 0.6 Mton.

Energy-saving in appliances

Regulation to increase efficiency in washing machines, dishwashers and cooling/freezing appliances by 5-10% can be implemented by 1 January 1997. Then a reduction of 0.5 Mton is possible in 2000.

Energy-saving in warm water

Energy use for warm water can be reduced from an average of 550 m³ a⁻¹ on 1 January 1996 to 400 m³ a⁻¹. A reduction of carbon dioxide of 0.1 Mton is expected in 2000.

Energy-saving in heating

The energy use for heating can be reduced from an average of 750 m³ a⁻¹ on 1 January 1996 to 600 m³ a⁻¹. A reduction of carbon dioxide emission of 0.1 Mton is possible in 2000.

Energy-saving in new offices

It is assumed that under legislation starting 1 January 1997, the average energy use of new buildings will be reduced by 34% with respect to 1990. It is estimated that between 1 January 1997 and 2000 about 13% of the floor space is new. A carbon dioxide emission reduction of 0.3 Mton is expected in 2000.

Extra landfill gas recovery

Waste gas contains 50% carbon dioxide. Carbon dioxide is removed in the upgrading process. In 2000 this leads to a reduction of 0.1 Mton.

Reforestation

In forest extension 14,000 ha were realized between 1977 and 1990. In 1990-2000 the aim is to extend the forest by another 30,000 ha. This is including the trees along lanes and parcels of land. Between 2000 and 2025 an extension of 7000-12,000 ha is planned. If an average storage of 9 ton CO₂ ha⁻¹ a⁻¹ rotated over 30 years is assumed, an extra storage capacity above 1990 of 0.3 Mton a⁻¹ is created in 2000. Under the same assumptions the total extra storage capacity in 2010 relative to 1990 is 0.7 Mton a⁻¹.

Energy levy

To further mitigate the carbon dioxide emissions in 2000, the possibilities of an energy tax will be studied. If only small users are taxed at 11 Dutch cents per m³ gas and 4 Dutch cents per kWh electricity (both including VAT), and if the measure is introduced in 1995, then the emissions will be reduced by 2 to 3 Mton carbon dioxide (from 192 to 190 Mton) in 2000 in the European Renaissance scenario (high energy prices), while in the Global Shift scenario with low prices only a reduction of 1 Mton will be realized (189 to 188 Mton).

An energy tax as proposed by the European Union (US\$10 per barrel) may reduce emissions in the European Renaissance scenario (high prices) by 5 Mton (from 192 to 187 Mton). In a low-price scenario this instrument is 2 to 3 times less effective. The effect of energy taxes cannot simply be added to the NEPP-2 package of measures because of double counting. On the other hand, subsidies on energy-saving measures might become more effective because of the higher energy price. The NEPP-2 package supplemented with an energy tax might lead to an emission reduction from 192 Mton in 1990 to 179 Mton in 2000. The exact reduction is hard to estimate because of opposing effects.

2.6 Conclusions

Carbon dioxide emissions are estimated for the Netherlands for 1980, 1985, 1990, 1991 and 1992.

Projections are made for 2000 and 2010. In the Netherlands feedstock use and bunkers are relatively large compared to other countries. Temperature-corrected actual net emissions (bunkers excluded, actual emissions from feedstocks included and mineral emissions and waste included) in 1990, 1991 and 1992 are 174.0, 174.4 and 176.6 Mton, respectively.

Projections of carbon dioxide emissions are made for 2000. These data are given according to conventions in the Netherlands (corrected for temperature, and potential emissions from feedstock use, including mineral emissions and emissions from waste incineration, and excluding bunkers). Results are summarized in Table 2.14. About 10-11 Mton can be subtracted in 1990 to 1992 to arrive at the net actual temperature corrected emissions. 13 Mton can be subtracted in 2000 and 16 Mton in 2010.

The package of measures planned to be implemented in the period before 2000 will reduce emissions by about 10 Mton carbon dioxide in both scenarios (European Renaissance with high real energy prices and Global Shift with low real energy prices). Including the effect of a energy levy this reduction might be 3 Mton CO₂ higher. The package of measures has an effect of a 5 Mton reduction in 2010.

Technical analyses showed that potentially available measures could lead to stabilization of emissions in the period between 2000 and 2010 (instead of a growth of 15% in the NEPP-2 package). Even a reduction of 15% in 2010 compared to 1990 levels is potentially possible. This is a reduction of 1.5% per year from 2000 onwards.

The uncertainty in the CO₂ emission estimates is about 2%. This is related to uncertainties in the activity data, errors in unit conversions, emission factors and the aggregated approach.

On a macroeconomic level many measures have negative costs. This is based on calculations with a depreciation period. If a period of five years is chosen, which is much closer to that which most energy consumers use than the technical lifetime, many measures are still profitable.

Table 2.14 Emissions of carbon dioxide in the European Renaissance scenario (high energy prices) feedstocks included.

CO ₂ Feedstocks included*	Unit billion kg	1985	1990	1991	1992	2000 Aim	2010			
							Baseline	Additional policies	Baseline	Additional policies
Industry		52	61	63	62	65	64	73	73	
Energy		47	52	53	53	49	46	69	68	
Transport		23	27	27	28	29	29	32	31	
Residential		23	22	22	22	21	19	18	16	
Other		19	22	22	22	27	24	23	21	
TOTAL		163	184	185	188	173- 177	192*	182**	219	214

* To obtain actual net emissions according to the IPCC methodology: subtract 11 Mton from industry in 1990, 1991 and 10 Mton in 1992, 13 Mton in 2000 and 16 Mton in 2010.

* in GS (low): 189 billion kg (Mton)

** in GS (low): 179 billion kg (Mton)

3. METHANE

3.1 Introduction

Next to water vapour, carbon dioxide and ozone, methane is the most important greenhouse gas in the atmosphere. Methane is also the most abundant hydrocarbon in the atmosphere and therefore, along with carbon monoxide, the major regulator of OH radicals, the primary sink for most atmospheric pollutants. Methane is both naturally occurring, formed under anaerobic conditions in wetlands, organic soils and ruminants, and influenced by such human activities as the production of fossil fuels. The current concentration (1720 ppbv) is more than double the pre-industrial (800 ppbv). Methane exerts a strong influence on the Earth's climate and the chemistry of the troposphere and stratosphere. It is an effective greenhouse gas because it traps part of the outgoing infrared radiation of the earth. Methane also plays an indirect role in climate as it reacts with hydroxyl radicals (OH) in the troposphere, thereby increasing tropospheric ozone and carbon monoxide, an ozone precursor. Methane in the stratosphere is a major source of formaldehyde, hydrogen and water vapour, thereby affecting the radiation balance. Methane is a powerful greenhouse gas with a potential direct warming effect of 11 times the effect of CO₂. If indirect effects are included the potential is even greater (19-43 times). In the eighties methane contributed about 16% to the potential warming. Recently, the growth rate of the atmospheric concentration has slowed down, in 1993 to practically zero. There is no satisfactory explanation for this anomaly (IPCC, 1992; IPCC, 1994; Van Amstel et al., 1993).

3.2 Emissions

Introduction

Methods for estimating emissions are based on Van Amstel et al. (1993), which is an update of Van den Born et al. (1991). The most used methodology is IPCC's (IPCC, 1994). Differences with this methodology are explicitly addressed.

Oil and gas

Tables 3.1 and 3.2 show the data on activities and emission factors as they are used in the calculations. One standard cubic metre of natural gas is assumed to contain 0.58 kg CH₄ in the calculations. Table 3.3 shows the current emissions in the Netherlands estimated according to the IPCC method (IPCC, 1994) and using Dutch emission factors. The emissions are based on the central value of the emission factors.

Gas production

In the Netherlands 71.8 billion m³ (st) or 2272 PJ of natural gas was produced and processed in 1989. On the basis of estimates and the recorded quantities of flared/vented natural gas, it is estimated that emissions in natural gas production were 52 (37 - 67) kton CH₄ a⁻¹ in 1989 (see Table 3.3). The emissions for 1990, 1991 and 1992 are calculated using the same emission factors (see Tables 3.2 and 3.3). Because most non-used gas is vented offshore, offshore emissions comprise 80% of the total.

Transport of natural gas

The high pressure transport of natural gas and sales to consumers is undertaken by the Netherlands Gasunie (the national gas authority). The Gasunie has two transport systems, one main national system operating at a pressure of 65 bar, and a regional system operating at a 40-bar maximum

pressure. The national network has a length of 4600 km. The regional network is 6200 km long. Eight compressor stations keep the systems under pressure. Maintenance leads to emissions from these stations. In 1988 an estimated 2.1 million m³ (st) natural gas or 1.2 kton methane per year was thus emitted (1 standard m³ of natural gas is 0.58 kg CH₄). Pressure reduction takes place at 1098 stations receiving gas, and the gas is sold to industry and energy distributors. This gas is distributed in the local networks. The energy content of the amount transported yearly is given in Table 3.1. Methane emissions occur in the transportation phase due to adjustments and maintenance works of the pipe system and compressor stations. The emissions have a fixed and a variable part. The fixed part, related to the regular maintenance, is estimated at 5 million m³ a⁻¹ (st) of natural gas, or 2.9 kton CH₄. The variable part is related to irregular problems with the system. It was estimated at 6 million m³ a⁻¹ (st) of natural gas or 3.5 kton CH₄ in 1989, a normal year. The total is strongly dependent on weather conditions: total is high at a high throughput in cold winter spells. Methane emissions from transport of gas in 1980, 1985, 1989, 1990, 1991 and 1992 are given in Table 3.3. The calculation is based on 0.015 to 0.020 vol % of the throughput. This is the same as 2753-3671 kg/PJ.

Distribution of natural gas

The total length of the regional and local distribution network was 93,000 km in 1987. An extra 42,000 km comprises pipes running from the network to the consumers. The length of pipes designed for dry gas is 84,880 km; the length of old pipes designed for town gas was 11,210 km in 1987. This old cast iron network for town gas in some places is more than 100 years old. Methane emissions during distribution are due, in particular, to leaks in this town network. The lead/oak joints in this network were designed for relatively wet town gas. At present 11% of the distribution network still consists of these grey cast iron pipes. At the moment 2-3 leaks per km are found in this network, compared to 1 leak per 10 km in the polyethylene network.

The Gasunie has estimated a loss of 120-150 million m³ natural gas or 71 (65-79) kton methane, assuming 10% oxidation in the soil covering the pipes (Nielen, 1991). This amounts to about 0.5 to 0.7% of the throughput; the highest losses are from the old network. Losses given in Table 3.3 are calculated using this emission factor, or the equivalent in kg/PJ.

Oil production

There are two concessions, Rijswijk and Schoonebeek, in the Netherlands and four concessions on the continental shelf. Total production was 3.83 million m³ (st) or 145 PJ in 1989. This was 13% less than in 1988 due to the companies going over their production top. Nielen (1991) estimated methane emissions in petroleum production at 18 (0.7 - 35) kton a⁻¹ in 1989. This estimate is confirmed by estimates given by the Netherlands Aardolie Maatschappij (NAM). The production and emissions for 1990 are slightly higher, and for 1991 and 1992 slightly lower. Oil transport in tankers is negligible, so no methane is assumed to be emitted in oil transport. Emissions during oil refinement are negligible as well.

Combustion

Methane emission during combustion of natural gas is estimated at 0.06 to 0.12 vol %. Emissions in 1990 amounted to 21 kton CH₄. Combustion of oil and other fuels results in minor amounts of methane. Activity data for combustion of oil and other fuels have been derived from the energy balances. Dutch emission factors are used to estimate emissions. Methane emission in 1990 was about 7 kton CH₄.

Table 3.1 Activity data for oil and gas in the Netherlands

	1980	1985	1989	1990	1991	1992
	PJ	PJ	PJ	PJ	PJ	PJ
Gas production	2860	2550	2270	2290	2610	2625
Gas transport	2860	2550	2270	2290	2610	2625
Gas distribution	755	725	650	660	760	725
Oil production	62	180	163	176	159	143
End-use gas combustion	1275	1355	1305	1270	1420	1375

Table 3.2 Methane emission factors for oil and gas in the Netherlands

	Low	High	Low	High
	Vol. %	Vol. %	kg/PJ	kg/PJ
Gas production	0.09	0.16	16302	29500
Gas transport	0.015	0.020	2753	3671
Gas distribution	0.5	0.7	91785	128499
Oil production	0.005	0.16	5000	240000
End-use gas combustion	0.06	0.12	10700	22200

Table 3.3 Methane emissions from oil and gas in the Netherlands (kton CH₄ a⁻¹)

	1980	1985	1989	1990	1991	1992
Gas production	65	58	52	52	60	60
Gas transport	9	8	7	7	8	8
Gas distribution	83	80	71	72	84	80
Oil production	7	20	18	18	17	17
Total oil and gas	164	166	148	149	169	165
End-use gas combustion	21	23	21	21	23	23
Combustion other fuels	7	5	7	7	5	5

Enteric fermentation

In the method followed (recommended by the IPCC) the quantity of methane emitted is calculated as a function of energy intake and energy demand of the animals. According to this method, methane emission is calculated for dairy cattle, beef cattle, sheep and goats. For pigs and horses IPCC recommends a simple approach using default emission factors.

Cattle in the Netherlands is kept inside during the winter period. In the summer period some of the dairy cattle is kept inside. The feeding level is high with a good digestibility of the fodder. The

formula taken from Blaxter and Clapperton (1965) is recommended by the IPCC for the calculation of methane emissions:

$$Y_m (\text{MJ CH}_4/100 \text{ MJ feed}) = 1.30 + 0.112\text{DMD} + \text{FL}(2.37 - 0.050\text{DMD})$$

where:

Y_m = the methane yield in MJ per 100 MJ of gross feed intake.

DMD = percent of feed digestibility at the maintenance level of feeding, expressed in per cent and not as a fraction. DMD is estimated by averaging digestibilities of commonly used feedstuffs.

FL = feeding level, expressed as a multiple of the maintenance level. FL is high in the Netherlands. Calculated FL ranges from 2 to 4, depending on age class and differences between beef and dairy cattle.

Methane megajoules (MJ) are converted to teragrammes (Tg) and multiplied by 365 and by the number of animals in each class to arrive at the annual methane production. Methane production per animal is expressed in $\text{kg CH}_4 \text{ a}^{-1}$ per head. FL was calculated by dividing metabolizable energy intake (ME_i) by metabolizable energy for maintenance (ME_m): $\text{FL} = \text{ME}_i/\text{ME}_m$. See the background document "Methane, the other greenhouse gas" for further details (Van Amstel et al., 1993).

The number of animals are given in Table 3.4. Mean methane emission results are given in Table 3.5. An uncertainty range of 15% is assumed for these estimates. Emissions from dairy cattle are decreasing, while emission from beef cattle is increasing. These trends reflect the results of European policies to reduce milk surpluses.

Table 3.4. Numbers of (pseudo) ruminants in the Netherlands

Type	Subtype	1980 (^{'000})	1985	1990	1991	1992
Cattle	total	5226	5248	4926	5062	4920
Cattle	dairy	4308	4222	3607	3628	3490
	beef	918	1026	1320	1435	1430
Cattle	dairy					
	young <1 year	870	796	806	820	774
	young female >1	1038	1014	880	908	893
	female	2356	2367	1878	1852	1775
	male >1	54	45	43	48	48
	beef					
	calves	582	638	602	622	638
	young	292	342	598	674	646
	female >2	44	46	120	139	146
Sheep	total	858	814	1702	1882	1954
Sheep	male	9	9	28	28	27
	female	368	358	790	857	877
	fattened lamb	481	447	884	993	1050
Goats	total		12	61	70	63
Goats	male			23	26	25
	female			38	43	38
Pigs	total	10138	12383	13915	13217	14161
Horses	total		62	70	77	86

Table 3.5 Methane emission factors and methane emissions from (pseudo) ruminants in the Netherlands (kton CH₄ a⁻¹)

Type	Subtype	Methane emission factor	Methane emission					
		kg per head per year	1980	1985	1990	1991	1992	
Cattle	dairy	young <1 year	49.25	42.9	39.2	39.7	40.4	38.1
		young female >1	62.80	65.2	63.7	55.3	57.0	56.1
		female	102.13	240.6	241.7	191.8	189.1	181.3
	beef	male >1	93.22	5.0	4.2	4.0	4.5	4.5
		calves	17.65	10.3	11.3	10.6	11.0	11.3
		young female >2	87.01	25.4	29.8	52.0	58.6	56.2
		102.13	4.5	4.7	12.3	14.2	14.9	
Sheep	total	8.0	6.8	6.6	13.5	15.1	15.6	
Sheep	male	8.0	0.1	0.1	0.2	0.2	0.2	
	female	8.0	2.9	2.9	6.3	6.9	7.0	
	fattened lamb	8.0	3.8	3.6	7.0	8.0	8.4	
Goats	total	8.0	NE	NE	0.5	0.5	0.5	
Goats	male	8.0	NE	NE	0.2	0.2	0.2	
	female	8.0	NE	NE	0.3	0.3	0.3	
Pigs	total	1.5	15.2	18.6	20.9	19.8	21.2	
Horses	total	18.0	NE	1.1	1.3	1.4	1.5	
Cattle	dairy	total	353.7	348.8	290.8	291.0	280.0	
Cattle	beef	total	40.2	45.8	74.9	83.8	82.4	
Cattle	total		393.9	394.6	365.7	374.8	362.4	
TOTAL*			415.9	420.7	401.9	411.6	401.2	

*Totals may not add up due to rounding off.

NE = not estimated because of missing data on activity.

Animal waste

The IPCC (1994) recommends using the method of Woodbury and Hashimoto (1994) for the estimate of methane emissions from animal waste and consists of the following steps:

- o Defining the different waste categories and waste handling systems.
- o Estimating the potential methane emission per unit of waste (Bo).
- o Estimating the fraction of the potential emission actually emitted for each waste management type (MCF).
- o Estimating the amount of waste and the volatile solids (VS) content in each category.
- o Estimating the actual methane emissions by multiplying the actual emission rate by the amount of waste in each category.

Potential methane emission is primarily a function of the quantity and quality of the degradable organic material content, or VS content, of the waste. Because the digestion processes of animals differ, the VS content is generally a function of animal type and feeding quality. So methane emission can be estimated as follows:

$$TM = (VS \times Bo \times MCF \times 365 \times \text{Density}) \times 10^9 \text{ (minus methane recovered from waste gas)}$$

where:

TM = total methane in Tg a⁻¹

VS = volatile solids in the waste

Bo = the methane emission potential

MCF = methane conversion factor

Density = 0.662 kg m⁻³ methane

The methane recovered from waste digesters should be subtracted from the methane emissions thus calculated.

Woodbury and Hashimoto (1994) collected information on potential emissions from 10 different animal types and eight major waste management systems. The extent to which these potential emissions are realized depends on how the waste is managed. Casada and Safley (1990) estimated the fraction of the potential methane emission for each waste management system. This is called the "methane conversion factor". The International IPCC Workshop held in Amersfoort, The Netherlands for methane experts in February 1993 suggested MCFs for three different temperature regimes: cool, temperate and warm (average annual temperature <15°C, 15 to 25°C and >25°C, respectively (Van Amstel, 1993). These MCFs have been used in this report.

The following waste management systems are relevant to the Netherlands.

1. Meadow (moist regions)
2. Slurry storage (>1 month)
3. Solid storage
4. Litter
5. Anaerobic digester

Casada and Safley's original MCFs (1990) were scaled down for the Dutch situation as suggested by the methane experts in the Netherlands because earlier research had indicated lower methane formation in all systems, due to, for instance, low average temperatures in the Netherlands (Zeeman and Hamelers, 1992). The following methane conversion factors (%) are assumed:

1. Meadow	0
2. Slurry storage (>1 month)	10
3. Solid storage	5
4. Litter	10
5. Anaerobic digester	80

Manure slurry in the Netherlands is increasingly stored in silos outside the stable. Statistics are available on the total number and volume. No distinction can be made between silos for cow manure or pig manure. So an overall emission factor had to be applied.

Manure statistics do not allow a detailed estimate for all systems, as only total production data per animal type are available. Slurry storage under the stable in a piggery is, for example, widespread but methane emission estimates cannot yet be made. Therefore a rough estimate has been made for a selection of systems. The manure production in the Netherlands according to CBS (1992) is summarized in Table 3.6. Table 3.7 summarizes the emission factors as used in the Netherlands.

Table 3.6. Manure production (10⁶ ton slurry) in the Netherlands

Manure	1970	1975	1980	1984	1986	1988	1990	1992
Cattle	56.1	64.3	67.2	78.6	69.5	59.9	60.9	59.6
o.w. in stable	28.1	32.2	33.7	35.6	32.8	27.5	27.9	27.3
Fattening steers						2.3	2.7	2.7
Fattening calves	1	1	1.3	1.8	2.2	2	1.9	2.0
Sheep and goats						1.3	1.9	2.1
Pigs	8.9	12.2	14.6	15.9	19.1	19.2	19.8	16.7
Poultry dry	1.1	1.3	1.7	0.6	0.7	0.9	0.9	0.9
Poultry slurry				1.6	1.7	1.5	1.5	1.5

o.w.= of which
Source: CBS, 1992

Table 3.7. Methane emission factors for animal waste in the Netherlands

	Volatile solids fraction	Emission potential m ³ /kgVS	MCF, fraction of potential
Cattle dairy			
o.w. in stable	0.124	0.17	0.05
o.w. in meadow	0.116	0.24	0
Fattening steers	0.116	0.33	0.1
Fattening calves	0.116	0.33	0.1
Sheep and goats	0.25	0.18	0.1
Pigs	0.101	0.45	0.1
Poultry dry	0.194	0.32	0.1
Poultry slurry	0.194	0.32	0.1
Total			

o.w.= of which
VS = volatile solids.
MCF = methane conversion factor

As no information was available on the quantity of waste and the storage time in the silos, an overall assumption was made that pig slurry is stored outside for more than 1 month (MCF: 10%) and that most of the cow manure is kept either in drylot or in slurry storage for less than a month (MCF: 5%). Slurry from beef steers and calves was assumed to be stored for about six months (MCF: 10%). It was assumed that cow manure in the meadow period does not emit methane (MCF: 0%). For sheep, goats and poultry waste an MCF of 10% was assumed.

A correction for the amount of covered silos could not as yet be made. More information is needed about the actual emissions. See Table 3.8 for results.

Table 3.8 Methane emissions (kton CH₄ a⁻¹) from manure in the Netherlands

	1970	1975	1980	1984	1986	1988	1990	1992
Cattle	23	25	27	27	29	30	31	31
dairy	20	22	24	25	23	19	19	19
beef	3	3	3	5	6	11	12	12
Sheep/Goats	NE	NE	NE	NE	NE	4	6	6
Pigs	27	37	44	48	57	58	60	50
Poultry	5	5	7	9	10	10	10	10
TOTAL	53	67	78	86	96	102	106	97

NE = not estimated due to lack of available data on activity

Landfills

The availability of sufficient data allows for the application of the second, detailed IPCC methodology to the whole of the Netherlands: a first-order kinetic model (OECD, 1991). Detailed information on landfilling for several years is available (SVA, 1973; CBS, 1988; CBS, 1989a; Nagelhout *et al.*, 1989; Nagelhout and Ballerini, 1993). It is assumed that during the Second World War not much waste was dumped, with the massive dumping of waste starting after 1945. Data for the remaining years were obtained via inter- or extrapolation. With respect to waste composition, a degradable organic matter fraction of 18% before 1986, and 17% between 1986 and 1995 is assumed. After 1995 the fraction decreases. This is based on two developments. Firstly, organic fractions like paper and wood waste are increasingly recycled. Secondly, the separate collection of fruit and garden waste is assumed to result in an additional decrease of organic carbon content of landfills. A decrease of 5% per year dating from 1995 is assumed. The government is aiming at a zero organic matter content in landfills. In practice, a maximum content of degradable organic material of 5% for all landfilled fractions is expected by 2000 (Beker, pers. comm.). Table 3.9 gives the amount of landfilled waste, degradable carbon in the waste and the methane recovery over the years.

The emissions have been calculated using the equation for specific gas production:

$$\alpha = 0.8 k P_o e^{-kt}$$

- α = production in m³ waste gas (ton a⁻¹)
- P_o = concentration of degradable organic matter in kg t⁻¹ refuse
- 0.8 = fraction that actually degrades
- k = degradation rate coefficient (0.1 a⁻¹)
- t = time after landfilling (year)

Source: Hoeks, 1983; Hoeks and Oosthoek, 1981

Current production potential of waste gas from material dumped in the past is accounted for by integrating the production potential over time. So far, waste gas potential and not methane emission is considered.

Table 3.9 Total landfilled waste, total organic carbon and total methane recovered in the Netherlands

Year	Landfilled waste	Organic carbon content	Methane production	Methane recovery	Methane emission	Uncertainty in emission estimate
	x100 kton a ⁻¹	kton C	kton CH ₄ a ⁻¹	kton CH ₄ a ⁻¹	kton CH ₄ a ⁻¹	
1950	12	2	8	0	8	50%
1955	23	4	31	0	31	50%
1960	35	6	63	0	63	50%
1965	47	8	100	0	100	50%
1970	59	11	141	0	141	50%
1975	83	15	192	0	192	50%
1980	106	19	260	0	260	50%
1985	130	23	341	18	323	50%
1990	139	24	420	43*	377	50%
1991					375	50%
1992					373	50%

*Expected recovery: 25% of potential; in 1991 actually only 26 kton was recovered (Oonk, 1993). The Landfill Gas Advisory Centre aims at 185 million m³ landfill gas (67 kton in 1995) (Annual report, 1992). 1 m³ landfill gas = 0.5 m³ CH₄ = 0.5 x 0.714 kg CH₄.

TNO measured actual methane emissions at three landfill sites (Verschut *et al.*, 1991). They calculated a mean degradation coefficient k based on their measurements of 0.1 a⁻¹. This means that half of the organic matter is degraded in seven years. This is about twice the rate related in Van den Born *et al.* (1991), and more in accordance with other literature findings on biogas formation (Scheepers, 1991). Based on this information a mean k factor of 0.1 a⁻¹ is used for the years 1945 to 1995.

Furthermore, to estimate the current emission, an oxidation percentage in the soil cover of 20% and a methane concentration of 50% waste gas are assumed. An uncertainty range of 50% around the mean must be expected because of the variability in circumstances in individual landfills. The emission of methane in 1990 is estimated at 377 kton a⁻¹. For 1991 and 1992 this amount is slightly lower. In 1995 370 kton a⁻¹ is expected. The actual government policy is aimed at reducing the amount of waste landfilled. According to *National Environmental Outlook 2* (RIVM, 1992) in the year 2000, 6 million tons of waste will still be landfilled (Nagelhout and Van Lohuizen, 1992). By then this waste will contain practically no degradable organic carbon because of recycling organic wastes (paper and wood) and separate collection of garden, fruit and kitchen (GFK) waste. In our model the degradable organic carbon content (Po) therefore decreases to about 5% between 1995 and 2000.

Government policy is also aimed at cost-effective landfill gas recovery. The action programme of NOVEM, which coordinates landfill gas recovery investments in the Netherlands, aims at

recovering 185 million m³ landfill gas in 1995 (NOVEM, 1991). This equals 67 kton CH₄ in 1995, or about 25% of the potential gas production. The NOVEM aim (25%) is assumed to be attainable with existing policies. In 1991, 74 million m³ of landfill gas was recovered; this equals 26 kton CH₄ (Oonk, 1993). Additional policies, with some extra cost-effective measures, are considered necessary to attain a 50% recovery; 90% of landfill gas may be recoverable after 2000 if the legislation on dumping ("Stortbesluit") requires impermeable top-lining systems and if new technology is applied. In practice less than 90% may be recovered in each landfill because of problems with the system and late project starts.

Waste gas recovery is a cost-effective measure to mitigate methane emissions. Compared to earlier estimates of Van den Born et al. (1991) more gas is formed in a shorter period of time. Investments in waste-gas recovery are therefore especially relevant in the period up to 2000. An advisory centre for waste-gas recovery has therefore been set up under the NOVEM programme to stimulate investments in recovery techniques (NOVEM, 1991). To date, waste-gas recovery projects have started after (part of) the landfill was covered with a layer of soil. The new "Stortbesluit" in which gas recovery or flares are made obligatory after closure of the landfill may need reconsideration. Landfill gas recovery in a compartment obviously has to start from the very beginning, even if it is still unstable, settling and open. New techniques, like temporary covers and gas recovery at the base of a landfill or landfill compartment, may be needed.

As organic fractions are increasingly recycled or collected separately, landfill gas may be a diminishing source, leading to consideration of alternatives like controlled fermenting of organic waste.

Wetlands

The national estimate of methane emissions from changes in wetland areas is based on the change in surface area of different ecosystems and groundwater classes, and on emission factors based on Aselmann and Crutzen (1989) and Moore and Knowles (1989). A summary for the situation in 1950 and 1990 is given in Table 3.10.

The change in methane emissions resulting from an increased surface water pollution between 1950 and 1990 is not taken into account.

Table 3.10 Methane emissions change in the Netherlands between 1950 and 1990 from drainage of wetlands

Wetlands	Area km ²		Emission factor kg CH ₄ /km ² a ⁻¹		Emission kton a ⁻¹	
	1950	1990	low	high	1950	1990
Wet organic soils	2000	373	29200	73000	58-146	11-27
Drained organic soils	0	1500	3650	36500	0	5-55
Inland and coastal waters	3400	3400	7300	18250	25-62	25-62
Small bodies of water	200	140	29200	73000	6-15	4-10
TOTAL					89-223	45-154

Methane uptake in forest soils

A very rough estimate of methane uptake through the years can be made using the methane uptake factor of Crill (1991) from the literature on temperate forests. The CBS (1989b) has provided data on the extent of the forest over the period 1940 to 1983. The forest area has grown slightly in the Netherlands since 1900. The results are summarized in Table 3.11.

Table 3.11 Methane uptake in forest soils in the Netherlands

Extent forest cover	Methane uptake factor (10^4 mg ha ⁻¹ a ⁻¹)	Methane uptake (kton a ⁻¹)
1938-1942: 250,000 ha	578-616	1.4-1.5
1952-1963: 260,000 ha	578-616	1.5-1.6
1964-1968: 299,000 ha	578-616	1.7-1.8
1980-1983: 334,000 ha	578-616	1.9-2.1

Conclusion

The sink capacity of the forest in the Netherlands is very small as compared to the strength of the sources.

3.3. Comparison with IPCC methodology

Enteric fermentation

The estimate for the Netherlands is based on a differentiation of animal categories. Values for feeding level were calculated using default values for net energy use at maintenance level for the Dutch situation. An uncertainty range of 15% is assumed for these estimates. In the chosen period methane emissions from dairy cattle are decreasing because of decreasing animal numbers. Beef cattle is increasing. These trends reflect the results of existing European policies to reduce the milk surplus.

Animal waste

In many cases data do not exist to confirm methane emission estimates from animal waste. The need to make assumptions adds to the uncertainty in the estimates. A comprehensive field measurement programme is needed to improve the basis for the MCF estimates. Even the new lower IPCC emission factors have led to results in the Netherlands which are much higher than earlier estimates.

Landfills

The IPCC second methodology was followed both in this and in earlier estimates. The difference in outcome between the two estimates is due to a different assumption with respect to the breakdown time of organic material (0.1 a⁻¹ instead of 0.0365 a⁻¹). Methane emissions from landfills are now believed to be higher and take place earlier than originally thought. Landfill gas recovery, an important option for reducing methane emissions, will be pursued in due course; this is because landfill gas formation after 2000 will diminish rapidly due to the increase in recycling and separate collection of organic waste.

Wetlands

As no IPCC method exists for wetland emissions or an emission change from wetland drainage, no

comparison could be made. As a result of drainage about 40-70 kton less methane is emitted in 1990 compared to 1950. This source is not likely to be intentionally managed to control methane emissions. On the contrary, it is expected that measures against desiccation will slightly increase the wetland area up to 2000. Expansion of natural wetland areas in the Netherlands may reverse the trend in methane emissions from this source.

Forest soils

An IPCC method for methane consumption in forest soils, a minor sink in the Netherlands, is non-existent.

3.4. Baseline projection

Introduction

The baseline projection is constructed from the European Renaissance scenario with high energy prices as described in National Environmental Outlook 3 (RIVM, 1993a), and the update as described in the study on the Environmental Effects of the Second Environmental Policy Plan (RIVM, 1993b). All measures that will come into force before 1 January 1995 are part of the baseline projection. The assumptions on the economic developments under the European Renaissance scenario with high energy prices have already been described in the section on carbon dioxide. Details are described under the sectors below.

Gas

Emissions of methane from the gas systems are a function of the energy demand, production, energy efficiency and emission per unit product. Emissions can be reduced either by reducing the demand for oil and gas, or by reducing the emission per unit product. The future demand for oil and gas and the technical options available to reduce leaking will determine the future emissions and reduction potentials.

Development of gas consumption

In both Global Shift and European Renaissance we expect a constant natural gas production, export and import until 2010. The volumes given by the Gasunie (1992) are taken as a "no additional policies scenario" for the period up to 2015. The Gasunie expects a domestic demand of between 40 and 45 x 10⁹ m³ a⁻¹, depending on economic developments and weather conditions during winter for the coming 25 years. It also expects an increase of exports to a level of about 40 x 10⁹ m³ a⁻¹ up to 2015 (Gasunie, 1992). Exports were 28, 33 and 38.6 x 10⁹ m³ in 1988, 1989 and 1991, respectively (CBS, 1991; Gasunie, 1992). Domestic demand has been between 40 and 45 x 10⁹ m³ in the years since 1980 (CBS, 1991).

Emissions

The emission calculations for the period 1980-2015 are based on the above assumptions and assuming that no extra technical measures are taken as a response to climate change. Total emissions from the natural gas sector, excluding end use, are estimated at 130 kton a⁻¹ in 2000 and 2010 under this current policy scenario.

Enteric fermentation

Emissions of methane from enteric fermentation are a function of the demand for meat and milk, the efficiency of the production and the emissions per unit product. Emissions are reduced by

addressing the surpluses in meat and milk, or by tackling the Dutch manure problem. Measures lead to reduced animal numbers. Emissions can also be reduced by an increase in the efficiency of the production; this means a reduction of emissions per unit of product.

Demand

There is a surplus of milk, meat and other products in the European Community. In 1991 the European Commission developed a plan to revise the Common Agricultural Policy of the EC known as the MacSharry plan. The MacSharry plan will result in drastic reductions of price guarantees for wheat and feeds. Feeding costs for livestock will consequently drop. It is expected that more European grain will replace the cheaper imported feeds from outside the European Community. The plan proposes to reduce price guarantees for milk and meat. Compensation will only be paid to farmers who use predominantly roughage to feed their herds. This will probably increase the methane emission per animal.

Existing policies have already affected animal numbers during the past years. The milk-quota instrument proved to be very effective in reducing the milk surplus and dairy cattle numbers. This trend is shown in the Dutch herd statistics up to 1992. A slight compensating effect is also noticeable in the growing beef cattle numbers. It is expected that the increase of beef cattle and suckling cows will accelerate. Ewe premiums have resulted in growing numbers of sheep in the Netherlands during the last few years. This will level off in the near future, as these premiums are restricted to a limited number of ewes. It is anticipated that the balance of all these trends will be a reduction in ruminant numbers and a slight increase in methane emissions per animal.

Recent update of current policies

There is an important side effect of the manure policy measures described in the "Policy Document of Third Phase Manure and Ammonia Policy" (Ministries of Agriculture, Nature Management and Fisheries and of Housing, Physical Planning and Environment, 1993). To reduce the manure surplus and ammonia deposition by 2000, bringing more phosphate on the land than is taken up by the crops will not be allowed. The extra costs lead to reduced animal numbers. The update of the current policies scenario of Environmental Outlook 3 with resulting animal numbers is given in Table 3.12. Methane emissions under the updated current policies scenario are given in Table 3.13.

The effects of the manure measures lead to a methane emission reduction of 35 kton a⁻¹ in enteric fermentation compared to the Outlook 3 scenarios. In 2010 this is 67 kton a⁻¹.

Emissions

Three institutes in the Netherlands, the Central Planning Bureau (CPB), the Agricultural Economics Research Institute (LEI) and the Research Foundation for Foodsecurity (SOW), have assessed the longer term effects of the MacSharry plan on agriculture in the Netherlands. No differences were found between the methane emissions under both National Environmental Outlook 3 scenarios (European Renaissance/Global Shift). Table 3.12 presents the differences in animal numbers between the original NEO3 scenario and the updated NEO3 scenario. Table 3.13 presents the differences in methane emissions of these scenarios. Figure 3.1 presents the resulting methane emissions in both animals and animal waste.

Table 3.12 Number of ruminants under the National Environmental Outlook 3 agriculture (ER/GS) current policies scenario and under the updated NEO3 scenario (2000a and 2010a)

Type	Subtype	2000 (x 000)	2000a	2010	2010a	
Cattle	dairy	young <1 year	633	618	571	471
		young female >1	681	664	614	506
	beef	female	1569	1530	1416	1396
		male >1	33	33	30	30
		calves	496	496	496	496
		young	661	462	677	387
Sheep	female >2	259	181	435	250	
	male	13	13	10	10	
	female	539	539	402	402	
Goats	fattened lamb	614	614	459	459	
	male	26	26	26	26	
Pigs	female	35	35	35	35	
		14004	10983	14004	8512	
Horses		101	101	101	101	

Table 3.13 Methane emission of enteric fermentation under the current policies scenario of Environmental Outlook 3 of the Netherlands and under the updated NEO3 scenario (2000a and 2010a) (kton a⁻¹)

Type	Subtype	Emission factor kg/head a ⁻¹	2000 kton a ⁻¹	2000a	2010	2010a	
Cattle	dairy	young <1	49.25	31	30	28	23
		young female >1	62.80	43	42	39	32
	beef	female	102.13	160	156	145	143
		male >1	93.22	3	3	3	3
		calves	17.65	9	9	9	9
		young	87.01	57	40	59	34
		female >2	102.13	26	18	44	26
		male	8.00	0	0	0	0
		female	8.00	4	4	3	3
		fattened lamb	4.00	2	2	2	2
Pigs	male	8.00	0	0	0	0	
	female	8.00	0	0	0	0	
Horses		1.50	21	16	21	13	
		18.00	2	2	2	2	
TOTAL			360	325	355	288	

Animal waste

Emission of methane from manure is a function of animal numbers, manure production per animal, composition of the manure, emissions per manure handling system, storage capacity per system and technical measures to utilize the biogas from small and large-scale digesters. Methane emissions from manure will decrease as manure is stored in silos outside the stable or collected in advanced digesters.

Manure production

The manure production in the Netherlands is summarized in Table 3.14. The calculations are based on animal numbers and production of manure per animal using the Agriculture Scenario of National Environmental Outlook 3 (ER/GS).

Table 3.14 Manure production (10⁶ ton slurry) in the Netherlands, Environmental Outlook 3 scenario 1993-2015

Manure from:	1994	1995	2000	2010	2015
Cattle	49.1	48.9	44.2	40.7	40.7
organic waste in stable	19.64	19.56	17.68	16.28	16.28
organic waste in meadow	29.46	29.34	26.52	24.42	24.42
Fattening steers	3	3	3	3	3
Fattening calves	1.8	1.7	1.7	1.7	1.7
Sheep and goats	2	2	2	2	2
Pigs	16.6	16.2	13.7	14.2	14.2
Poultry (dry)	0.7	0.8	0.9	0.9	0.9
Poultry (slurry)	1.4	1.0	0.4	0.3	0.3

Table 3.15 Methane emissions from animal waste in the Netherlands, scenario of Environmental Outlook 3

Methane from animal waste from:	1994 (kton a ⁻¹)	1995	2000	2010	2015
Cattle					
of which in stable	14	14	12	11	11
of which in meadow	0	0	0	0	0
Fattening steers	8	8	8	8	8
Fattening calves	5	4	4	4	4
Sheep and goats	6	6	6	6	6
Pigs	50	49	41	43	43
Poultry (dry)	3	3	4	4	4
Poultry (slurry)	6	4	2	1	1
TOTAL	90	88	77	77	77

Future methane emissions are calculated from production data and storage assumptions using the method from Casada and Safley (1990), but with lower emission factors, as discussed earlier. The results are summarized in Table 3.15. The calculated emissions are provisional and considered

maximum values until more measurements of actual emissions are carried out.

Current policies (update of Environmental Outlook 3)

The manure measures result in lower animal numbers. This results in a reduction of methane emissions from manure from 77 kton a⁻¹ in 2000 to 65 kton a⁻¹ in 2000, thus a reduction of 12 kton a⁻¹ in 2000. This effect is the same in 2010. The total effect of the manure measures in agriculture is a reduction of 48 kton a⁻¹ in 2000 and 78 kton a⁻¹ in 2010. See Figure 3.1.

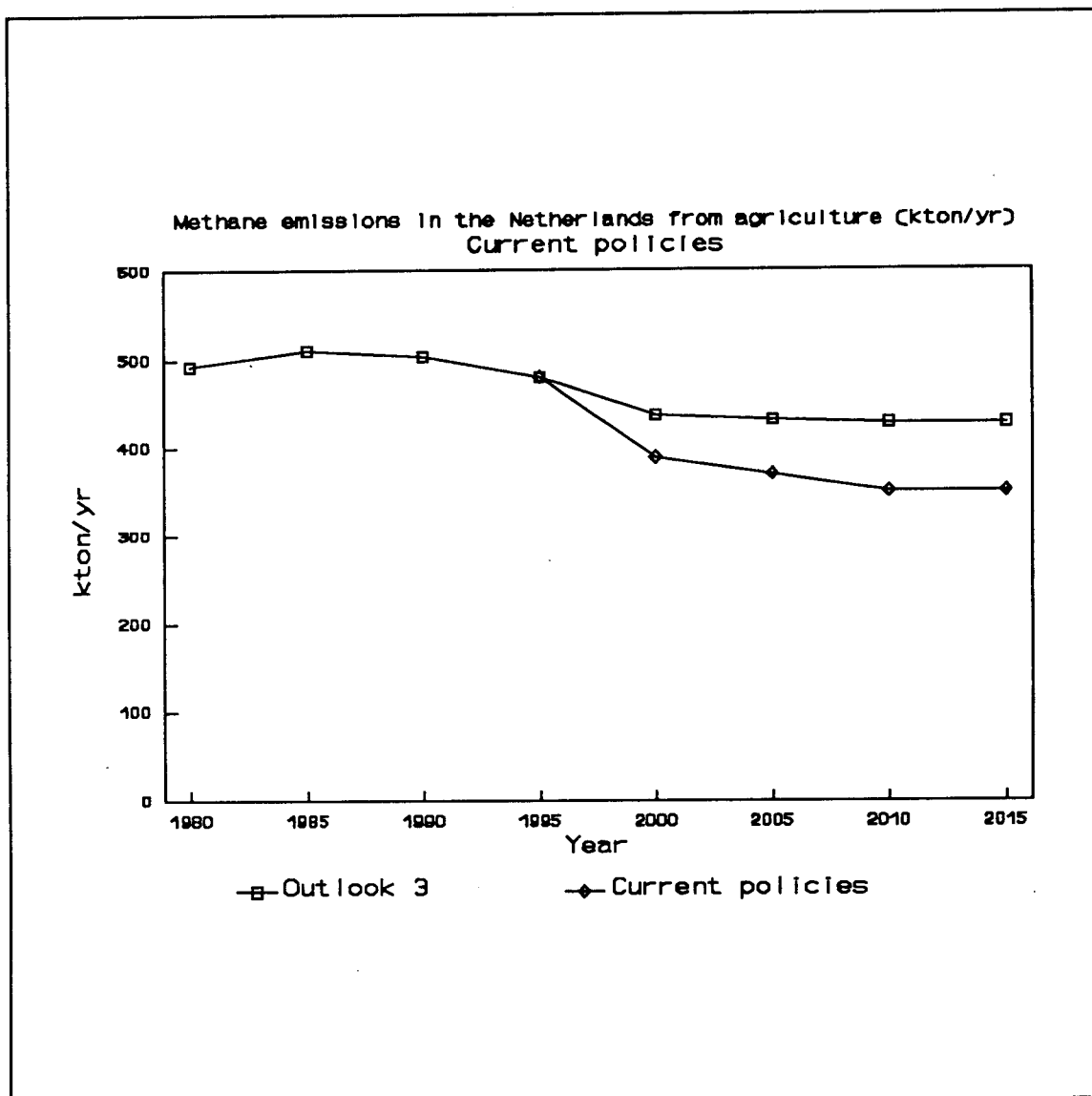


Figure 3.1 Methane emissions in agriculture in the Netherlands.

Landfills

In the Netherlands Second National Environmental Policy Plan the main aims are waste prevention, improvement of the waste disposal structure and stimulation of recycling. Landfilling should be kept to a minimum. Emissions of methane from landfills are a function of the amount of waste landfilled, the composition of the waste, the actual processes in the landfills and the age of the

waste tips. All of these are changing as more waste is collected separately and treated differently. Because of prevention and recycling being stimulated now, less waste will be landfilled in the near future. The garden, fruit and kitchen (GFK) waste will be collected separately and composted, or eventually fermented with biogas recovery.

To evaluate the effects of different waste prevention programmes on methane emissions from landfills, we formulated landfilling scenarios up to 2050. Nagelhout and Lohuizen (1992) have made a prognosis for waste disposal in the Netherlands for National Environmental Outlook 3 for the period 1990-2015. They expect that after prevention and recycling, and the incineration of unusable products, a total of 6 million tons will be left to be landfilled in 2000. When the degradable organic carbon content of this waste was assessed, it was found that this waste still contained about 5% degradable organic carbon, mainly from paper and wood waste. To calculate the methane emissions from landfills, the *k* factor in our model was set at 0.1 for the period 1945-1995 and at 0.0365 from 1995-2050 to account for the residual enrichment in the waste of paper and wood with a mean degradation half-lifetime of 20 years (half of the material degraded in 20 years).

Current policies scenario

In the National Environmental Outlook 3 scenario taken for the development of the amount of waste, we assumed a 10% per year decrease in landfilling from 1990 due to prevention, recycling and the increase in capacity for incinerating waste. We assumed a 5% per year decrease in degradable organic carbon in the landfilled waste because of separate collection of GFK waste (interpretation of data from Nagelhout and Lohuizen, 1992). A waste gas recovery of 25% of the potential production is assumed. The result of this scenario together with the additional policy scenario is given in Figure 3.3.

This figure and Table 3.16 show that the average methane emissions decrease from 377 kton in 1990 to 257 kton in 2000, 124 kton in 2010 and 87 kton in 2015.

3.5 Projection of additional policy

Gas

In the Netherlands the emission of methane in natural gas production is important due to the large gas production activities. Offshore natural gas production is responsible for the larger part of these emissions. Offshore fields only produce 25% of the total natural gas production in the Netherlands, but are responsible for 80% of emissions. The reason is that offshore excess natural gas is mainly vented and onshore flaring is practised. In the distribution system leak repair can reduce the emissions. Modernization of old cast-iron systems is an expensive measure. This measure may be less expensive if only leak repair is intensified.

The following measures are additional, in study. Total reductions of 52 kton a⁻¹ are possible in 2000 (RIVM, 1994). The reduction scenarios are given in Figure 3.2. These measures have not been agreed upon in the NEPP-2.

1. Increased gas use on platforms offshore during gas production

Gas otherwise vented at offshore gas platforms in the North Sea is increasingly used, requiring necessary, however, cost-effective investments on the platforms. If another system is installed for gas condensate measurement, less gas will have to be vented. The effect in 2010 is an emission reduction of 21 kton a⁻¹ compared to the emission in 2010 under the current policies scenario.

2. Further increased gas use on offshore platforms during gas production
 Gas will be desorbed from the condensate and fed in the mainstream. This way an emission reduction of 31 kton a⁻¹ can be realized in 2010 compared to the current policies scenario.

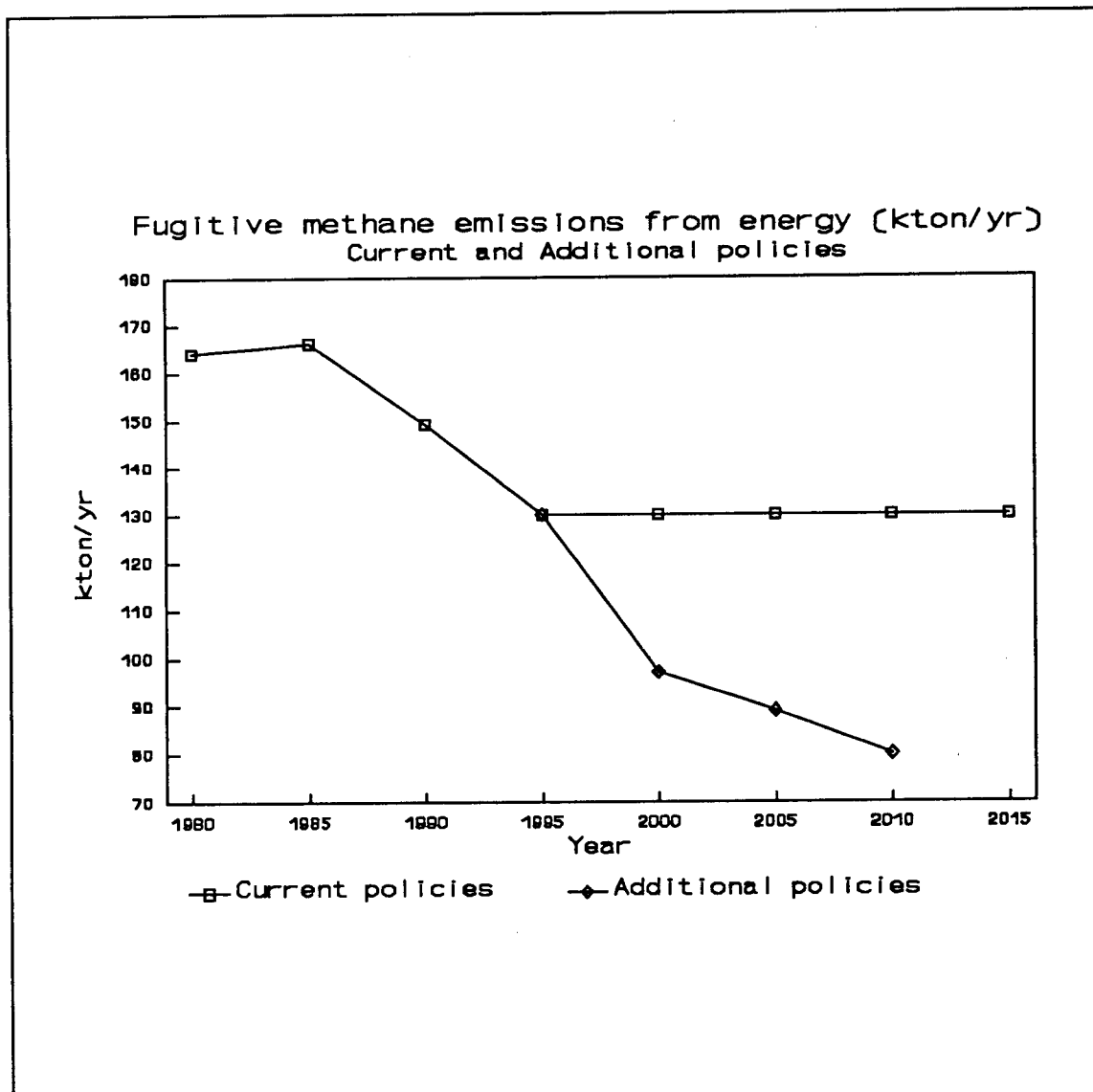


Figure 3.2 Fugitive methane emissions in energy, additional policies in study.

Landfills

In the earlier scenarios, emissions of methane are either stable or increase up to 1995. The most cost-effective method of abatement is waste gas recovery. In the current policy scenario 25% of waste gas recovery is assumed. In the additional policies scenario 50% waste gas recovery—about the economic maximum—is expected. NOVEM made a waste gas recovery plan for the time up to 1995. In 1990 only 70 million m³ waste gas was recovered. NOVEM is expecting a potential production of 540-840 million m³ a⁻¹ between 1992 and 2000. They expect 50% of this amount (270-420 million m³ a⁻¹) to be recoverable. In 1995 the NOVEM expects to recover 185 million m³ waste gas per year. This equals 140 Mm³ natural gas equivalents (0.58 kg methane); these are still

seen as minor amounts of total gas.

Table 3.16 shows that emissions in the current policies scenario decrease from 377 kton in 1990 to 257 kton in 2000 and 124 kton in 2010. In the additional policies scenario emissions decrease from 377 kton in 1990 to 227 kton in 2000 and 109 kton in 2010. In 2000 this is a 30-kton difference using the current policies scenario. Figure 3.3 gives the results.

Realizing a 50% methane recovery necessitates sophisticated technical means to fully recover the methane potential in the waste. This implies a temporary impermeable cover of the waste and methane recovery from the early stages of the dumping. If this can be realized, an extra waste-gas recovery of 30 kton a⁻¹ in 2000 and an extra recovery of 15 kton in 2010 would result.

Table 3.16 Methane emissions (kton a⁻¹) from landfills according to the different scenarios

Year	Current policies		Additional policies	
	Emissions	Recovery	Emissions	Recovery
1980	260	0	260	0
1985	323	18	323	18
1990	377	43	377	43
2000	257	37	227	74
2010	124	19	109	38

In all scenarios garden, fruit and kitchen (GFK) waste is collected separately. It is assumed that eventually most of this waste can be fermented/gasified in a controlled way to make best use of the (bio)gas potential. Possibly more organic waste categories could be fermented. This way the paper and wood fraction could also be utilized for gas production.

Conclusions

In Figure 3.3 a summary is given of the methane emissions from landfills in the Netherlands under current and additional policies. There is not much extra reduction achieved with the additional policies. The emission reduction is mainly driven by the policies to reduce landfilling. Waste gas recovery can be much more profitable in controlled closed systems with separately collected organic waste because most gas leaks away from landfills.

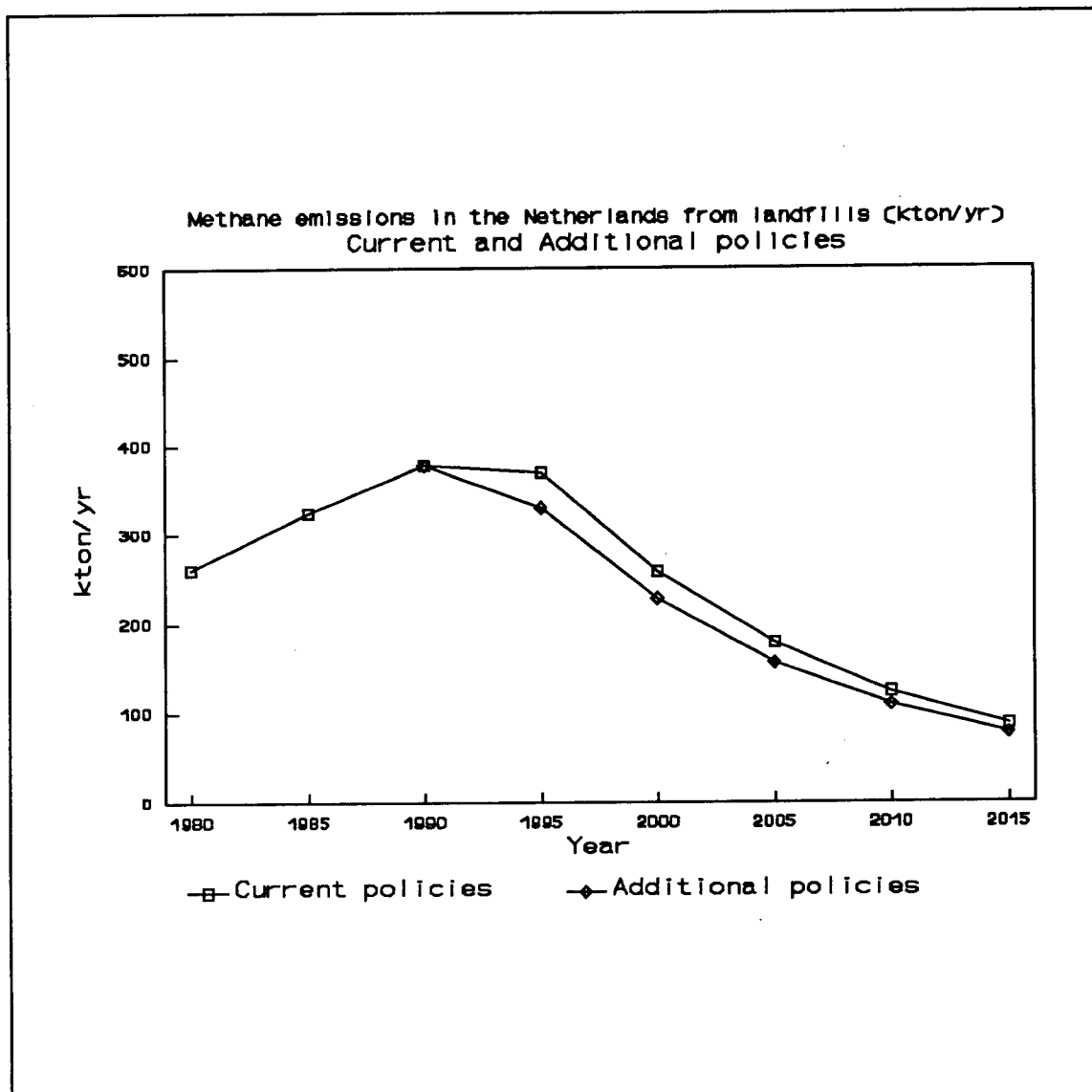


Figure 3.3 Methane emissions from landfills in the Netherlands.

3.6 Overall conclusions

Methane emission reductions of ca. 240 kton are expected between 1990 and 2000, and of ca. 170 kton between 2000 and 2015 with no extra climate policies. This is expected as a result of policies to reduce landfilling, acid deposition and the manure surplus. With additional policies especially developed for methane reductions an extra ca. 90 kton a⁻¹ can be mitigated in 2000 and an extra 80 kton a⁻¹ in 2010. If other policies fail, methane reductions are not expected to be large. In Table 3.17 the results of the current policies and the additional policies scenario are summarized. Background natural emissions from wetlands and (small) bodies of water are not considered in the national total emissions but given for reasons of comparison here.

Table 3.17 Methane emissions in the Netherlands, with and without additional policies (kton CH₄ a⁻¹)

Methane emissions	Baseline		Additional policies						
	1980	1985	1990	1991	1992 ¹	2000	2010	2000	2010
Gas production	65	58	52	60	60	52	52	19	5
Gas transportation	9	8	6	8	8	6	6	6	6
Gas distribution	83	80	72	84	80	72	72	72	72
Oil production	7	20	19	17	17	0	0	0	0
Energy	164	166	149	169	165	130	130	97	83
Animals	416	421	402	412	401	327	290	327	290
Animal waste	78	91	106	100	97	77	77	65	65
Agriculture	494	512	508	512	498	402	365	390	353
Landfills	260	323	377	375	373	257	124	223	105
(Sewage) water treatment	5	5	5	5	5	5	5	5	5
Combustion	28	28	28	28	28	26	24	26	24
Other	33	33	33	33	33	31	29	31	29
TOTAL	951	1034	1067	1089	1069	820	648	741	570
Natural wetlands and water	121	121	121	121	121	121	121	121	121

¹ In the Annual Emissions Report 1994 of RIVM/TNO/CBS different values are given for 1992. The differences are a result of different methods.

4. NITROUS OXIDE

4.1 Introduction

The atmospheric concentration of nitrous oxide (N_2O) has increased since preindustrial times by 8% to 310 ppbv (Watson et al., 1992). The current annual increase amounts to 0.25 - 0.31% (Prinn et al., 1990). Because of its relatively long atmospheric lifetime of 130 (110 - 168) years and relatively strong radiation absorption per molecule, the Global Warming Potential of N_2O is 270 times as large as that of carbon dioxide (direct GWP over 100 years; Isaksen et al., 1992). About 6% of the radiative forcing during the 1980s was caused by N_2O (Shine et al., 1990). Nitrous oxide is chemically inert in the troposphere. In the stratosphere, on the other hand, N_2O is broken down, partly by photolysis, partly by $O(^1D)$. The latter process may result in NO production, which is an important intermediate in stratospheric ozone destruction. Thus elevated concentrations of N_2O contribute both to the enhancement of the greenhouse effect and the stratospheric ozone depletion.

Worldwide emissions of N_2O are relatively poorly understood. The total budget can be best estimated based on the stratospheric sink and the observed increase in atmospheric concentrations. Global emissions amount to about 13 Tg N_2O -N a^{-1} , about 70% of which originate from natural (undisturbed) emissions. About 30% of the global emissions are the result of human activities (Watson et al., 1992; Khalil and Rasmussen, 1992). In the Netherlands virtually all emissions are anthropogenic (Van den Born et al., 1991).

Table 4.1 summarizes estimated N_2O emissions from the Netherlands (in kton N_2O a^{-1}) for the period 1980 - 2015. Even though the number of identified sources has increased since a previous inventory of Dutch emissions (Van den Born et al., 1991), the present study may not cover all sources of N_2O for two reasons. Firstly, a number of known sources is presently not yet quantifiable. Secondly, there may still be unidentified anthropogenic sources of N_2O .

4.2 Emissions

Emission factors

The overall uncertainty in emission factors is high. It could range from 50 to 100%, depending on the source (Van den Born et al., 1991; Spoelstra, 1993; De Soete, 1993; Olivier, 1993). Nevertheless, the uncertainty with regard to a number of sources has decreased considerably since Van den Born et al. (1991). We can make better estimates, especially for N_2O emissions from fossil fuel use.

Energy

Nitrous oxide is produced during fossil fuel combustion in several ways. Production takes place during the burning process itself, and atmospheric deposition of nitrogen oxides (NO and NO_2) can result in enhanced N_2O biogenic emissions from soils and oceans. N_2O production in the atmosphere, for instance, around high voltage emission lines or in NO_x polluted air also might occur. The present inventory only takes into account direct N_2O formation during the burning process. Table 4.1 shows that four different sectors for fossil fuel use are distinguished: energy, industry, commercial and residential, and transport.

The emission factors used for fossil fuel-related N_2O emissions from stationary sources have been adopted from De Soete, 1993; (Table 4.2). These are somewhat higher than those reported by

Spoelstra (1993), who estimated that Dutch N₂O emissions from stationary fossil fuel burning and waste-burning plants are 0.06 - 0.19 kton N₂O-N a⁻¹. This is at the lower end of the range, according to De Soete (1993). Spoelstra's emission factors cover fewer sources than those of De Soete, and are not expressed in the units of emission factors needed to calculate emissions. Therefore these are less useful for the present inventory.

The emission factors used for N₂O emissions from stationary combustion do not include the possible impact of catalytic NO_x reduction. In vehicles, catalytic NO_x reduction is known to increase N₂O production. The significance of this process in stationary combustion is, however, not known. It is therefore assumed here that in stationary sources denox installations do not affect N₂O emissions.

Transport

For combustion in mobile sources too, only direct emissions of N₂O taking place during the burning of fossil fuels are considered in the present inventory. Emission factors used are from Baas (1991) (Table 4.3). Baas distinguishes diesel vehicles and petrol/LPG vehicles without catalytic converters and vehicles with (several types of) catalytic converters of various ages. It is assumed here that in 1980 and 1985 there were no catalytic-converter equipped petrol/LPG cars. For 1990 the number of kilometres driven by petrol/LPG vehicles is a mixture of kilometres driven in vehicles with or without, new or old, closed- or open-loop catalytic converters. The emission factors used for 1991/92 are assumed equal to those of 1990. This may be a good assumption for 1991. In 1992, however, the number of old catalytic converters emitting considerably more N₂O than new catalytic converters has increased in relation to 1990/91 (Thomas, 1993). Therefore the number of N₂O emissions for 1992 are underestimated. For the years from 2000 on it is assumed that all vehicles are catalytic-converter equipped, and that 85% of the vehicle kilometres are performed by vehicles having old catalytic converters.

Industry

This category includes direct emissions of N₂O from industrial processes, excluding those due to energy use. Several industrial processes can result in N₂O emissions, but for most processes, emission factors are not known, not even as a broad uncertainty range (Olivier, 1993b). Two relatively well-known sources are the production of adipic acid (mainly for nylon 6,6 manufacturing) and nitric acid (mainly for synthetic nitrogen fertilizer). In the Netherlands, no production of adipic acid takes place. Emissions of N₂O during nitric oxide production are estimated as 17 (7 - 27) g N₂O-N kg⁻¹ HNO₃-N (Olivier, 1993; De Soete, 1993). In the Dutch Emission Registration system another industrial activity has been identified as a source of N₂O emissions (VROM, 1990).

Waste incineration

Incineration of domestic waste can be a source of N₂O. Spoelstra (1993) reports an emission factor of 12.7 g N₂O-N per ton domestic waste. This factor is used here for all waste categories, although uncertainties exist about N₂O production during burning of non-domestic wastes. Since domestic waste is about half of the total amount of waste produced, the emission factor used here may be too high.

Agricultural and non-agricultural soils

In both natural, undisturbed and agricultural soils biogenic N₂O production takes place. Biogenic N₂O production may be enhanced after additions of nitrogen to soils, for instance by fertilization or atmospheric deposition. N₂O production may also occur during storage of livestock manure. Finally, atmospheric production of N₂O might occur in NH₃ polluted air.

Soil emissions of N_2O are calculated here following Bouwman and Van der Hoek (1991), who distinguish different types of land use and different soil types. Nitrogen input from both synthetic fertilizers and animal manure are considered. Emissions of N_2O from animal manure are estimated based on total nitrogen excretion by livestock, and no correction is made for NH_3 emissions. As a result, the calculated N_2O emissions must be considered to not only be caused by manure application to agricultural soils, but also by atmospheric deposition of volatilized ammonia. Since ammonium is deposited on both agricultural and non-agricultural soils, total N_2O emissions from soils are presented (Table 4.1). Natural (undisturbed) N_2O emissions from soils are estimated to be about 3 kton $N_2O a^{-1}$. This is sometimes called the "natural background" emission.

Some agricultural sources of N_2O are not considered in the present inventory because of lack of reliable data. For instance, N_2O production in agricultural soils may be affected by the mode of application of fertilizer (fertilizer injection vs. surface application; see also below). Similarly, some measures to reduce NH_3 emissions from animal manure (for instance, deep-litter stables or acid treatment of manure) may enhance N_2O production during storage of animal manure. Enhanced N_2O emissions from soils due to atmospheric deposition of NO_x have not been taken into account. And finally, atmospheric formation cannot be quantified at present.

Inland and coastal surface waters

Pollution of inland and coastal surface waters is a source of N_2O . Biogenic N_2O production may increase due to human activities as a result of elevated nitrogen inputs in waters. Elevated nitrogen concentrations in surface waters may be caused by, for instance, leaching of fertilizer nitrogen, atmospheric deposition of NO_x or NH_3 , and effluent from wastewater treatment plants.

Emissions of N_2O from surface waters are calculated according to Bouwman and Van der Hoek (1991). It is assumed that 20 (10 - 30)% of nitrogen input in inland surface water is denitrified. In addition, it is assumed that 75% of the nitrogen input in inland waters is transported to coastal waters, where 45 (40 - 50)% is denitrified. Related N_2O emissions are estimated as 5% of denitrified nitrogen. Thus the N_2O emissions presented here reflect the total of natural and anthropogenically induced emissions from surface waters. The "background" emission from unpolluted water is considered negligible.

Wastewater treatment

Wastewater treatment plants are a potential source of N_2O . When treatment of waste water includes (de)nitrification, part of the nitrogen in waste water may volatilize as N_2O . Emissions of N_2O from wastewater treatment plants are calculated here as 7.5 (5 - 10)% of the nitrogen removed (Bouwman and Van der Hoek, 1991).

Other sources of N_2O

As mentioned above, several known sources of N_2O have, due to lack of reliable emission factors, not been included in the present inventory. It is uncertain if inclusion of these neglected sources would result in a complete inventory of N_2O emissions. Although present knowledge on N_2O emissions is sufficient to explain the observed increase in atmospheric concentrations, the uncertainties in the strengths of known sources is too large to exclude the possibility of not yet identified significant sources.

Activity levels

Energy

Energy use for the years 1985 - 1992 have been taken from CBS (1991, 1992a, and 1992b) and corrected for temperature (Table 4.4). Future energy use, as assumed in the European Renaissance

scenario of the National Environmental Outlook 3 is used (RIVM, 1993).

Transport

Table 4.5 shows an overview of the assumed number of vehicle kilometres driven in the Netherlands and fuel use in off-road transport. The transport sector is the only one for which two different scenarios for future activities are used. In European Renaissance more vehicle kilometres are assumed to be driven than in Global Shift.

Industry

Annual production of nitric acid in the Netherlands is estimated as 545 ton N (Table 4.6). This estimate refers to the period 1985 - 1992 (Olivier, 1993; Duesmann et al., 1992). Nitric acid production in 1980 is assumed to be 440 kton N a⁻¹, based on CBS (1984/85). Future production is based on assumed growth in synthetic fertilizer production in the European Renaissance scenario of National Environmental Outlook 3 (RIVM, 1993). Thus for 2000, 2010 and 2015 nitric acid production is assumed to have increased 15%, 28%, and 33%, respectively, in relation to 1990.

Other industries identified as sources of N₂O in the Netherlands emitted an estimated 1.08 kton N₂O-N in 1990 (VROM, 1990). The assumed future increase of this source is based here on assumed growth of petrochemistry of the same European Renaissance scenario, implying a growth of 31%, 63% and 78% in 2000, 2010 and 2015, respectively, in relation to 1990.

Waste incineration

Between 1980 and 1990 the amount of waste incinerated has increased from 1900 to 3400 kton of waste per year (RIVM, 1993). The European Renaissance scenario of National Environmental Outlook 3 (RIVM, 1993) is used for future amounts of waste incinerated (Table 4.7).

Agricultural and non-agricultural soils

Agricultural land use, production of nitrogen in animal manure and synthetic fertilizer use are based on LEI / CBS (1992, 1993) for 1980 - 1992 (Table 4.8). The European Renaissance scenario of the National Environmental Outlook 3 (RIVM 1993) is used for projections.

Inland and coastal surface waters

Sources of nitrogen in waters are shown in Table 4.9. The leaching data for 1985 are based on the "Central" scenario taken from Kroes et al. (1990). Other 1985 data are have been adopted from CBS (1989). A category "other agricultural emissions" is based on Bouwman and Van der Hoek (1991). Most sources for 1990 - 2015 are based on the National Environmental Outlook 3 (RIVM, 1993) (Table 4.9).

Wastewater treatment

Nitrogen removal in wastewater treatment plants is estimated as the difference between nitrogen-influent and nitrogen-effluent (Table 4.10). In 1990, the influent was 73 kton N a⁻¹. For other years the 1990 influent is corrected for the Dutch population. For future years influent and effluent are taken from the European Renaissance scenario of the National Environmental Outlook 3 (RIVM, 1993). Effluent is shown in Table 4.9.

Emissions of N₂O between 1980 and 1990

Table 4.1 shows that between 1980 and 1990 the estimated Dutch emissions of N₂O show a slow increase to about 63 kton N₂O a⁻¹. Introduction of three-way catalytic convertors in cars appears to be the major cause of the increase in emissions. On the other hand, emissions of N₂O from soils have decreased since 1980 due to reduced use of synthetic fertilizers and a reduction in the

grassland area (Table 4.8).

Industrial emissions account for 26% of Dutch 1990 emissions. However, the estimates of nitric acid production and the corresponding emission factor are relatively uncertain. The industrial N₂O emissions presented in Table 4.1 are therefore tentative estimates.

4.3 Comparison with IPCC methodology

Table 4.12 compares N₂O emissions as calculated using two different methodologies. The emissions presented in the "National Communication" are adopted from RIVM's National Environmental Outlook 3 (RIVM, 1993), using the methodology as described above. This method differs from the draft IPCC methodology, as proposed in Amersfoort in 1992 (Van Amstel, 1993). In the following these differences are described.

Energy (excl. transport)

No difference.

Transport

Most default emission factors proposed by IPCC are somewhat higher than the factors used for National Environmental Outlook 3. The latter are based on Baas (1991).

Other industrial processes

The methods are the same for nitric acid and adipic acid production. The estimate of the National Environmental Outlook includes another industrial source based on the Dutch Emission Registration, which needs further investigation.

Waste

The IPCC method only includes waste incineration. In the National Environmental Outlook wastewater treatment plants are included as well.

Agriculture

IPCC proposes calculating N₂O emissions as 0.4% of the nitrogen input (fertilizer, manure and biological N₂ fixation) into soils. The 3.5 kton N₂O a⁻¹ in Table 4.12 is based on total fertilizer consumption in the Netherlands (412.4 kt N a⁻¹), total manure production corrected for NH₃ emission and export (585.2 kt N a⁻¹, of which 155.6 is emitted as NH₃, and 6 kton N is exported) and a category "other manure" (11 kt N a⁻¹). In addition, 15 kton of N is biologically fixed per year by legumes.

In National Environmental Outlook 3 soil emissions are calculated following the "country" approach of Bouwman and Van der Hoek (1991). The natural emissions are included (about 3 kton N₂O per year).

Other

In the National Environmental Outlook N₂O emissions from polluted surface waters are estimated to be 10.9 kt N₂O a⁻¹. These emissions are the result of anthropogenic nitrogen loading, mainly due

to leaching of fertilizers and manure used in agriculture.

Conclusion

The IPCC method results in lower emissions (25 kton N₂O per year) than the methodology of the National Environmental Outlook 3 (63 kt N₂O per year). The difference is partly caused by different emission factors used (in particular for agriculture). The most important reason for the difference however, is the fact that IPCC includes not all sources of N₂O. Most importantly, N₂O emissions as a result of nitrogen loading to surface waters, and wastewater treatment plants are not included in the IPCC methodology.

4.4 N₂O baseline projections

The Netherlands emissions for the National Environmental Outlook 3, European Renaissance scenario with high energy prices (RIVM, 1993), have been presented. For most sources it is assumed that the estimates for a Global Shift scenario with low energy prices are equal to those of the European Renaissance scenario; however, total emissions from transport in the Global Shift scenario are 1 kton lower in 2000.

Existing policy

In the Netherlands the aim is to stabilize N₂O emissions in 2000 at the 1990 level. A nitrous oxide action programme is in preparation. No measures have been defined yet to achieve this goal. However, existing policy can indirectly affect N₂O emissions in several ways. In the near future, both EU and Dutch agricultural policies may influence N₂O emissions from soils. Especially Dutch policy with regard to NH₃ emissions ("derde fase ammoniakbeleid") may affect N₂O emissions. Likewise, fossil-fuel related N₂O emission may be influenced by measures to reduce emissions of other nitrogen oxides (NO and NO₂). And policy measures for waste may affect emissions due to waste incineration and wastewater treatment.

N₂O emissions between 1990 and 2015

Total N₂O emissions continue to increase between 1990 and 2015 (Table 4.1). In 2015 estimated emissions from the Netherlands amount to 69.4 kton N₂O a⁻¹. This is 11% more than in 1990. Fossil sources are the main reason for emissions to increase.

Table 4.1 shows that emissions from fossil fuels, used for transport in particular, will increase considerably. By 2015 transport-related emissions may be 13.3 kton N₂O a⁻¹, which is an increase of about 130 - 150% relative to 1990, and 230 - 300% relative to 1980. This is mainly the result of the introduction and aging of three-way catalytic convertors in petrol- and LPG-fuelled vehicles, increasing estimated N₂O emissions per vehicle kilometre by a factor of 7 (Table 4.3). It should be noted here that the effects of denox facilities in stationary sources are neglected. Moreover, decreased N₂O emissions from soils, as a result of decreased deposition of NO_x, is not considered in the present inventory.

The estimated biogenic emissions decrease between 1990 and 2015. Table 4.1 shows that by 2015 soil emissions amount to 19.5 kton N₂O a⁻¹. This is 23% lower than in 1990. The reduction is caused by reductions in the fertilizer use, animal manure production and the grassland area. The Dutch production of animal manure is expected to decrease in the future. The estimated related emissions decline from 3.5 to 2.8 kton N₂O-N per year between 1990 and 2015. Also synthetic fertilizer use on agricultural soils is expected to decrease, resulting in related N₂O emissions

decreasing from 1.7 in 1990 to 0.4 kton N₂O-N in 2010 (Table 4.8).

A number of possible policy influences on soil emissions are not considered in the present inventory because of lack of knowledge on their exact effects. These involve the mode of fertilizer application to soils and storage of animal manure. For example, injection of animal manure into soils may cause higher N₂O emissions than surface application of similar amounts of nitrogen. Similarly, acid treatment of animal manure to reduce NH₃ emissions may promote N₂O production during storage. Also deep-litter stables are found to be potential sources of enhanced N₂O emissions. At present, the net effect of Dutch policy on N₂O emissions related to animal manure is not clear. On the one hand, decreased livestock numbers and low(er) nitrogen diets result in a decrease in nitrogen input in Dutch soils. On the other hand, N₂O emissions may increase due to different manure storage and mode of application of nitrogen to soils.

4.5 Conclusions

Dutch N₂O emissions are targeted to stabilize at the 1990 level by 2000 (VROM, 1991). The aim of the Dutch Government to stabilize N₂O emissions by 2000 at the revised 1990 level will not be met without additional policy. By 2015 emissions of N₂O are 11% higher than in 1990 (Table 4.1). The existing policy cannot prevent a net increase in N₂O emissions during the coming decades. The expected decrease in soil emissions is more than compensated by increased fossil emissions. Especially emissions from transport are found to increase due to the introduction of three-way catalytic convertors in cars.

The present inventory of Dutch N₂O emissions may be incomplete, and not all potential effects of existing policy on N₂O emissions can be quantified at present. Nevertheless, effects that are not taken into account here seem to increase N₂O emissions rather than decrease them for all years. Therefore a more complete inventory on Dutch N₂O emissions would probably not affect the conclusion that stabilization of Dutch emissions will not be realized without additional policy measures.

Table 4.1 Dutch N₂O emissions for the period 1985 - 2015 (European Renaissance scenario)

N ₂ O emissions in kton N ₂ O a ⁻¹	1980	1985	1990	1991	1992	2000	2010	2015
<i>Fossil sources</i> ²								
Fossil fuels:								
- Energy sector	0.4	0.4	0.5	0.4	0.4	0.4	0.5	0.5
- Industry	0.4	0.3	0.1	0.1	0.1	0.1	0.1	0.2
- Residential + commercial sector	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
- Transport	3.3	3.5	5.4	5.4	5.6	11.0	12.6	13.3
Industry (excl. energy)	13.6	16.4	16.4	16.4	16.4	19.1	21.6	22.6
Waste incineration	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2
<i>Total fossil sources</i>	17.9	20.8	22.5	22.5	22.8	30.9	35.1	36.9
<i>Biogenic sources</i> ²								
Agriculture and deposition on natural terrain*	26.1	26.4	25.1	25.3	24.9	20.7	19.7	19.5
Pollution of inland and coastal waters ¹	10.8	10.8	10.9	11.0	10.7	6.9	5.9	5.3
Wastewater treatment plants	4.0	4.0	4.0	4.2	4.5	6.8	7.4	7.7
<i>Total biogenic sources</i> *	40.9	41.2	40.0	40.6	40.1	34.4	33.0	32.5
<i>TOTAL fossil + biogenic sources</i> *	58.8	62.1	62.6	63.2	62.9	65.3	68.1	69.4

* Including about 3 kton N₂O as natural "background" emission

¹ Contributing sectors: agriculture, energy, transport, industry, households, etc.

² Emissions for 1992 can be different from a RIVM/TNO/CBS report on emissions in 1992, due to different methods.

Table 4.2 Emission factors (g N₂O-N/GJ) as used for fossil fuels (De Soete, 1993)

Fossil fuel	Emission factor
Natural gas	0.064
Coal	0.891
Oil	0.382

Table 4.3 Emission factors (g N₂O km⁻¹) as used for transport (Baas, 1991)

	Emission factors				
	1980 ¹	1985	1990	1991/92 ²	≥2000
Passenger cars					
- petrol	0.015	0.015	0.034	0.034	0.107
- diesel	0.031	0.031	0.031	0.031	0.031
- LPG	0.015	0.015	0.034	0.034	0.107
Freight vehicles					
- light-duty petrol	0.015	0.015	0.045	0.045	0.142
- light-duty diesel	0.031	0.031	0.031	0.031	0.031
- light-duty LPG	0.015	0.015	0.045	0.045	0.142
- heavy-duty trucks	0.200	0.200	0.200	0.200	0.200
- heavy-duty trailers	0.200	0.200	0.200	0.200	0.200
Special vehicles					
- petrol	0.015	0.015	0.045	0.045	0.142
- diesel	0.200	0.200	0.200	0.200	0.200
Buses (diesel)	0.200	0.200	0.200	0.200	0.200
Motor(ized bi)cycles					
- motorcycles	0.010	0.010	0.010	0.010	0.010
- mopeds	0.004	0.004	0.004	0.004	0.004
Water/rail etc. ⁴	0.69 ³	0.69 ³	0.69 ³	0.69 ³	0.69 ³

¹ Assumed to be the same as in 1985

² Assumed to be the same as in 1990

³ g N₂O kg⁻¹ fuel

⁴ And others as transport in agriculture, construction, services and a small category "other"

Table 4.4 Energy use excluding transport (PJ a⁻¹, unless mentioned otherwise) and related N₂O emissions (kton N₂O-N per year) as used for the European Renaissance and Global Shift scenarios

Sector	1980	1985	1990	1991	1992	2000	2010	2015
<i>Energy use¹</i>								
Energy sector								
- gas	211	328	262	306	324	205	291	305
- coal ²	90	163	250	227	225	189	277	270
- oil	364	121	1	1	1	0	0	0
Industry								
- gas (incl. CO gas) ³	393	397	366	384	350	478	529	492
- oil ³	376	282	83	70	98	23	20	19
- coal	72	93	35	31	34	43	48	77
Commercial								
- gas	663 ⁴	655 ⁴	302	310	325	402	388	374
- oil	126 ⁴	122 ⁴	44	45	51	53	56	58
Residential								
- gas			384	377	370	397	344	326
- oil			10	10	10	7	7	7
<i>N₂O emissions⁵</i>								
Energy sector								
- gas	0.013	0.021	0.017	0.019	0.021	0.013	0.019	0.019
- coal	0.080	0.145	0.223	0.202	0.200	0.168	0.247	0.241
- oil	0.139	0.046	0.000	0.000	0.000	0.000	0.000	0.000
- coal fluidized bed	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Industry								
- gas	0.025	0.025	0.023	0.022	0.022	0.030	0.034	0.031
- oil	0.144	0.108	0.032	0.027	0.037	0.009	0.008	0.007
- coal	0.064	0.083	0.034	0.028	0.030	0.038	0.043	0.069
Commercial								
- gas	0.042 ⁴	0.042 ⁴	0.019	0.020	0.021	0.026	0.025	0.024
- oil	0.048 ⁴	0.047 ⁴	0.017	0.017	0.019	0.020	0.021	0.022
Residential								
- gas			0.024	0.024	0.024	0.025	0.022	0.021
- oil			0.004	0.004	0.004	0.003	0.003	0.003

¹ Albers (1993); data for 1990/92 from CBS (1991, 1992a, 1992b) temperature corrected; for the years dating from 2000, based on European Renaissance scenario of the National Environmental Outlook 3 (RIVM, 1993)

² Including blast furnace gas and coke oven gas

³ Final use plus cogeneration; gas includes natural gas, blast furnace gas and coke oven gas.

⁴ Including household

⁵ Emission factors according to De Soete (1993); see Table 2.

Table 4.5 Vehicle kilometres driven (millions/year) and related N₂O emissions (kton N₂O-N per year) in the European Renaissance scenario of National Environmental Outlook 3 (RIVM, 1993)

	1980	1985	1990	1991 ¹	1992 ¹	2000	2010	2015
<i>Vehicle-kilometres²</i>								
Passenger cars								
- petrol	49450	46516	50519	51246	54310	49306	52934	54250
- diesel	4197	9462	15293	15543	15350	23297	26313	28311
- LPG	7705	11854	14233	14030	13680	14645	16807	17495
Freight vehicles								
- light-duty petrol	2069	1728	1698	1635	1630	2123	2836	3192
- light-duty diesel	1541	2641	5551	6033	6538	6939	9270	10436
- light-duty LPG	337	378	440	422	430	550	735	827
- heavy-duty trucks	3497	3228	3700	3641	3946	4921	7104	8325
- heavy-duty trailers	1405	1654	2304	2359	2556	2742	3871	4562
Special vehicles								
- petrol	57	96	48	38	30	54	60	62
- diesel	440	308	307	293	290	344	381	399
Buses (diesel)	560	590	628	624	630	798	697	697
Motorcycles	878	702	946	1017	1080	1419	1419	1419
Mopeds	1920	1710	1710	1310	1190	1710	1710	1710
Water/rail etc. ³	1517	1517	1517	1512	1512	1545	1551	1480
<i>N₂O emission⁴</i>								
Passenger cars								
- petrol	0.5	0.4	1.1	1.1	1.2	3.4	3.6	3.7
- diesel	0.1	0.2	0.3	0.3	0.3	0.5	0.5	0.6
- LPG	0.1	0.1	0.3	0.3	0.3	1.0	1.1	1.2
Freight vehicles								
- light-duty petrol	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.3
- light-duty diesel ⁵	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2
- light-duty LPG	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
- heavy-duty trucks ⁵	0.4	0.4	0.5	0.5	0.5	0.6	0.9	1.1
- heavy-duty trailers ⁵	0.2	0.2	0.3	0.3	0.3	0.3	0.5	0.6
Special vehicles								
- petrol	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
- diesel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Buses (diesel)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Motorcycles	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mopeds	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water/rail etc.	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.6
Total	2.1	2.2	3.4	3.4	3.6	7.0	8.0	8.5

¹ 1991/1992: tentative figures

² Data for 1980-1990 from CBS (1992c); for 1991 (Thomas, 1993); for 1992 CBS (1993); European Renaissance future scenario, National Environmental Outlook 3 (RIVM, 1993)

³ kton fuel; 1980 and 1985 assumed to be the same as 1990; 1992 assumed to be the same as 1991

⁴ Emission factors according to Baas (1991); see Table 3.

⁵ 1992 Ratio vehicle kilometres diesel:heavy-duty as in 1991

Table 4.6 Nitric acid (NA) production (kton $\text{HNO}_3\text{-N a}^{-1}$) and other industrial N_2O emissions (kton $\text{N}_2\text{O-N a}^{-1}$)

	1980	1985	1990	1991 ⁴	1992 ⁴	2000	2010	2015
Nitric acid production ¹	440	545	545	545	545	627	698	725
N_2O emission NA ²	7.6	9.4	9.4	9.4	9.4	10.8	12.0	12.4
Other industrial N_2O ³	1.1	1.1	1.1	1.1	1.1	1.4	1.8	1.9
Total	8.6	10.4	10.4	10.4	10.4	12.2	13.7	14.4

¹ Olivier (1993); Duesmann et al. (1992)

² Emission factor from Olivier (1993)

³ VROM (1990); Olivier (1993)

⁴ 1991/92 assumed to be equal to 1990

Table 4.7. Incineration of waste (10^6 kg a^{-1}) and related N_2O emissions (kton $\text{N}_2\text{O-N}$ per year)

	1980	1985	1990	1991-92 ³	2000	2010	2015
Waste incineration ¹	1900	3000	3400	3400	6300	9800	10800
N_2O emissions ²	0.02	0.04	0.04	0.04	0.08	0.12	0.14

¹RIVM (1993); European Renaissance future scenario; 1991/92 assumed to be equal to 1990

² Emission factors according to Spoelstra (1993)

³ 1991/92 assumed to be equal to 1990

Table 4.8 Agricultural land use (1000 ha), nitrogen input (kton N a⁻¹) and soil N₂O emissions (kton N₂O-N a⁻¹)

	1980	1985	1990	1991	1992	2000	2010	2015
<i>Areas and N input</i>								
Grassland on peat ¹	299	291	274	270	266	247	239	236
Grassland on sand ¹	898	873	822	810	798	742	717	709
Arable land ^{1,5}	812	826	877	884	899	923	869	846
Legumes ¹	10	28	32	27	23	24	22	22
Synthetic fertilizer use ²	483	500	412	400	392	110	84	84
Manure N production ²	533	585	585	639	619	470	459	459
Other fertilizers ²	11	11	11	11	11	11	11	11
<i>N₂O soil emissions³</i>								
Grassland total ⁴	9.5	9.3	8.7	8.6	8.5	7.9	7.6	7.5
Arable land ^{4,5}	1.5	1.6	1.6	1.7	1.7	1.7	1.6	1.6
Legumes ⁴	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Natural terrain ⁴	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1
Synthetic fertilizer use	2.0	2.1	1.7	1.7	1.6	0.5	0.4	0.4
Manure N production	3.2	3.5	3.5	3.8	3.7	2.8	2.8	2.8
Other fertilizers	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total ⁶	16.6	16.8	16.0	16.1	15.9	13.2	12.5	12.4

¹ LEI / CBS (1992, 1993); Projections based on the European Renaissance scenario of the National Environmental Outlook 3 (RIVM, 1993).

² RIVM (1993); Projections based on European Renaissance scenario; for synthetic fertilizer in 1991/92 CBS (1993)

³ Calculated as in Bouwman and Van der Hoek (1991)

⁴ Background anthropogenic N₂O emission because of N-input and deposition in historic years

⁵ Excluding legumes

⁶ Including natural background emission

Table 4.9 Nitrogen loading to surface waters (ton N per year) and related N₂O emissions (kton N₂O-N per year)

	1980 ¹	1985	1990	1991 ²	1992 ²	2000	2010	2015
<i>N loading</i>								
Effluent sewage treatment plants ³	37	37	39	37	35	21	19	17
Households ³	5	5	5	5	5	4	4	4
Industry ³	19	19	12	12	11	7	7	7
Atmospheric deposition ³	15	15	18	17	17	12	11	11
Leaching ⁴	169	169	173	180	175	116	94	83
Other agricultural emissions ⁵	11	11	11	10	10	4	4	4
Total N load	256	256	258	261	253	164	139	126
<i>N₂O emission⁶</i>								
Inland waters	2.6	2.6	2.6	2.6	2.5	1.6	1.4	1.3
Coastal waters	4.3	4.3	4.4	4.4	4.3	2.8	2.3	2.1
Total	6.9	6.9	6.9	7.0	6.8	4.4	3.7	3.4

¹ N loading in 1980 is assumed to be equal to 1985.

² Leaching of N in 1991-1992 is related to the growth in manure and fertilizer use relative to 1990; other N loading in 1991-92 is assumed to decrease linearly to the 2000 level.

³ 1985 from CBS (1989); RIVM (1991); for the future, the European Renaissance scenario of National Environmental Outlook 3 (RIVM, 1993)

⁴ Verkeer en Waterstaat (1990)

⁵ RIVM (1993); for the future the European Renaissance scenario of the National Environmental Outlook 3; 1985 assumed to be equal to 1990.

⁶ Calculated as in Bouwman and Van der Hoek (1991)

Table 4.10 Wastewater treatment plants: nitrogen influent (kton N/year), nitrogen removal (kton N per year) and related N₂O emissions (kton N₂O-N per year)

	1980 ¹	1985	1990	1991 ²	1992 ²	2000	2010	2015
N influent ³	71	71	73	73	73	78	82	82
N removal ⁴	34	34	34	36	38	57	63	65
N ₂ O emission ⁵	2.6	2.6	2.6	2.7	2.9	4.3	4.7	4.9

¹ N influent and N removal in 1980 are assumed to be equal to 1985

² N influent in 1991/92 is assumed to be equal to 1990

³ Data for 1990 based on Verstappen (1993); other years: influent 1990 corrected for human population

⁴ Difference between influent (this table) and effluent (Table 9)

⁵ Calculated according to Bouwman and Van der Hoek (1991)

Table 4.11 Emissions of N₂O from the Netherlands (kton N₂O per year). ER = European Renaissance; GS = Global Shift (difference only 1 kton in 2010 in transport)

	1985	1990	2000 ER	2000 GS	2010 ER	2010 GS
Agriculture	26	25	21	21	20	20
Transport	4	5	11	11	13	12
Aquatic sources	11	11	7	7	6	6
Sewage treatment plants	4	4	7	7	7	7
Other	17	17	20	20	23	23
Total¹*	62	63	65	65	68	67

¹ The data presented here differ slightly from those presented in Appendix A of the National Environmental Outlook 3 (RIVM, 1993), because improved estimates are presented here for emissions due to stationary and mobile combustion of fossil fuels. * Including 3 kton N₂O natural "background" emission.

Table 4.12 Comparison of emission estimation methods of nitrous oxide for 1990 in the Netherlands (kton N₂O a⁻¹).

	Nat. Env. Outlook 3	IPCC Methods
Energy (excl. transport)	0.7	0.7 (0.1 - 4.8)
Transport	5.4	5.8 (1.6 - 9.9)
Other industry	16.4	14.6 (6.0 - 23.1)
Waste	4.1	0.1 (0.0 - 0.7)
Agriculture	25.2	3.5 (1.4 - 14.8)
Other	10.9	0
TOTAL	62.7*	24.7 (9.1 - 53.3)

* Including 3 kton N₂O natural "background" emission.

5. NITROGEN OXIDES, SULFUR DIOXIDE, AMMONIA, CARBON MONOXIDE AND NON-METHANE HYDROCARBONS

5.1 Emissions and projections

Nitrogen oxides and sulfur dioxide are emitted during stationary and mobile combustion. Ammonia is mainly emitted in agriculture. Carbon monoxide is mainly emitted from the stationary and mobile combustion sources and from the iron and steel industry. Non-methane hydrocarbons are emitted from transport, in energy production and solvent use. In the National Environmental Outlook 3 (NEO3) (RIVM, 1993a) emissions are given for 1985 and 1990, and for 2000, 2010, and 2015 under the ER and GS scenarios. In the study of effects of the Second Environmental Policy Plan (NEPP2) (RIVM, 1993b), results are updated because certain policy measures to be introduced between 1990 and 1995 were considered baseline measures. The updated results follow below.

Table 5.1 Emissions of NO_x, SO₂ and NH₃ per sector (Gg a⁻¹)

	1985	1990	2000 aim	Baseline	Add. policies	2010 aim	Baseline	Addit. policies
NO_x								
Transport	339	351	158	228	224	.	228	163
-domestic	153	148	40	43	42	40	35	31
-freight	102	124	72	106	103	25	119	57
-other	84	79	46	79	79	.	74	74
Industry	86	86	28	48	43	7	43	23
Energy transf.	80	72	30	31	31	16	17	17
Refineries	14	20	9	12	12	3	10	3
Other	57	47	24	60	56	14	32	21
TOTAL	576	575	238-243	379	366	60-120	330	227
SO₂								
Transport	32	35	14	15	15	12	17	13
Industry	64	49	15	23	23	7	27	27
Energy transf.	62	45	18	16	16	18	15	15
Refineries	86	66	36	36	36	18	33	18
Other	15	12	9	2	2	1	2	2
TOTAL	259	207	75-90	92	92	50-100	95	76
NH₃								
Agriculture	242	200	70	72	72	45	56	56
Manure	230	189	67	68	68	.	52	52
-cattle	131	112	.	45	45	.	36	36
-pigs	72	61	.	17	17	.	11	11
-poultry	26	16	.	6	6	.	5	5
Fertilizer	12	11	3	4	4	.	4	4
Industry	7	6	3	3	3	1	3	3
Residential	9	10	9	11	11	.	11	11
TOTAL	258	216	82	86	86	25-50	70	70

Table 5.2 Carbon monoxide emissions (Gg a⁻¹)

	1985	1990	2000 aim	ER	GS	2010 aim	ER	GS
CO								
Stationary sources	342	313	.	216	173	.	274	208
-steel industry	239	229	.	108	75	.	128	87
Mobile sources	962	716	.	410	401	.	391	364
-road transport	923	675	.	358	353	.	342	321
TOTAL	1300	1030	520	630	570	.	670	570

Table 5.3 Emissions and projections of non-methane hydrocarbons (Gg a⁻¹)

	1985	1990	2000 aim	Baseline	Addit. policies	2010 aim	Baseline	Addit. policies
NMHC								
Industry/refineries	133	123	53	66	66	25	79	79
refineries	23	19	5	6	6	3	6	6
Transport	232	195	80	114	100	57	90	67
passenger cars	176	141	35	67	57	35	38	28
trucks	30	30	30	20	20	12	22	12
other transport	26	24	15	27	23	10	25	26
Residential/commercial	32	30	19	15	15	6	19	19
Other	112	111	41	60	64	30	62	64
TOTAL	509	459	193	255	245	117	250	230

6. HALOCARBONS (CFCs, HCFCs, HFCs, PFCs)

6.1 Emissions in the Netherlands

In the Netherlands potential emissions are based on data on the use of halocarbons. Every two years the CFC commission reports on the use of several halocarbons in the Netherlands (CFC commission, 1993). Table 6.1 gives an overview of these data and global warming potential is estimated.

Table 6.1 Use of halocarbons in the Netherlands (ton a⁻¹) and total global warming of potential emissions

	GWP 100 only direct effects	1986	1989	1990	1991	1992
CFC-11	3400	7952	5815	5317	5116	3836
CFC-12	7100	4843	2586	1043	687	670
CFC-13	13000	7	0	3	4	3
CFC-113	4500	1335	1403	1197	983	963
CFC-114	7000	91	71	99	127	85
CFC-115	7000	96	104	105	114	85
Halon 1211	4900	292	NE	212	157	70
Halon 1301	4900	171	NE	170	132	90
Carbon tetrachloride	1300	NE	689	777	794	547
Trichloroethane	100	NE	5915	5540	4751	3803
HCFC-22	1600	NE	1616	2120	2669	3342
HCFC-141b	580	NE	0	0	25	287
HCFC-142b	1800	NE	829	1023	934	1031
Total HFCs		0	0	0	0	0
Total CO₂ equivalent emissions Mton		71.1	51.2	41.0	37.3	32.6

Source: CFC action programme: Annual report 1992. Global warming potentials from IPCC, (1992)
GWP data on halon 1211 not available; assumed to be the same as for halon 1301
NE = not estimated

RIVM has estimated halocarbon use for different applications (Olivier et al., 1993). In Tables 6.2 and 6.3 the results are given for 1986 and 1990.

Table 6.2 Estimated use of halocarbons for different applications in the Netherlands in 1986 (ton a⁻¹)

	CFC 11	CFC 12	CFC 113	CFC 114	CFC 115	Halon 1211	Halon 1301	Total
Aerosols/sterilizers	1676	1775	292	46				3789
Foams								8506
-open	913							913
-closed	5254	2262	28	45				7593
Solvents/cleaning	14		1015					1029
Cooling	95	806 ¹			96			997
Fire extinguishers						292	171	463
TOTAL	7952	4843	1335	91	96	292	171	14780

¹ Of which 60 ton a⁻¹ is for airconditioning in cars

Source: Olivier et al., 1993

Table 6.3 Estimated use of halocarbons for different applications in the Netherlands in 1990 (ton a⁻¹)

	CFC 11	CFC 12	CFC 113	CFC 114	CFC 115	Halon 1211	Halon 1301	Total ¹
Aerosols/sterilizing	215	271	115	49				650
Foams								602
-open	602							602
-closed	4419	200	79	50				4751
Solvents/cleaning	14		1003					1017
Cooling	67	572 ²			105			744
Fire extinguishers						212	170	382
TOTAL	5317	1043	1197	99	105	212	170	8143

¹ On top of this, 2120 tons HCFC-22 and 1023 tons HCFC-142b were used in 1990

² of which 60 ton for air-conditioning in cars.

Source: Olivier et al., 1993

Polyfluorinated carbon (CF₄ and C₂F₆) emissions

Polyfluorinated carbons (PFCs) like carbon tetrafluoride (CF₄, also known as CFC-14 or tetrafluoromethane) and C₂F₆ are extremely potent greenhouse gases. CF₄ has a Global Warming Potential (GWP) of 5100 to 10,000 times that of CO₂ when calculated over a 100-year time horizon. C₂F₆ has a Global Warming Potential of over 10,000 (Jacobs, 1993; Abrahamson, 1992). The compounds are well-known byproducts of aluminium smelters. This is the most important anthropogenic source. Both substances may also be formed during CFC manufacturing, steel and uranium production, and etching (Isaksen, 1992; Cicerone, 1979).

CF₄ had an atmospheric concentration of 69.9±7.2 pptv in 1979. C₂F₆ has an atmospheric concentration of about 4 pptv (Penkett et al., 1981). The atmospheric increase of polyfluorinated carbons is about 2% per year or 20,000 metric tons (Khalil and Rasmussen, 1985). The lifetimes of these inert gases are extremely long, Abrahamson (1992) calculated lifetimes of 10,900 years for CF₄ and 11,500 years for C₂F₆. Recently, Ravishankara et al. (1993) assessed the possible atmospheric loss processes for these gases by determining the rate coefficients for the reactions with O(1D), H and OH and the absorption cross sections at 121.6 nm in the laboratory. They concluded lifetimes of more than 50,000 years for CF₄ and more than 20,000 years for C₂F₆ (Ravishankara et al., 1993).

Both substances are simultaneously produced during the process of aluminium smelting. They are accidental byproducts of the Hall-Heroult electrolysis process, introduced about 100 years ago. Traces of the compounds are produced during normal operations but most of the emissions of CF₄ and C₂F₆ result from the "anode effect". Aluminium is smelted in "pots". A low voltage electric current flows between carbon electrodes (the anode) and the pot walls (the cathode) in a fluoride-containing bath of aluminium oxide (bauxite) and cryolite (with about 50% fluoride). The current splits aluminium oxide into aluminium and oxygen. At the anode carbon dioxide is formed from the anode carbon and the free oxygen. During normal operations the electric current is too low for the formation of CF₄. The potential for CO₂ formation is 1.16 V against 2.5 V for CF₄. When aluminium oxide is depleted of alumina the anode effect can occur. When electric arcing occurs as a result of occasional high voltages at the anode, this is called the anode effect, after which CF₄ and minor quantities of C₂F₆ will be formed.

In recent years a new design for the ovens and the introduction of process control through computers have greatly reduced the number and duration of the anode effects. As a consequence the CF₄ and C₂F₆ emissions will have been reduced considerably. However, measurements are not available because the direct measuring in the ovengas stream is complex, labour intensive and plagued with measurement errors.

Method for estimating emissions of CF₄ and C₂F₆

Global estimates can be based on emission factors and global primary aluminium production. Detailed information on the exact processes that lead to these emissions is lacking. Until more information is available, emissions can be estimated from current knowledge on these processes.

About 1.5 to 3.0 kg CF₄ is produced per metric ton of aluminium produced (Jacobs, 1993). C₂F₆ can be detected two or three orders of magnitude less than CF₄. Abrahamson (1992) calculated that approximately 26,000 metric tons of CF₄ and 3200 metric tons of C₂F₆ accumulated in the atmosphere during the eighties. If all originated from aluminium smelters, the average emission factor might be about 1.6 kg CF₄ per ton and 0.2 kg C₂F₆ per ton of primary aluminium produced.

Calculations from the industry show emissions of 1.0-1.5 kg CF₄ per metric ton aluminium. At a yearly primary production in the World of 15 mln. ton aluminium, this leads to an emission of 15,000 - 22,500 tons. The yearly increase calculated from the increase in atmospheric concentration is 20,000 tons (Fabian et al., 1987). Both estimates are in reasonable agreement.

Jacobs (1993) suggests an emission factor of 1-3 kg CF₄ per metric ton of aluminium produced. Country-specific estimates can be based on production data from actual aluminium smelters and the application of a default range for the emission factors, 1-3 kg CF₄ per ton Al and 0.2 kg C₂F₆ per ton Al.

A preliminary estimate of emissions in the Netherlands is made using these default values. Aluminium production in the Netherlands is reported by the National Bureau of Statistics. The production and emissions are reported in Table 6.4.

Table 6.4 Primary aluminium production and emissions of CF₄ and C₂F₆

	Primary aluminium production	Emission factor CF ₄	Emission factor C ₂ F ₆	Emission CF ₄	Emission C ₂ F ₆
	mln kg	kg per ton	kg per ton	1000 kg	1000 kg
1980	258	2	0.2	516	51.6
1985	251	2	0.2	502	50.2
1987	276	2	0.2	552	55.2
1988	278	2	0.2	556	55.6
1989	279	2	0.2	558	55.8
1990	258	2	0.2	516	51.6
1991	254	2	0.2	508	50.8
1992	227	2	0.2	454	45.4

6.2 Baseline projection

Olivier et al. (1993) have estimated the use of halocarbons in the Netherlands for different scenarios for the period 1993-2015. Table 6.5 shows future Dutch halocarbon use for a London (L) scenario, a Copenhagen (C) scenario and an Additional policies (A) scenario. These scenarios are based on the Montreal Protocol, and the London and Copenhagen amendments to ban the use of ozone depleting substances.

London scenario

Unlimited use of HCFCs and HFCs is assumed to substitute CFCs and halons. Under certain assumptions this results globally in 40% substitution by HCFCs and HFCs and 60% by other substances. London-1 assumes the use of substitutes that are available within 10 years, London-2 also assumes the use of substitutes that are available after a longer period of time.

Copenhagen scenario

HCFCs are phased out in 2030. All HCFCs are assumed to be substituted by HFCs. In reality substitution will be less, so this scenario represents a maximum for HFC use in the future. Three alternative scenarios are formulated: in C-middle each of the HFCs-125, 134a, 143a and 152a-substitutes 25% of the HCFCs in the respective applications, in C-high and C-low, HFCs with respective high and low global warming potentials are used (for instance, HFC-143a and HFC-152a).

Additional policies scenario

In this scenario substances with an ozone depletion potential are no longer used (no HCFCs) and HFCs only if they have a Global Warming Potential smaller than 720. This means that only HFC-152a will be used in the future (with ODP=0 and GWP=150).

In all scenarios CFCs, halons, trichloroethane and CCl_4 will be phased out. The results refer to the period 2000-2010. Figure 6.1 shows the same data expressed in CO_2 equivalents.

In scenario L, where both HCFCs and HFCs are used unrestrictedly to replace CFCs and halons, use of HFCs increases to 720-1100 ton a^{-1} . This is 5-7% of the Dutch CFC use in 1986. HFCs are found to be used mainly as cooling and blowing agents. Especially HFC-134a and HFC-125 are used, and in the longer term HFC-143a as well. Figure 6.1 shows that in scenarios L, Dutch halocarbon use equals 8-9 CO_2 equivalents by 2000-2010. This is a doubling relative to 1990 (assuming $\text{GWP} = 0$ for CFCs and halons). In the near future, HFC-134a, having a GWP of 1200, is to be used most widely for CFC and halon replacement (scenario L-1). However, once HFC-125 and HFC-143a, with higher GWPs, become more widely available, the radiative effects of the halocarbon mix used is found to increase (scenario L-2).

In all C scenarios, where HCFCs are phased out, Dutch use of HFCs equals 7085 ton a^{-1} . This includes HFCs which are used for HCFC replacement. If expressed in CO_2 equivalents, the scenarios differ. Figure 6.2 shows that in scenarios C-low, halocarbon use is almost equal to 1990, in C-middle halocarbon use is 4.5 times higher, and in C-high, halocarbon use is almost nine times higher than 1990 (assuming $\text{GWP} = 0$ for CFCs and halons). Moreover, in scenarios C-middle and C-high the CO_2 equivalent halocarbon use is 2-4 times higher than in scenario L. Since these scenarios seem more realistic than scenario C-low, an HCFC phase-out is likely to increase the global warming of Dutch halocarbon use.

As yet, mobile air-conditioning is uncommon in the Netherlands. However, the number of air-conditioners in Dutch cars is increasing relatively fast. This could increase use of HFCs

considerably. In scenario C-high an annual use of 5000 tons of HFC-134a in mobile air-conditioning is assumed; this equals 6 Mton CO₂ equivalents. This amount would be needed for about 80% of Dutch passenger cars by 2000. Recycling of the cooling agent from mobile air-conditioning is relatively inefficient, since it easily leaks from the air-conditioning system. In the C-middle scenario it is assumed that about 20% of Dutch cars are air-conditioned by the year 2000 (or 1000 ton HFC-134a per year).

In scenario A only HFC-152a is used as a substitute for CFCs and halons as a result of Additional policy. This reduces Dutch halocarbon use to 0.01 Mton CO₂ equivalents per year, which is 95% less than in scenarios L and C.

Table 6.5 Dutch use of halocarbons in ton a⁻¹ in 1986, 1990, and as estimated for 2000-2010, assuming a total phase-out of CFCs and halons in scenarios L, C, en A. A constant demand for halocarbons is assumed between 1986 and 2010 (except for mobile air-conditioning, for which an increase is assumed in C-middle and C-high scenarios). Also shown are the Global Warming Potentials (GWPs) and Ozone Depleting Potentials (ODPs) over 100 years (Houghton et al., 1992).

	CFCs ¹	HCFCs	HFC-125	HFC-134a	HFC-143a	HFC-152a	Total
GWP-100	0-7100	90-1800	3400	1200	3800	150	
ODP-100			0	0	0	0	
1986	14780	0	0	0	0	0	14780
1990	8143	3143	0	0	0	0	11286
Scenarios London							
L-1	0	6235	185	443	0	88	6952
L-2	0	5992	329	540	144	80	7085
Scenarios Copenhagen							
Substitution							
C-Low	0	0	329	540	144	6072	7085
C-Middle	0	0	1827	2038	1642	1578	7085
C-High	0	0	329	540	6136	80	7085
Car airco increase							
C-Low	0	0	0	0	0	0	0
C-Middle	0	0	0	1000	0	0	1000
C-High	0	0	0	5000	0	0	5000
Additional policies scenario	0	0	0	0	0	80	80

¹ Including halocarbons, excluding trichloroethane and CCl₄. The range reflects the uncertainties with regard to direct and indirect radiative forcing by CFCs and halons.

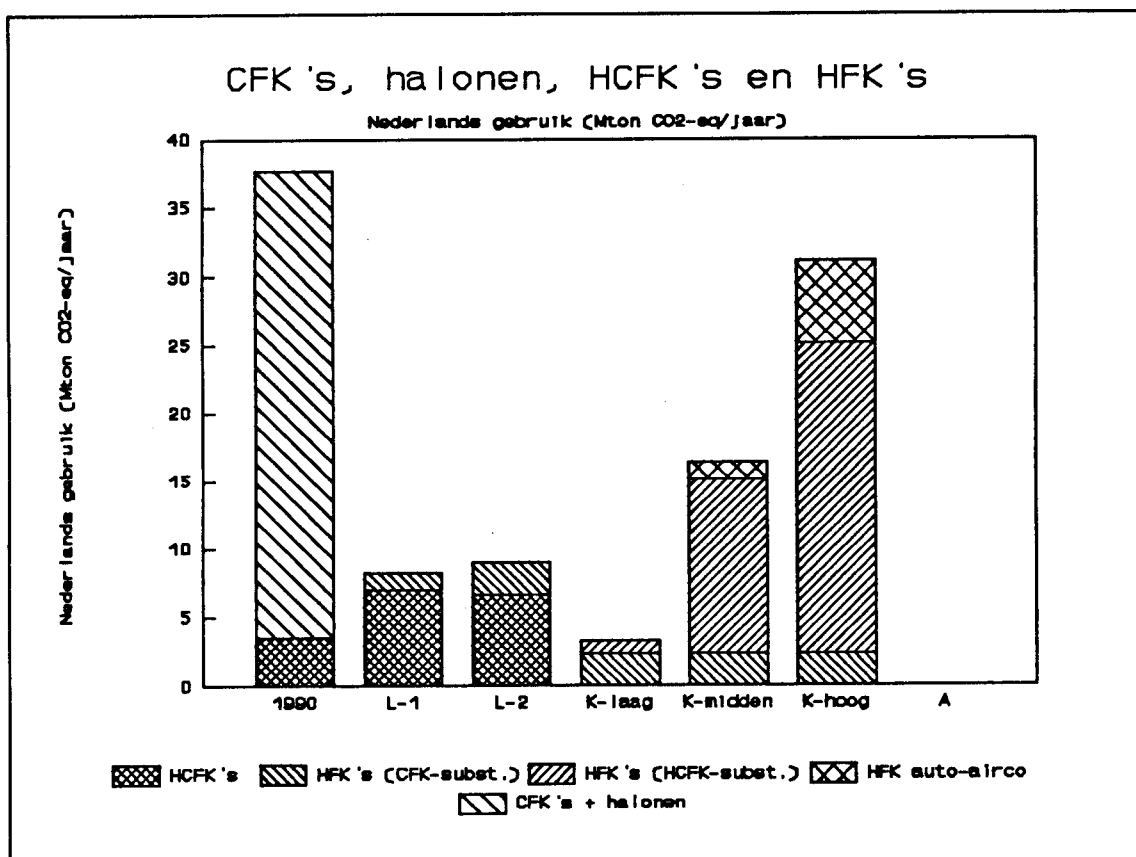


Figure 6.1 Dutch halocarbon use in Mton CO₂ equivalents in 1990, 2000 and in 2000-2010 in L-1, L-2, C-Low, C-Middle, C-High and A scenarios (constant demand for halocarbons, except for mobile air-conditioning in scenarios C; excluding trichloroethane and CCl₄). For CFCs and halons the uncertainties about indirect radiative effects via stratospheric ozone depletion are included by using GWPs ranging from 0 (no net radiative forcing) to direct radiative forcing.

As a result of halocarbon emissions the *total* direct greenhouse gas emissions for the Netherlands can increase by 9% in 2010 compared with 1990 (GS/C-middle scenario; assuming a net GWP for CFCs of 0). In the most extreme variant (ER/C-high scenario) this increase could even amount to about 26%. However, this variant seems less likely. When only compounds with a GWP of (almost) 0 are used as substitutes for CFCs (scenario A), the Netherlands policy on reduction of greenhouse gas emissions can be more easily realized than would be possible without a specific HFC policy. Thus emissions of halocarbons clearly influence the total emission pattern.

6.3. Evaluation

In this report it is assumed that most probably 6 ktons HCFCs and 1 kton HFCs will be emitted by 2000-2010, according to the London-2 scenario. It is assumed that substitution of HCFCs with HFCs and a strong increase in car air-conditioning could lead to 12 ktons HFC emissions at a maximum, and zero HCFC emissions in 2010 according to the Copenhagen-high scenario.

Assuming a constant demand for halocarbon applications in the Netherlands, we conclude that as a result of the phase-out of halocarbons, the Dutch greenhouse gas emissions from these sources may stay constant, but will more likely rise strongly to 2-4 times the 1990 level by 2010 (Figure 6.1).

A phase-out of HCFCs may lead to a further doubling of greenhouse gas emissions from halocarbons by 2010.

The share of halocarbons in total Dutch emissions of direct greenhouse gases will increase from 3% in 1990 to 7 to 11% in 2010 (assuming a GWP of zero for CFCs). Substitution of halocarbon use by zero GWP alternatives, in conjunction with assumptions on other greenhouse gases, leads to a stabilization of greenhouse gas emissions in most scenarios. The assumed increased usage of HFCs due to further constraints on HCFC use will lead to an increase of total direct greenhouse gases in the Netherlands of about 9% at a maximum. Thus additional policy on halocarbon use can play an important role in a comprehensive climate policy.

From our review we conclude that additional climate policy is certainly possible, since for all or almost all applications of present halocarbons, zero GWP alternatives are available. However, technical, economic, and health and safety aspects need to be evaluated carefully. In the absence of this, costs and Ozone Depletion Potentials will be the major factors determining the choices of substitute compounds and processes, and may lead to the above-mentioned share of HFCs of 9% in total Dutch emissions by 2010. When a more stringent reduction policy for HCFCs is introduced, additional HFC policy will be even more effective.

As the GWP values of HCFCs and of HFCs are dependent on the specific compound, climate policy on halocarbons will be most effective when differentiated into individual compounds (including PFCs) instead of into groups of compounds, as is the approach in the phase-out policy of ozone depleting substances.

7. TOTAL GREENHOUSE GAS EMISSIONS

7.1 Global warming potentials according to IPCC (1990 and 1992)

Greenhouse gases can have direct and indirect effects on the radiation balance of the Earth. A direct effect occurs when gas molecules trap part of the longwave back radiation from the Earth's surface. An indirect effect occurs when a gas reacts in the Earth's atmosphere to form other gases with radiative effects. The Global Warming Potential concept, developed as an integrative measure of the radiative effect of emissions from all kinds of different gases, is defined as the extra radiative forcing that results from a unit of emission of a gas over a unit of time. The radiative forcing is expressed in CO₂ equivalents. The Global Warming Potential of CO₂ is set to 1 by definition. The IPCC has published GWPs for most greenhouse gases for different time horizons, namely 20, 100 and 200 years (IPCC, 1990, 1992). The GWP100 is mostly used to integrate the greenhouse effect.

In 1994 the GWPs will be re-evaluated in the light of the latest scientific insights. As these are not yet "available", the IPCC 1992 values have been used. Table 7.1 gives all available GWPs.

Between 1990 and 1992 the direct GWP values of some of the HCFCs and HFCs have been increased by 20-50% as a result of new information on their atmospheric lifetimes. The direct value of methane is revised. The indirect values for methane and other reactive gases like NMHCs and CO were given in 1990. In 1992, these values were declared positive but of unknown magnitude. The indirect effect of NO_x is uncertain. Indirect effects of some halogens are negative because of the ozone depletion.

Table 7.1 Global warming potentials according to IPCC

	Time horizon					
	20		100		500	
Direct	IPCC 1990	IPCC 1992	IPCC 1990	IPCC 1992	IPCC 1990	IPCC 1992
CO ₂	1	1	1	1	1	1
CH ₄	38	35	12	11	5	4
N ₂ O	270	260	290	270	190	170
CFC 11	4500	4500	3500	3400	1500	1400
CFC 12	7100	7100	7300	7100	4500	4100
CFC 13		11000		13000		15000
CF ₄ (CFC 14)		>3500		>4500		>5300
C ₂ F ₆				>10000		
CFC 113	4500	4600	4200	4500	2100	2500
CFC 114	6000	6100	6900	7000	5500	5800
CFC 115	5500	5500	6900	7000	7400	8500
CFC 116		>4800		>6200		>7200
Halon 1211	5800	5600	5800	4900	3200	2300
Halon 1301	5800	5600	5800	4900	3200	2300
HCFC 22	4100	4200	1500	1600	510	540
HCFC 123	310	330	85	90	29	30
HCFC 124	1500	1500	430	440	150	150
HCFC 141b	1500	1800	440	580	150	200
HCFC 142b	3700	4000	1600	1800	540	620
HFC 125	4700	5200	2500	3400	860	1200
HFC 134a	3200	3100	1200	1200	420	400
HFC 143a	4500	4700	2900	3800	1000	1600
HFC 152a	510	530	140	150	47	49
CCl ₄	1900	1800	1300	1300	460	480
CH ₃ CCl ₃	350	360	100	100	34	34
CHCl ₃		92		25		9
CH ₂ Cl ₂		54		15		5
Indirect						
CH ₄	24		8		3	
CO	5		1		0	
NO _x	150		40		14	
VOC	28		8		3	

Note:

GWP data on halon 1211 not available; it is assumed to be the same GWP as mentioned for halon 1301

7.2 CO₂ equivalent emissions 1985-2010

The total potential greenhouse warming of the emissions is estimated on the basis of the disaggregated tables in the other chapters. Here, a summary is given in Figure 7.1 and Table 7.2.

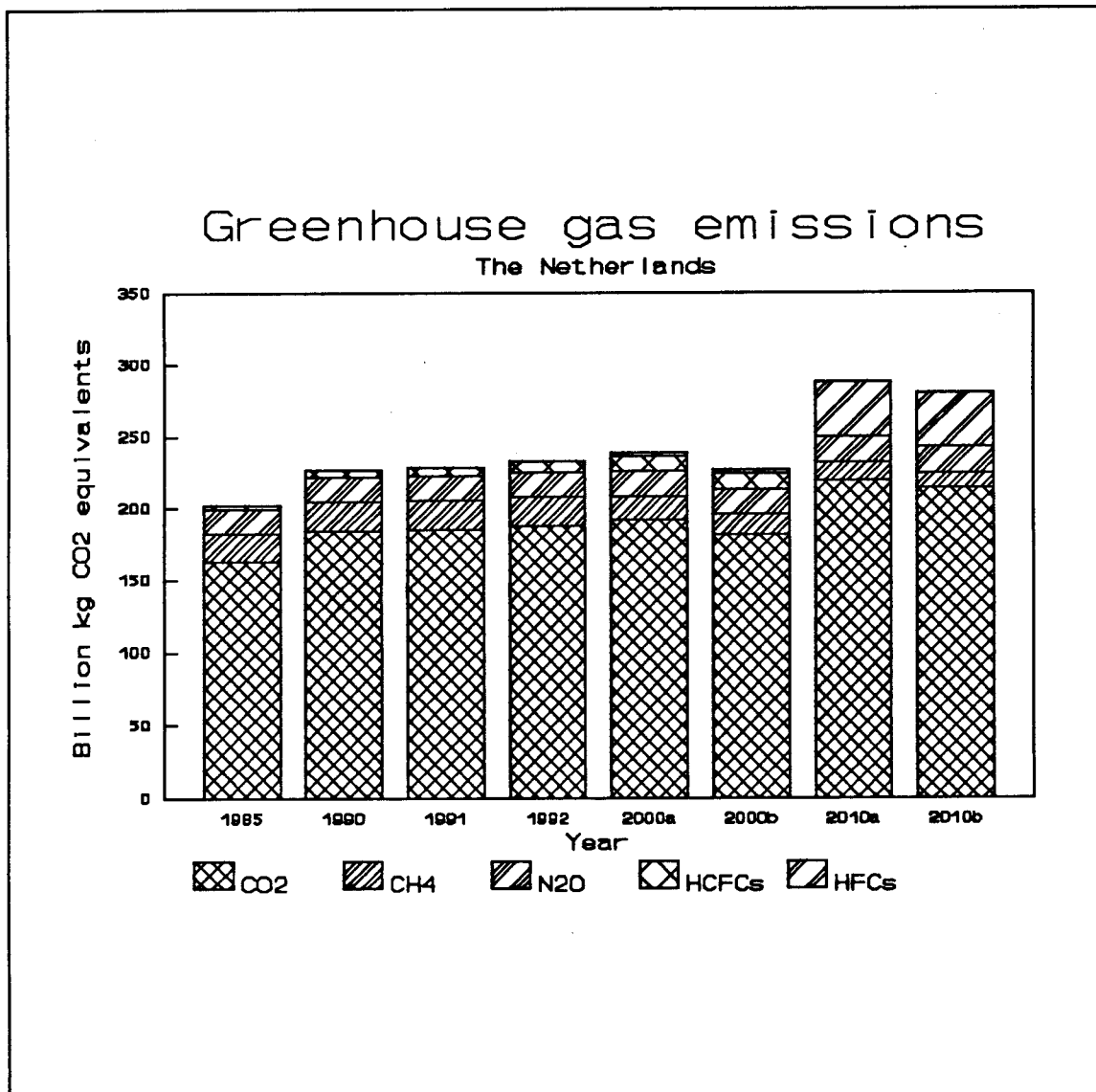


Figure 7.1 Greenhouse gas emissions in CO₂ equivalents in the Netherlands.

a = Updated current policies

b = Additional policies.

Table 7.2 Emissions, aims and scenarios for greenhouse gases (HCFC and HFC use is reported)

Emissions	Unit	1985	1990	1991	1992	2000	2010	Base-	Add.	Base-	Add.
						Aim	Aim	line	policies	line	policies
CO ₂	(10 ⁹ kg)	163	184	185	188	173-177	.	192	182	219	214
CH ₄	(10 ⁶ kg)	1034	1067	1089	1069	970	.	820	741	648	570
N ₂ O	(10 ⁶ kg)	62	63	63	63	63	.	65	65	67	68
CO	(10 ⁶ kg)	1300	1030	NE	NE	520	.	630	570	670	570
NO _x	(10 ⁶ kg)	576	575	NE	NE	238-243	60-120	330	366	330	227
NMVOG	(10 ⁶ kg)	509	459	NE	NE	193	117	255	245	250	230
HCFCs	(10 ⁶ kg)	1.7	3.5	3.5	4.6	.	.	6	6	0	0
HFCs	(10 ⁶ kg)	0	0	0	0	.	.	1	1	12	12
CF ₄	(10 ⁶ kg)	0.5	0.5	0.5	0.5	.	.	0.5	0.5	0.5	0.5
C ₂ F ₆	(10 ⁶ kg)	0.05	0.05	0.05	0.05	.	.	0.05	0.05	0.05	0.05
CO ₂ equivalent emissions (10 ⁶ kg)	Total GWP100										
CO ₂	1	163	184	185	188	177	0	192	182	219	214
CH ₄	19	20	20	21	20	18	0	16	14	13	10
N ₂ O	270	17	17	17	17	17	0	18	18	18	18
CO	1	1	1	0	0	1	0	1	1	1	1
NO _x	40	23	23	0	0	10	4	16	15	13	9
NMVOG	8	4	4	0	0	2	1	2	2	2	2
HCFCs	1700	3	6	6	8	.	0	10	10	0	0
HFCs	3200	0	0	0	0	.	0	3	3	38	38
CF ₄	4500	2	2	2	2	.	0	2	2	2	2
C ₂ F ₆	10000	1	1	1	1	.	0	1	1	1	1
Total		233	258	231	236	224	5	261	247	307	295

7.3 Evaluation

Equivalent emissions increase steadily with the growth of the economy. As no additional policy measures are formulated yet for the years after 2000, the emissions in 2010 show a large increase. A stabilization of carbon dioxide emissions without hampering energy supply in a growing economy may be achieved in the future with investments in renewable energy sources. A policy for after 2000 will be developed in a Second Memorandum on Climate Change due in 1995.

The contribution of the HFCs in 2010 is relatively large. The HFCs are substitutes for the ozone depleting substances like CFCs and HCFCs. HFCs have no ozone depleting effects but a relatively large global warming potential. Restricting HFCs might be necessary to reduce the potential warming effect.

The aim of reducing carbon dioxide 3-5% will not be reached. A 3% reduction however is within reach. The aim for reduction of 10% for methane will be reached if policies to reduce waste, the manure surplus and ammonia deposition are successful. Potentially even a 25% reduction is possible without extra policy measures. The aim of stabilizing nitrous oxide emissions will not be reached. Policies are in place for the reduction of the gases that have an indirect warming effect like CO, NO_x and NMVOC; the agreed reductions will not be reached without additional policies.

HCFCs will be phased out in 2030 according to the Copenhagen amendment of the Montreal Protocol. The HFCs will need policy consideration in the near future. They are increasingly used as a substitute for CFCs and HCFCs. Scenario results indicate large increases in use in 2010, e.g. in car airconditioning devices. HFCs have no ozone depleting effects but a relatively large Global Warming Potential and a long atmospheric lifetime. Small quantities in the atmosphere have already large potential warming effects.

More attention to the other trace gases with relatively high global warming potentials like the PFCs is needed. Small emissions have already large effects, as can be seen from Table 7.2. Here emissions are already seen to have 3.10⁹ kg carbon dioxide equivalents, and that in a small country like the Netherlands.

REFERENCES

INTRODUCTION

- Central Planning Bureau, 1992: Scanning the Future. A long-term study of the World Economy 1990-2015. SDU Publishers, the Hague.
- IPCC, 1994: Draft Guidelines for National Greenhouse Gas Inventories. Volume 1: Reporting instructions; Volume 2: Workbook; Volume 3: Reference Manual. IPCC/OECD Joint Programme, Paris.
- Ministry of Housing, Physical Planning and Environment, 1993: National Environmental Policy Plan 2 (NEPP 2). SDU Publishers, the Hague. (in Dutch).
- Ministry of Economic Affairs, 1993: Second Memorandum on Energy Conservation (SMEC). SDU Publishers, the Hague. (in Dutch).
- RIVM, 1992: National Environmental Outlook 2: 1990-2010. Samsom H.D. Tjeenk Willink, Alphen aan den Rijn.
- RIVM, 1993a: National Environmental Outlook 3: 1993-2015. Samsom H.D. Tjeenk Willink, Alphen aan de Rijn.
- RIVM, 1993b: Effects for the Environment of the Second Environmental Policy Plan. Samsom H.D. Tjeenk Willink, Alphen aan de Rijn.
- RIVM, 1994: Effects for the Environment of the Second Environmental Policy Plan. Annex E - H. Bilthoven. The Netherlands.
- UN, 1992. United Nations Framework Convention on Climate Change.

CARBON DIOXIDE

- Albers, R. (ed.) 1993: Energy and Emissions of CO₂, NO_x and SO₂. Backgrounddocument to the Third National Environmental Outlook. ECN, CPB and RIVM, Bilthoven, the Netherlands (In Dutch).
- Annema, J.A. et al., 1992: Production of primary iron and steel. RIVM, Bilthoven, the Netherlands.
- Central Bureau of Statistics, 1980, 1985, 1990, 1991, 1992, 1993: Energy balances for the Netherlands. Voorburg. (in Dutch).
- De Jager, D. and K. Blok, 1993: Carbon balance of the Dutch waste system. Ecofys, Utrecht. (in Dutch).
- Loos, B., 1992: Production of glass, glass fiber and glass wool. RIVM, Bilthoven, the Netherlands.
- Mohren, G.M.J. and C.G.M. Klein Goldewijk, 1990: CO₂ vastlegging in bos. Bosbouw in Nederland als maatregel in het kader van de klimaat/CO₂ - problematiek. De Dorschkamp Wageningen (In Dutch).
- Ministry of Agriculture, Nature Management and Fisheries, 1992: Evaluatie Meerjarenplan Bosbouw. The Hague. (in Dutch).
- Nabuurs, G.J. and G.M.J. Mohren, 1993: Carbon fixation through forestation activities. Institute for Forestry and Nature Research (IBN-DLO) Wageningen and Foundation FACE, Arnhem. The Netherlands.
- Nabuurs, G.J. and G.M.J. Mohren, 1993: Carbon stocks and fluxes in Dutch forest ecosystems. Institute for Forestry and Nature Research (IBN-DLO) Wageningen, The Netherlands.
- OECD, 1991: Estimation of greenhouse gas emissions and sinks. Final Report from the OECD Experts Meeting. Paris.
- Okken, P.A., D.J. Gielen and T. Kram, 1993: Correcting fossil fuel CO₂ emission statistics for non-energy use, flue gas desulfurization and CO₂ removal. ECN-RX-93-039. Energy Research Foundation, Petten.
- RIVM, 1993: National Environmental Outlook 3. Samsom H.D. Tjeenk Willink. Alphen a.d. Rijn.
- Smit, J.R.K., 1993: Production of cement. RIVM, Bilthoven.
- Zonneveld, E.A., 1991: Emissiefactoren van kooldioxide and de CO₂ uitwerp door het stoken van fossiele brandstoffen 1975-1989. Kwartaalberichten Milieustatistieken 91/1 CBS. Voorburg.

METHANE

- Aselmann, I. and Crutzen, P.J., 1989. Global Distribution of Natural Freshwater Wetlands and Rice Paddies Their Net Primary Productivity, Seasonality and Possible Methane Emissions. J. of Atmos. Chem. 8: 307-358.
- Blaxter, K.L. and Clapperton, J.L., 1965. Prediction of the amount of methane produced by ruminants. British Journal of Nutrition, 19: 511-522.
- Casada, M.E. and Safley, L.M.J., 1990. Global methane emission from livestock and poultry manure. Report Climate Change Division, USEPA.
- CBS, 1988. Bedrijfsafvalstoffen, 1986. Kwartaalbericht Milieustatistieken (CBS), 5: 14-18.
- CBS, 1989a. Bedrijfsafvalstoffen 1986. Voorburg, the Netherlands.
- CBS, 1989b. Soil Statistics. Voorburg, the Netherlands.
- CBS, 1991. Statistisch Jaarboek 1991. SDU, The Hague, the Netherlands.
- CBS, 1992. Landbouwcijfers 1992. The Hague, 271 pp. the Netherlands.
- CBS, 1993. Statistisch Jaarboek 1993. SDU, The Hague, the Netherlands.
- CBS, 1994. Statistisch Jaarboek 1994. SDU, The Hague, the Netherlands.

- CPB, 1992. Scanning the Future. SDU, The Hague, the Netherlands.
- Crill, P.M., 1991. Seasonal patterns of methane uptake and carbon dioxide release by a temperate woodland soil. *Global Biogeochemical Cycles*, 5: 319-334.
- De Jager, D. and Blok, K., 1993. Cost-effectiveness of emission-reducing measures for methane in the Netherlands. Ecofys, Utrecht, the Netherlands.
- Gasunie, 1992. Jaarverslag 1991. Groningen, the Netherlands.
- Hoeks, J., 1983. Significance of biogas production in waste tips. *Waste Management and Research*, 323-335.
- Hoeks, J. and Oosthoek, J., 1981. Gaswinning uit Afvalstortterreinen. Gas, the Netherlands.
- IPCC, 1990. Climate Change. The scientific assessment. Cambridge University Press, 365 pp.
- IPCC, 1991. Climate Change: The IPCC Response Strategies. Island Press, UK.
- IPCC, 1992. Climate Change 1992. The Supplementary Report to the IPCC Scientific Assessment. Cambridge University Press, 200 pp.
- IPCC, 1994. Draft Guidelines for National Greenhouse Gas Inventories. Three volumes. IPCC/OECD Joint Programme. Paris.
- Landfill Gas Advisory Centre. Annual Report 1992. Apeldoorn.
- Ministry of Agriculture, Nature Management and Fisheries and Ministry of Housing, Physical Planning and Environment, 1993. Document on Third Phase Ammonia policies. The Hague.
- Moore, T.R. and R. Knowles, 1989: The influence of water table levels on methane and carbon dioxide emissions from peatland soils. *Canadian Journal of Soil Science* 69: 33-38.
- Nagelhout, D., Wieringa, K. and Joosten, J.M., 1989. Afval 2000. National Institute of Public Health and Environmental Protection, RIVM report 738605002, the Netherlands.
- Nagelhout, D. and Van Lohuizen, Z.I., 1992. Afvalverwijdering 1990-2010. National Institute of Public Health and Environmental Protection. RIVM report 736201010, the Netherlands.
- Nagelhout, D. and E. Ballerini, 1993. Afvalverwijdering 1993-2015. RIVM report 776204001, the Netherlands.
- Nielen, R.J., 1991. Kwantificering van methaanemissies als gevolg van aardgasverliezen en oliewinning in Nederland. TNO report, Apeldoorn, the Netherlands.
- NOVEM, 1991. Taakstellend plan stortgaswinning en benutting. Utrecht, the Netherlands.
- OECD, 1991. Estimation of greenhouse gas emissions and sinks. Final Report of the OECD Experts Meeting, 18-21 February 1991. Paris.
- Oonk, H., 1993. Landfill gas recovery and utilization in The Netherlands. TNO, Apeldoorn.
- RIVM, 1992: National Environmental Outlook 2: 1990-2010. Samsom H.D. Tjeenk Willink, Alphen aan den Rijn.
- RIVM, 1993a: National Environmental Outlook 3: 1993-2015. Samsom H.D. Tjeenk Willink, Alphen aan de Rijn.
- RIVM, 1993b: Effects for the Environment of the Second Environmental Policy Plan. Samsom H.D. Tjeenk Willink, Alphen aan de Rijn.
- RIVM, 1994: Effects for the Environment of the Second Environmental Policy Plan. Annex E - H. Bilthoven. The Netherlands.
- Scheepers, M.J.J., 1991. Schatting van de hoeveelheid stortgas dat in Nederlandse Stortplaatsen wordt gevormd. Gas Research Institute, Apeldoorn, the Netherlands.
- SVA, 1973. Inventarisatie benodigde stortruimte. Amersfoort, the Netherlands.
- Van Amstel, A.R., R.J. Swart, M.S. Krol, J.P. Beck, A.F. Bouwman and K.W. van der Hoek, 1993: Methane, the other greenhouse gas, research and policy in the Netherlands. RIVM report 481507001, Bilthoven, the Netherlands.
- Van Amstel, A.R. (ed.), 1993. Proceedings of the International IPCC Workshop "Methane and Nitrous Oxide: Methods in National Emission Inventories and Options for Control". RIVM, Bilthoven, the Netherlands.
- Van den Born, G.J., Bouwman, A.F., Olivier, J.G.J. and Swart, R.S., 1991. The emissions of greenhouse gases in the Netherlands. National Institute of Public Health and Environmental Protection (RIVM), the Netherlands.
- Verschut, C., Oonk, J. and Mulder, W., 1991. Broeikasgassen uit vuilstort in Nederland. TNO report, Apeldoorn, the Netherlands.
- Woodbury, J. and A. Hashimoto, 1994: Methane emissions from livestock manure. In: International anthropogenic methane emissions: Estimates for 1990. USEPA Washington.
- Zeeman, G. and Hamelers, H.V.M., 1992. Voorspelling van de methaanproductie in mestvergisters en mestopslagen. Samenvatting. Report Agricultural University Wageningen.

NITROUS OXIDE

- Albers, R.A.W. (ed.) 1993: Energy and Emissions of CO₂, NO_x and SO₂. Backgrounddocument to the Third National Environmental Outlook. ECN, CPB and RIVM, Bilthoven, the Netherlands (In Dutch).
- Baas J. (1991). (In Dutch). Literatuuronderzoek naar de lachgasemissie door het wegverkeer. TNO rapport R 91/322. TNO-Milieu en Energie, Instituut voor Milieuwetenschappen (IMW), Delft, The Netherlands.
- Bouwman A.F. and K.W. Van Der Hoek (1991). Analysis of soil and water borne emissions of nitrous oxide and methane in The Netherlands. RIVM report 736301010, National Institute for Public Health and Environmental Protection, Bilthoven, The Netherlands.

- CBS (1984/85). (In Dutch). Jaarstatistiek van de kunstmeststoffen. Netherlands Central Bureau of Statistics, Voorburg/Heerlen, The Netherlands.
- CBS (1989). (In Dutch). Kwartaalberichten Milieu 89/4. Netherlands Central Bureau of Statistics, Voorburg/Heerlen, The Netherlands.
- CBS (1991). (in Dutch). De nederlandse energiehuishouding, jaarcijfers 1990. Netherlands Central Bureau of Statistics, Voorburg/Heerlen, The Netherlands.
- CBS (1992a). (in Dutch). De nederlandse energiehuishouding, jaarcijfers 1991. Deel 1 en 2. Netherlands Central Bureau of Statistics, Voorburg/Heerlen, The Netherlands.
- CBS (1992b). (in Dutch). De nederlandse energiehuishouding, uitkomsten van maand- en kwartaaltellingen 1992-1, 1992-2, 1992-3 en 1992-4. Netherlands Central Bureau of Statistics, Voorburg/Heerlen, The Netherlands.
- CBS (1992c). (In Dutch). Luchtverontreiniging, emissies door wegverkeer 1980 - 1990. Concept getallen. Netherlands Central Bureau of Statistics, Voorburg/Heerlen, The Netherlands.
- CBS (1993). (In Dutch). Maandstatistiek verkeer 1993/8. Netherlands Central Bureau of Statistics, Voorburg/Heerlen, The Netherlands.
- De Soete G.G. (1993). Nitrous oxide from combustion and industry: chemistry, emission and control. In: A.R. Van Amstel (ed.) Proceedings of the International IPCC Workshop "Methane and Nitrous Oxide: Methods in National Emission Inventories and Options for Control", Amersfoort, 3-5 February 1993. RIVM, Bilthoven, the Netherlands.
- Duesmann H.B., E.A.E.M. Kohnen and B. Loos (1992). (In Dutch). Productie van stikstofkunstmest. SPIN-Publicatie. RIVM Rapport nr. 773006147. 15 pp. National Institute for Public Health and Environmental Protection, Bilthoven, The Netherlands.
- Isaksen I.S.A., V. Ramaswamy, H. Rodhe, T.M.L. Wigley (1992). Radiative forcing of climate. In: J.T. Houghton, B.A. Callander, and S.K. Varney (Eds). Climate Change 1992. The supplementary report to the IPCC scientific assessment. Published for the Intergovernmental Panel on Climate Change. Cambridge University Press, New York. pp. 47 - 67.
- Khalil M.A.K. and R.A. Rasmussen (1992). The global sources of nitrous oxide. J.Geophys.Res. 97, 14651-14660.
- Kroes J.G., G.W.J. Roest, P.E. Rijtema, L.J. Loch, 1990. De invloed van enige bemestingsscenario's op de afvoer van stikstof en fosfor naar het oppervlaktewater in Nederland. Rapport 55: Staringcentrum, Wageningen, the Netherlands, 170 pp.
- Kroeze, C. et al. 1994: Nitrous oxide. Emission inventory and options for control in the Netherlands. RIVM report 773001004, Bilthoven, the Netherlands.
- LEI / CBS (1992). (In Dutch). Landbouwcijfers 1992. Landbouweconomisch Instituut (LEI-DLO), Den Haag; Centraal Bureau voor de Statistiek, Voorburg, The Netherlands.
- LEI / CBS (1993). (In Dutch). Landbouwcijfers 1993. Landbouweconomisch Instituut (LEI-DLO), Den Haag; Centraal Bureau voor de Statistiek, Voorburg, The Netherlands.
- RIVM (1991). (In Dutch). Nationale Milieuverkenningen 2: 1990-2010. Rijksinstituut voor Volksgezondheid en Milieuhygiene. Samson H.D. Tjeenk Willink, Alphen aan den Rijn, The Netherlands.
- RIVM (1993). (In Dutch). Nationale Milieuverkenningen 3: 1993-2015. Rijksinstituut voor Volksgezondheid en Milieuhygiene. Samson H.D. Tjeenk Willink, Alphen aan den Rijn, The Netherlands.
- Olivier J.G.J. (1993). Nitrous oxide emissions from industrial processes. In: Van Amstel, A.R. (ed), Proceedings of the International IPCC Workshop: "Methane and Nitrous Oxide: Methods in National Emission Inventories and Options for Control", Amersfoort, 3-5 February 1993. RIVM, Bilthoven, the Netherlands.
- Prinn R., D. Cunnold, R.A. Rasmussen, P. Simmonds, F. Aleya, A. Crawford, P. Fraser and R. Rosen (1990). Atmospheric emissions and trends of nitrous oxide deduced from ten years of ALE-GAGE data. J.Geophys.Res. 95: 18369-18385.
- Shine K.P., R.G. Derwent, D.J. Wuebbles, and J-J Morcrette (1990). Radiative forcing of climate. In: Houghton J.T., G.J. Jenkins, and J.J. Ephraums (Eds). Climate change. The IPCC scientific assessment. Published for the Intergovernmental Panel on Climate Change. Cambridge University Press, New York. pp 41-68.
- Spoelstra H. (1993). N₂O emissions from combustion processes used in the generation of electricity. 10143-KES/MME 92-4029. KEMA Environmental Services, Arnhem, The Netherlands. 27 pp.
- Thomas R. (1993). Personal communication. National Institute for Public Health and Environmental Protection, Bilthoven, The Netherlands.
- Van Amstel, A.R. (ed), (1993). International IPCC Workshop "Methane and Nitrous Oxide: methods in national emission inventories and options for control. Proceedings. RIVM, Bilthoven, the Netherlands.
- Van den Born G.J., A.F. Bouwman, J.G.J. Olivier, and R.J. Swart (1991). The emissions of greenhouse gases in the Netherlands. RIVM report No. 222901003, National Institute for Public Health and Environmental Protection, Bilthoven The Netherlands. 128 pp.
- Verkeer en Waterstaat (1990). (In Dutch). Derde Nota Waterhuishouding. Tweede Kamer, 21 250.
- VROM (1990). (In Dutch). Project Emission Registration. Ministry of Housing, Physical Planning and the Environment, The Hague, The Netherlands.
- VROM (1991). (In Dutch). Klimaatverandering. Tweede Kamer der Staten-Generaal. Vergaderjaar 1990-1991, 22232,

nrs. 1-2.

- Verstappen G. (1993). Personal Communication. National Institute for Public Health and Environmental Protection, Bilthoven The Netherlands.
- Watson R.T., L.G. Meira Filho, S. Sanhueza, and A. Janetos (1992). Greenhouse gases: sources and sinks. In: J.T. Houghton, B.A. Callander, and S.K. Varney (Eds). Climate Change 1992. The supplementary report to the IPCC scientific assessment. Published for the Intergovernmental Panel on Climate Change. Cambridge University Press, New York. pp. 25-46.

NITROGEN OXIDES ETC.

- RIVM, 1992: National Environmental Outlook 2: 1990-2010. Samsom H.D. Tjeenk Willink, Alphen aan den Rijn.
- RIVM, 1993a: National Environmental Outlook 3: 1993-2015. Samsom H.D. Tjeenk Willink, Alphen aan de Rijn.
- RIVM, 1993b: Effects for the Environment of the Second Environmental Policy Plan. Samsom H.D. Tjeenk Willink, Alphen aan de Rijn.
- RIVM, 1994: Effects for the Environment of the Second Environmental Policy Plan. Annex E - H. Bilthoven. The Netherlands.

HALOCARBONS

- Abrahamson, D. 1992: Aluminum and global warming. Nature 356.
- Aluminum Delfzijl, 1992: Polyfluorinated carbon compounds and the greenhouse effect. In Dutch.
- Brackemann, H. en Hanhoff-Stemping, I. (Eds.), 1989: Responsibility means doing without - How to rescue the ozone layer. Umweltbundesamt, Berlin.
- CFC-commission, 1993: CFK Aktieprogramma. Jaarrapportage 1992.
- Cicerone, R.J. 1979: Atmospheric Carbontetrafluoride: A nearly inert gas. Science 206, Oct. 5.
- Cohen, S. and Pickaver, A. (eds.), 1992: Climbing out of the ozone hole. A preliminary survey of alternatives to ozone-depleting chemicals. Greenpeace International, October, 1992.
- Deutscher Bundestag, 1991: Protecting the earth: a status report with recommendations for a new energy policy. Third report. Vol. 1. German Bundestag, Bonn. ISBN 30924521-71-9.
- Houghton J.T., B.A. Callander, and S.K. Varney (eds.), 1992: Climate change 1992. The supplementary report to the IPCC Scientific Assessment.
- Isaksen, I.S.A. 1992: An assessment of the role of CF₄ and C₂F₆ as Greenhouse gases. Oslo, Norway.
- Jacobs, C.B. 1993 and 1994: Preliminary method (version 1 and 2) for estimating country emissions of carbon tetrafluoride. USEPA.
- Khalil M.A.K. and Rasmussen R.A., 1985: Atmospheric Carbon tetrafluoride. Sources and Trends. Geophysical Research Letters 12, 10.
- Kroeze, C. and Reijnders, L., 1992: Halocarbons and global warming. III. Sc. Tot. Env. 111, 291-314
- Olivier, J.G.J., C. Kroeze, A.C. Matthijsen and H.J. Van der Woerd, 1993: Scenarios for Global and Dutch use of Hydrofluorocarbons (HFCs) and their consequences for global warming. RIVM. Paper for Maastricht 13-15 Dec. 1993.
- Penkett S.A., N.J.D. Prosser, R.A. Rasmussen, and M.A.K. Khalil, 1981: Atmospheric measurements of CF₄ and other fluorocarbons containing the CF₃ grouping. J. of Geophys. Research 86, C6, June 20.
- Pepper, W., Leggett, J., Swart, R., Wasson, J., Edmonds, J. and Mintzer, I., 1992: Emission scenarios for the IPCC; an update. Assumptions, methodology, and results. Prepared for IPCC Working Group 1. May 1992.
- Ravishankara, A.R., S. Solomon, A.A. Turnipseed and R.F. Warren, 1993: Atmospheric lifetimes of long-lived halogenated species. Science 259: 194-198.
- RIVM, 1993a: National Environmental Outlook 3: 1993-2015. Samsom H.D. Tjeenk Willink, Alphen aan de Rijn.
- RIVM, 1993b: Effects for the Environment of the Second Environmental Policy Plan. Samsom H.D. Tjeenk Willink, Alphen aan de Rijn.
- UNEP, 1991: Handbook for the Montreal Protocol on substances that deplete the ozone layer. Second edition. Ozone secretariat, Nairobi, Kenya.
- UNEP, 1992: Report of the fourth meeting of the parties to the Montreal Protocol on substances that deplete the ozone layer. Na.92-6155. UNEP/OzL.Pro.4/15.
- Ybema, J.R., 1992: Effecten van isolatiematerialen op broeikasgasemissies. ECN, Petten, Juni 1992. Rapport no. ECN-C-92-025.

TOTAL GREENHOUSE GASES

- IPCC, 1990: Climate Change. The Scientific Assessment. Cambridge University Press, 365 pp.
- IPCC, 1992: Climate Change 1992. The Supplementary Report to the IPCC Scientific Assessment. Cambridge University Press, 200 pp.

**SUMMARY TABLES
GREENHOUSE GAS EMISSIONS**

Table 1. GREENHOUSE GASES IN THE NETHERLANDS 1980 (Gg a⁻¹ full molecular weight).

Greenhouse gas emissions (Gg = 10 ⁹ g)	CO ₂	CH ₄	N ₂ O	NO _x	CO	NM VOC
Total net national emissions	167200	951	55.8			
1. All energy combustion and fugitive	165200	192	4.2			
A. Fuel combustion total	165200	28	4.2			
Energy and transformation	46900	NE	0.4			
Industry	47900	NE	0.4			
Actual from feedstocks	8300	NE	NE			
Transport	23400	NE	3.3			
Commercial/institutional	19400	NE	0.05			
Residential	27200	NE	0.05			
Agriculture/forestry	IE	NE	NE			
Other	0	NE	NE			
Biomass burned for energy	NE	NE	NE			
B. Fugitive fuel emissions	NA	164	NA			
Crude oil	NA	7	NA			
Natural gas	NA	157	NA			
Coal mining	NA	0	NA			
2. Industrial processes (ISIC)	1500	NA	13.6			
A. Chemicals	NE	NA	13.6			
B. Non-metallic mineral products	1500	NA	NA			
C. Other	NE	NA	NA			
3. Solvents and other product use	NA	NE	NA			
4. Agriculture	0	494	23.1			
A. Enteric fermentation	0	416	NA			
B. Animal wastes	0	78	IE			
C. Rice cultivation	NA	NA	NE			
D. Agricultural soils	0	0	23.1			
E. Agricultural waste burning	0	NA	NE			
F. Savanna burning	NA	NA	NA			
5. Land-use change and forestry	NE	0	0			
A. Forest clearing	0	0	0			
B. Conversion of grass to cult.	0	0	0			
C. Plantation establishment	0	0	0			
D. Logging/managed forests	0	0	0			
E. Abandonment of managed lands	0	0	0			
6. Waste	500	263	4.0			
A. Landfills	NA	260	NE			
B. Sewage treatment	NA	3	4.0			
C. Waste incineration	500	NE	0			
7. Other	NA	2	10.8			
specify	NA	2	NE			
A. Drinking-water treatment	NA	2	NE			
A. Polluted surface waters	NA	NE	10.8			

Notes: a. NMVOC = Non-methane volatile organic compounds. b. ISIC = International standard industrial classification
c. CO₂ from biomass burning is not included in the energy category total. If net CO₂ emissions result from unsustainable bioenergy use, this will appear in the land-use change category. d. NE = not estimated e. NA = not applicable f. IE = included elsewhere

Halocarbons (Gg)	
HCFCs	1
HFCs	0
CF ₄	0.5
C ₂ F ₆	0.05

International bunkers (Gg)	
CO ₂ from marine bunkers	30200
CO ₂ from aviation bunkers	2800

Uncertainty: CO₂ 5%; CH₄ 25%; N₂O 50%.

Table 2. GREENHOUSE GASES IN THE NETHERLANDS 1985 (Gg a⁻¹ full molecular weight).

Greenhouse gas emissions (Gg = 10 ⁹ g)	CO ₂	CH ₄	N ₂ O	NO _x	CO	NMVOC
Source categories						
Total net national emissions	152400	1034	59.1	576	1300	509
1. All energy combustion and fugitive	150400	194	4.3	576	1300	397
A. Fuel combustion total	150400	28	4.3	576	1300	
Energy and transformation	42600	NE	0.4	80	342	
Industry	38700	NE	0.3	100	IE	133
Actual from feedstocks	13500	NE	NE	NE		
Transport	23500	NE	3.5	339	962	232
Commercial/institutional	13600	NE	0.05	IE	IE	16
Residential	25000	NE	0.05	IE	IE	16
Agriculture/forestry	6800	NE	NE	IE	IE	
Other	0	NE	NE	57	IE	
Biomass burned for energy	NE	NE	NE	NE	NE	
B. Fugitive fuel emissions	NA	166	NA	NA	NA	
Crude oil	NA	20	NA	NA	NA	
Natural gas	NA	146	NA	NA	NA	
Coal mining	NA	NA	NA	NA	NA	
2. Industrial processes (ISIC)	1500	NE	16.4		NA	
A. Chemicals	NE	NE	16.4			
B. Non-metallic mineral products	1500	NE	NE			
C. Other	NE	NE	NE			
3. Solvents and other product use	NA	NE	NA			112
4. Agriculture	0	512	23.4			
A. Enteric fermentation	0	421	NA			
B. Animal wastes	0	91	IE			
C. Rice cultivation	NA	NA	NA			
D. Agricultural soils	0	NE	23.4			
E. Agricultural waste burning	0	NA	NE			
F. Savanna burning	NA	NA	NA			
5. Land-use change and forestry	NE	0	0			
A. Forest clearing	0	0	0			
B. Conversion of grass to cult.	0	0	0			
C. Plantation establishment	NE	0	0			
D. Logging/managed forests	0	0	0			
E. Abandonment of managed lands	0	0	0			
6. Waste	500	326	4.1			
A. Landfills	NA	323	NE			
B. Sewage treatment	NA	3	4.0			
C. Waste incineration	500	0	0.1			
7. Other specify	NA	2	10.8			
A. Drinking-water treatment	NA	2	NE			
B. Polluted surface waters	NA	NA	10.8			

Notes a. NMVOC = Non-methane volatile organic compounds. b. ISIC = International standard industrial classification
c. CO₂ from biomass burning is not included in the energy category total. If net CO₂ emissions result from unsustainable bioenergy use, this will appear in the land-use change category. d. NE = not estimated e. NA = not applicable f. IE = included elsewhere

Halocarbons (Gg)
HCFCs 1.7
HFCs 0
CF₄ 0.5
C₂F₆ 0.05

International bunkers (Gg)
CO₂ from marine bunkers 28200
CO₂ from aviation bunkers 3500

Uncertainty: CO₂ 5%; CH₄ 25%; N₂O 50%.

Table 3. GREENHOUSE GASES IN THE NETHERLANDS 1990 (Gg a⁻¹ full molecular weight).

Greenhouse gas emissions (Gg = 10 ⁹ g)	CO ₂	CH ₄	N ₂ O	NO _x	CO	NM VOC
Source categories						
Total net national emissions	167600	1067	59.6	575	1030	459
1. All energy combustion and fugitive	164800	177	6.1	575	1030	348
A. Fuel combustion total	164800	28	6.1	575	1030	
Energy and transformation	51400	NE	0.5	72		
Industry	33400	NE	0.1	106	229	123
Actual from feedstocks	14800	NE	NE			
Transport	26900	NE	5.4	351	716	195
Commercial/institutional	9500	NE	0.05			15
Residential	19200	NE	0.05			15
Agriculture/forestry	8600	NE	NE			
Other	0	NE	NE	47	84	
Statistical differences	1100	NE	NE			
Biomass burned for energy	NE	NE	NE			
B. Fugitive fuel emissions	NA	149	NA			
Crude oil	NA	19	NA			
Natural gas	NA	130	NA			
Coal mining	NA	NA	NA			
2. Industrial processes (ISIC)	1900	NE	16.4			
A. Chemicals	NE	NE	16.4			
B. Non-metallic mineral products	1900	NE	NE			
C. Other	NE	NE	NE			
3. Solvents and other product use	NE	NE	NE			111
4. Agriculture	0	508	22.1			
A. Enteric fermentation	0	402	NA			
B. Animal wastes	0	106	IE			
C. Rice cultivation	NA	NA	NA			
D. Agricultural soils	0	NE	22.1			
E. Agricultural waste burning	0	NA	NA			
F. Savanna burning	NA	NA	NA			
5. Land-use change and forestry	(-120)*	0	0			
A. Forest clearing	0	0	0			
B. Conversion of grass to cult.	0	0	0			
C. Plantation establishment	(-120)	0	0			
D. Logging/managed forests	0	0	0			
E. Abandonment of managed lands	0	0	0			
6. Waste	900	380	4.1			
A. Landfills	NE	377	NE			
B. Sewage treatment	NE	3	4.0			
C. Waste incineration	900	0	0.1			
7. Other	IE	2	10.9			
A. Drinking-water treatment	IE	2	NE			
A. Polluted surface waters	NA	NE	10.9			

Notes: a. NMVOC = Non-methane volatile organic compounds. b. ISIC = International standard industrial classification
c. CO₂ from biomass burning is not included in the energy category total. If net CO₂ emissions result from unsustainable bioenergy use, this will appear in the land-use change category. d. NE = not estimated, small e. NA = not applicable. f. IE = included elsewhere

* Not included in national Total.

Halocarbons (Gg)	
HCFCs	3.5
HFCs	0
CF ₄	0.5
C ₂ F ₆	0.05

International bunkers (Gg)	
CO ₂ from marine bunkers	35900
CO ₂ from aviation bunkers	4500

Uncertainty: CO₂ 5%; CH₄ 25%; N₂O 50%

Table 4. GREENHOUSE GASES IN THE NETHERLANDS 1991 (Gg a⁻¹ full molecular weight).

Greenhouse gas emissions (Gg = 10 ⁹ g)	CO ₂	CH ₄	N ₂ O	NO _x	CO	NM VOC
Source categories						
Total net national emissions	174000	1089	60.2			
1. All energy combustion and fugitive	171200	197	6.0			
A. Fuel combustion total	171200	28	6.0			
Energy and transformation	52900	NE	0.4			
Industry	32300	NE	0.1			
Actual from feedstocks	15600	NE	NE			
Transport	26900	NE	5.4			
Commercial/institutional	11300	NE	0.05			
Residential	21700	NE	0.05			
Agriculture/forestry	9400	NE	NE			
Other	0	NE	NE			
Statistical differences	1000	NE	NE			
Biomass burned for energy	NE	NE	NE			
B. Fugitive fuel emissions	NA	169	NA			
Crude oil	NA	17	NA			
Natural gas	NA	152	NA			
Coal mining	NA	NA	NA			
2. Industrial processes (ISIC)	1900	NE	16.4			
A. Chemicals	NE	NE	16.4			
B. Non-metallic mineral products	1900	NE	NE			
C. Other	NE	NE	NE			
3. Solvents and other product use	NE	NE	NA			
4. Agriculture	0	512	22.3			
A. Enteric fermentation	0	412	NA			
B. Animal wastes	0	100	IE			
C. Rice cultivation	NA	NA	NA			
D. Agricultural soils	0	NE	22.3			
E. Agricultural waste burning	0	NA	NA			
F. Savanna burning	NA	NA	NA			
5. Land-use change and forestry	(-120)*	0	0			
A. Forest clearing	0	0	0			
B. Conversion of grass to cult.	0	0	0			
C. Plantation establishment	(-120)	0	0			
D. Logging/managed forests	0	0	0			
E. Abandonment of managed lands	0	0	0			
6. Waste	900	378	4.3			
A. Landfills	NA	375	NE			
B. Sewage treatment	NA	3	4.2			
C. Waste incineration	900	0	0.1			
7. Other	IE	2	11.0			
A. Drinking-water treatment	IE	2	NE			
A. Polluted surface waters	NA	NE	11.0			

Notes: a. NM VOC = Non-methane volatile organic compounds. b. ISIC = International standard industrial classification
c. CO₂ from biomass burning is not included in the energy category total. If net CO₂ emissions result from unsustainable bioenergy use, this will appear in the land-use change category. d. NE = not estimated, small
e. NA = not applicable. f. IE = included elsewhere.

* Not included in national total.

Halocarbons (Gg)

HFCs	3.5
HFCs	0
CF ₄	0.5
C ₂ F ₆	0.05

International bunkers (Gg)

CO ₂ from marine bunkers	36700
CO ₂ from aviation bunkers	5000

Uncertainty: CO₂ 5%; CH₄ 25%; N₂O 50%.

Table 5. GREENHOUSE GASES IN THE NETHERLANDS 1992 (Gg a⁻¹ full molecular weight).

Greenhouse gas emissions Source categories	CO ₂	CH ₄	N ₂ O	NO _x	CO	NM VOC
Total net national emissions	172100	1069	59.9			
1. All energy combustion and fugitive	169300	193	6.2			
A. Fuel combustion total	169300	28	6.2			
Energy and transformation	53200	NE	0.4			
Industry	34300	NE	0.1			
Actual from feedstocks	14900	NE	NE			
Transport	28000	NE	5.6			
Commercial/institutional	10600	NE	0.05			
Residential	19500	NE	0.05			
Agriculture/forestry	9300	NE	NE			
Other	0	NE	NE			
Statistical differences	-400	NE	NE			
Biomass burned for energy	NE	NE	NE			
B. Fugitive fuel emissions	NA	165	NA			
Crude oil	NA	17	NA			
Natural gas	NA	148	NA			
Coal mining	NA	NA	NA			
2. Industrial processes (ISIC)	1900	NE	16.4			
A. Chemicals	NE	NE	16.4			
B. Non-metallic mineral products	1900	NE	NE			
C. Other	NE	NE	NE			
3. Solvents and other product use	NE	NE	NE			
4. Agriculture	0	498	21.9			
A. Enteric fermentation	0	401	NA			
B. Animal wastes	0	97	IE			
C. Rice cultivation	NA	NA	NA			
D. Agricultural soils	0	NE	21.9			
E. Agricultural waste burning	0	NE	NA			
F. Savanna burning	NA	NA	NA			
5. Land-use change and forestry	(-120)*	0	0			
A. Forest clearing	0	0	0			
B. Conversion of grass to cult.	0	0	0			
C. Plantation establishment	(-120)	0	0			
D. Logging/managed forests	0	0	0			
E. Abandonment of managed lands	0	0	0			
6. Waste	900	376	4.6			
A. Landfills	NA	373	NE			
B. Sewage treatment	NA	3	4.5			
C. Waste incineration	900	0	0.1			
7. Other specify	IE	2	10.7			
A. Drinking-water treatment	IE	2	NE			
B. Polluted surface waters	NA	NE	10.7			

Notes: a. NMVOC = Non-methane volatile organic compounds b. ISIC = International standard industrial classification
c. CO₂ from biomass burning is not included in the energy category total. If net CO₂ emissions result from unsustainable bioenergy use, this will appear in the land-use change category. d. NE = not estimated, small e. NA = not applicable f. IE = included elsewhere

* Not included in national total.

Halocarbons (Gg)

HCFCs	4.6
HFCs	0
CF ₄	0.5
C ₂ F ₆	0.05

International bunkers (Gg)

CO ₂ from marine bunkers	36800
CO ₂ from aviation bunkers	5900

Uncertainty: CO₂ 5%; CH₄ 25%; N₂O 50%.

**SUMMARY TABLES
GREENHOUSE GAS EMISSIONS
(Temperature corrected for CO₂)**

Table 6. GREENHOUSE GASES IN THE NETHERLANDS 1988 (Gg a⁻¹ full molecular weight). Temperature corrected for CO₂ only.

Greenhouse gas emissions (Gg = 10 ⁹ g)	CO ₂	CH ₄	N ₂ O	NO _x	CO	NMVOC
Total net national emissions	166500	951	55.8			
1. All energy combustion and fugitive	164500	192	4.2			
A. Fuel combustion total	164500	28	4.2			
Energy and transformation	46900	NE	0.4			
Industry	47800	NE	0.4			
Actual from feedstocks	8300	NE	NE			
Transport	23400	NE	3.3			
Commercial/institutional	19200	NE	0.05			
Residential	26800	NE	0.05			
Agriculture/forestry	IE	NE	NE			
Other	0	NE	NE			
Biomass burned for energy	NE	NE	NE			
B. Fugitive fuel emissions	NA	164	NA			
Crude oil	NA	7	NA			
Natural gas	NA	157	NA			
Coal mining	NA	0	NA			
2. Industrial processes (ISIC)	1500	NA	13.6			
A. Chemicals	NE	NA	13.6			
B. Non-metallic mineral products	1500	NA	NA			
C. Other	NE	NA	NA			
3. Solvents and other product use	NA	NE	NA			
4. Agriculture	0	494	23.1			
A. Enteric fermentation	0	416	NA			
B. Animal wastes	0	78	IE			
C. Rice cultivation	NA	NA	NE			
D. Agricultural soils	0	0	23.1			
E. Agricultural waste burning	0	NA	NE			
F. Savanna burning	NA	NA	NA			
5. Land-use change and forestry	NE	0	0			
A. Forest clearing	0	0	0			
B. Conversion of grass to cult.	0	0	0			
C. Plantation establishment	0	0	0			
D. Logging/managed forests	0	0	0			
E. Abandonment of managed lands	0	0	0			
6. Waste	500	263	4.0			
A. Landfills	NA	260	NE			
B. Sewage treatment	NA	3	4.0			
C. Waste incineration	500	NE	0			
7. Other	NA	2	10.8			
specify	NA	2	NE			
A. Drinking-water treatment	NA	2	NE			
A. Polluted surface waters	NA	NE	10.8			

Notes: a. NMVOC = Non-methane volatile organic compounds. b. ISIC = International standard industrial classification
c. CO₂ from biomass burning is not included in the energy category total. If net CO₂ emissions result from unsustainable bioenergy use, this will appear in the land-use change category. d. NE = not estimated e. NA = not applicable f. IE = included elsewhere

Halocarbons (Gg)	
HCFCs	1
HFCs	0
CF ₄	0.5
C ₂ F ₆	0.05

International bunkers (Gg)	
CO ₂ from marine bunkers	30200
CO ₂ from aviation bunkers	2800

Uncertainty: CO₂ 5%; CH₄ 25%; N₂O 50%.

Table 7. GREENHOUSE GASES IN THE NETHERLANDS 1985 (Gg a⁻¹ full molecular weight). Temperature corrected for CO₂.

Greenhouse gas emissions (Gg = 10 ⁹ g)	CO ₂	CH ₄	N ₂ O	NO _x	CO	NMVOG
Total net national emissions	149600	1034	59.1	576	1300	509
1. All energy combustion and fugitive	147600	194	4.3	576	1300	397
A. Fuel combustion total	147600	28	4.3	576	1300	
Energy and transformation	42500	NE	0.4	80	342	
Industry	38200	NE	0.3	100	IE	133
Actual from feedstocks	13500	NE	NE	NE		
Transport	23500	NE	3.5	339	962	232
Commercial/institutional	13200	NE	0.05	IE	IE	16
Residential	23500	NE	0.05	IE	IE	16
Agriculture/forestry	6400	NE	NE	IE	IE	
Other	0	NE	NE	57	IE	
Biomass burned for energy	NE	NE	NE	NE	NE	
B. Fugitive fuel emissions	NA	166	NA	NA	NA	
Crude oil	NA	20	NA	NA	NA	
Natural gas	NA	146	NA	NA	NA	
Coal mining	NA	NA	NA	NA	NA	
2. Industrial processes (ISIC)	1500	NE	16.4		NA	
A. Chemicals	NE	NE	16.4			
B. Non-metallic mineral products	1500	NE	NE			
C. Other	NE	NE	NE			
3. Solvents and other product use	NA	NE	NA			
4. Agriculture	0	512	23.4			
A. Enteric fermentation	0	421	NA			
B. Animal wastes	0	91	IE			
C. Rice cultivation	NA	NA	NA			112
D. Agricultural soils	0	NE	23.4			
E. Agricultural waste burning	0	NA	NE			
F. Savanna burning	NA	NA	NA			
5. Land-use change and forestry	NE	0	0			
A. Forest clearing	0	0	0			
B. Conversion of grass to cult.	0	0	0			
C. Plantation establishment	NE	0	0			
D. Logging/managed forests	0	0	0			
E. Abandonment of managed lands	0	0	0			
6. Waste	500	326	4.1			
A. Landfills	NA	323	NE			
B. Sewage treatment	NA	3	4.0			
C. Waste incineration	500	0	0.1			
7. Other specify	NA	2	10.8			
A. Drinking-water treatment	NA	2	NE			
B. Polluted surface waters	NA	NA	10.8			

Notes a. NMVOG = Non-methane volatile organic compounds. b. ISIC = International standard industrial classification
c. CO₂ from biomass burning is not included in the energy category total. If net CO₂ emissions result from unsustainable bioenergy use, this will appear in the land-use change category. d. NE = not estimated e. NA = not applicable f. IE = included elsewhere

Halocarbons (Gg)
HCFCs 1.7
HFCs 0
CF₄ 0.5
C₂F₆ 0.05

International bunkers (Gg)
CO₂ from marine bunkers 28200
CO₂ from aviation bunkers 3500

Uncertainty: CO₂ 5%; CH₄ 25%; N₂O 50%.

Table 8. GREENHOUSE GASES IN THE NETHERLANDS 1990 (Gg a⁻¹ full molecular weight). Temperature corrected for CO₂.

Greenhouse gas emissions (Gg = 10 ⁹ g)	CO ₂	CH ₄	N ₂ O	NO _x	CO	NM VOC
Total net national emissions	174000	1067	59.6	575	1030	459
1. All energy combustion and fugitive	171200	177	6.1	575	1030	348
A. Fuel combustion total	171200	28	6.1	575	1030	
Energy and transformation	51600	NE	0.5	72		
Industry	34100	NE	0.1	106	229	123
Actual from feedstocks	14800	NE	NE			
Transport	26900	NE	5.4	351	716	195
Commercial/institutional	10900	NE	0.05			15
Residential	22300	NE	0.05			15
Agriculture/forestry	9700	NE	NE			
Other	0	NE	NE	47	84	
Statistical differences	1100	NE	NE			
Biomass burned for energy	NE	NE	NE			
B. Fugitive fuel emissions	NA	149	NA			
Crude oil	NA	19	NA			
Natural gas	NA	130	NA			
Coal mining	NA	NA	NA			
2. Industrial processes (ISIC)	1900	NE	16.4			
A. Chemicals	NE	NE	16.4			
B. Non-metallic mineral products	1900	NE	NE			
C. Other	NE	NE	NE			
3. Solvents and other product use	NE	NE	NE			111
4. Agriculture	0	508	22.1			
A. Enteric fermentation	0	402	NA			
B. Animal wastes	0	106	IE			
C. Rice cultivation	NA	NA	NA			
D. Agricultural soils	0	NE	22.1			
E. Agricultural waste burning	0	NA	NA			
F. Savanna burning	NA	NA	NA			
5. Land-use change and forestry	(-120)*	0	0			
A. Forest clearing	0	0	0			
B. Conversion of grass to cult.	0	0	0			
C. Plantation establishment	(-120)	0	0			
D. Logging/managed forests	0	0	0			
E. Abandonment of managed lands	0	0	0			
6. Waste	900	380	4.1			
A. Landfills	NE	377	NE			
B. Sewage treatment	NE	3	4.0			
C. Waste incineration	900	0	0.1			
7. Other specify	IE	2	10.9			
A. Drinking-water treatment	IE	2	NE			
A. Polluted surface waters	NA	NE	10.9			

Notes: a. NMVOC = Non-methane volatile organic compounds. b. ISIC = International standard industrial classification
c. CO₂ from biomass burning is not included in the energy category total. If net CO₂ emissions result from unsustainable bioenergy use, this will appear in the land-use change category. d. NE = not estimated, small e. NA = not applicable. f. IE = included elsewhere

* Not included in national Total.

Halocarbons (Gg)

HCFCs	3.5
HFCs	0
CF ₄	0.5
C ₂ F ₆	0.05

International bunkers (Gg)

CO ₂ from marine bunkers	35900
CO ₂ from aviation bunkers	4500

Uncertainty: CO₂ 5%; CH₄ 25%; N₂O 50%

Table 8. GREENHOUSE GASES IN THE NETHERLANDS 1991 (Gg a⁻¹ full molecular weight). Temperature corrected for CO₂.

Greenhouse gas emissions (Gg = 10 ⁹ g)	CO ₂	CH ₄	N ₂ O	NO _x	CO	NMVOG
Total net national emissions	174400	1089	60.2			
1. All energy combustion and fugitive	171600	197	6.0			
A. Fuel combustion total	171600	28	6.0			
Energy and transformation	52900	NE	0.4			
Industry	32400	NE	0.1			
Actual from feedstocks	15600	NE	NE			
Transport	26900	NE	5.4			
Commercial/institutional	11400	NE	0.05			
Residential	21900	NE	0.05			
Agriculture/forestry	9500	NE	NE			
Other	0	NE	NE			
Statistical differences	1000	NE	NE			
Biomass burned for energy	NE	NE	NE			
B. Fugitive fuel emissions	NA	169	NA			
Crude oil	NA	17	NA			
Natural gas	NA	152	NA			
Coal mining	NA	NA	NA			
2. Industrial processes (ISIC)	1900	NE	16.4			
A. Chemicals	NE	NE	16.4			
B. Non-metallic mineral products	1900	NE	NE			
C. Other	NE	NE	NE			
3. Solvents and other product use	NE	NE	NA			
4. Agriculture	0	512	22.3			
A. Enteric fermentation	0	412	NA			
B. Animal wastes	0	100	IE			
C. Rice cultivation	NA	NA	NA			
D. Agricultural soils	0	NE	22.3			
E. Agricultural waste burning	0	NA	NA			
F. Savanna burning	NA	NA	NA			
5. Land-use change and forestry	(-120)*	0	0			
A. Forest clearing	0	0	0			
B. Conversion of grass to cult.	0	0	0			
C. Plantation establishment	(-120)	0	0			
D. Logging/managed forests	0	0	0			
E. Abandonment of managed lands	0	0	0			
6. Waste	900	378	4.3			
A. Landfills	NA	375	NE			
B. Sewage treatment	NA	3	4.2			
C. Waste incineration	900	0	0.1			
7. Other	IE	2	11.0			
A. Drinking-water treatment	IE	2	NE			
A. Polluted surface waters	NA	NE	11.0			

Notes: a. NMVOG = Non-methane volatile organic compounds. b. ISIC = International standard industrial classification

c. CO₂ from biomass burning is not included in the energy category total. If net CO₂ emissions result from unsustainable bioenergy use, this will appear in the land-use change category. d. NE = not estimated, small
e. NA = not applicable. f. IE = included elsewhere.

* Not included in national total.

Halocarbons (Gg)

HCFCs	3.5
HFCs	0
CF ₄	0.5
C ₂ F ₆	0.05

International bunkers (Gg)

CO ₂ from marine bunkers	36700
CO ₂ from aviation bunkers	5000

Uncertainty: CO₂ 5%, CH₄ 25%, N₂O 50%

Table 10. GREENHOUSE GASES IN THE NETHERLANDS 1992 (Gg a⁻¹, full molecular weight). Temperature corrected for CO₂.

Greenhouse gas emissions	CO ₂	CH ₄	N ₂ O	NO _x	CO	NM VOC
Total net national emissions	176600	1069	59.9			
1. All energy combustion and fugitive	173800	193	6.2			
A. Fuel combustion total	173800	28	6.2			
Energy and transformation	53300	NE	0.4			
Industry	34800	NE	0.1			
Actual from feedstocks	14900	NE	NE			
Transport	28000	NE	5.6			
Commercial/institutional	11500	NE	0.05			
Residential	21600	NE	0.05			
Agriculture/forestry	10100	NE	NE			
Other	0	NE	NE			
Statistical differences	-400	NE	NE			
Biomass burned for energy	NE	NE	NE			
B. Fugitive fuel emissions	NA	165	NA			
Crude oil	NA	17	NA			
Natural gas	NA	148	NA			
Coal mining	NA	NA	NA			
2. Industrial processes (ISIC)	1900	NE	16.4			
A. Chemicals	NE	NE	16.4			
B. Non-metallic mineral products	1900	NE	NE			
C. Other	NE	NE	NE			
3. Solvents and other product use	NE	NE	NE			
4. Agriculture	0	498	21.9			
A. Enteric fermentation	0	401	NA			
B. Animal wastes	0	97	IE			
C. Rice cultivation	NA	NA	NA			
D. Agricultural soils	0	NE	21.9			
E. Agricultural waste burning	0	NE	NA			
F. Savanna burning	NA	NA	NA			
5. Land-use change and forestry	(-120)*	0	0			
A. Forest clearing	0	0	0			
B. Conversion of grass to cult.	0	0	0			
C. Plantation establishment	(-120)	0	0			
D. Logging/managed forests	0	0	0			
E. Abandonment of managed lands	0	0	0			
6. Waste	900	376	4.6			
A. Landfills	NA	373	NE			
B. Sewage treatment	NA	3	4.5			
C. Waste incineration	900	0	0.1			
7. Other	IE	2	10.7			
A. Drinking-water treatment	IE	2	NE			
B. Polluted surface waters	NA	NE	10.7			

Notes: a. NMVOC = Non-methane volatile organic compounds b. ISIC = International standard industrial classification
c. CO₂ from biomass burning is not included in the energy category total. If net CO₂ emissions result from unsustainable bioenergy use, this will appear in the land-use change category. d. NE = not estimated, small e. NA = not applicable f. IE = included elsewhere

* Not included in national total.

Halocarbons (Gg)

HCFCs	4.6
HFCs	0
CF ₄	0.5
C ₂ F ₆	0.05

International bunkers (Gg)

CO ₂ from marine bunkers	36800
CO ₂ from aviation bunkers	5900

Uncertainty: CO₂ 5%; CH₄ 25%; N₂O 50%.

Annex 1. IPCC default and Netherlands emission factors for carbon dioxide from energy, used in the detailed fuel approach.

Fuel	Emission factor IPCC defaults kg C/GJ	Energy content IEA defaults GJ/Tonne	Emission factor Netherlands kg C/GJ	Energy content Netherlands GJ/Tonne or /1000 m ³
LIQUID FOSSIL				
Primary fuels				
Crude oil	20.0		19.9	42.7
Natural gas liquids	15.2			44.0
Secondary fuels/products				
Gasoline	18.9	44.80	19.9	44.0
Kerosene	19.6	44.75		43.5
Jet fuel	19.5	44.59		43.5
Gas/Diesel oil	20.2	43.33		42.7
Residual fuel oil	21.1	40.19	21.0	41.0
LPG	17.2	47.31	18.0	45.2
Naphtha	20.0*	45.01		44.0
Bitumen	22.0	40.19		41.5
Lubricants	20.0*	40.19		41.4
Petroleum coke	27.5	40.19	28.1	35.2
Refinery feedstocks	20.0*	44.80		
Other oil	20.0*	40.19		
SOLID FOSSIL				
Primary fuels				
Coking coal	25.8		28.1	35.2
Steam coal	25.8		27.5	27.0
Lignite	26.1		27.5	21.0
Sub-bituminous coal	27.6		27.5	21.0
Peat	28.9			
Secondary fuels/products				
BKB and Patent fuel	25.8*			
Coke	29.5		28.1	28.5
GASEOUS FOSSIL				
Natural gas (dry)	15.3		15.3	31.65
Refinery feedstock gas			15.3	31.65
BIOMASS				
Solid biomass	25.8*		28.4	15.5
Liquid biomass	20.0*			
BUNKERS				
Jet fuel bunkers	19.5	44.59		43.5
Gas/Diesel oil bunkers	20.2	43.33		42.7
Residual fuel oil bunkers	21.1	40.19	21.0	41.0
Other oil bunkers	20.0*	40.19		41.0
MUNICIPAL SOLID WASTE			20.0	10.5

* This value is a default value until a fuel specific carbon emission factor is determined. For oil products and liquid biomass fuel, the default value is that for crude oil. For coal products and solid biomass fuel, the default value is that for steam coal.

Sources: IPCC/OECD Draft Guidelines for National Greenhouse Gas Inventories, December 1993. Zonneveld, 1991. CBS, 1993.