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THE EMISSION OF GREENHOUSE GASES IN THE NETHERLANDS

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ABBREVIATIONS

AER	Algemene Energie Raad (General Energy Advisory Council)
CAEP	Committee on Aviation Environmental Protection of ICAO
CBS	Centraal Bureau voor de Statistiek (Central Bureau for Statistics)
CEC	Commission of the European Communities
CFCs	Chlorofluorocarbons
CNG	Compressed Natural Gas
CVT	Continuous Variable Transmission
DGMK	Deutsche Wissenschaftliche Gesellschaft für Erdöl, Erdgas und Kohle (German Society for Petroleum Science and Coal Chemistry)
EAEC	European Atomic Energy Community
EC	European Community
ECN	Energie-onderzoek Centrum Nederland (Neth. Energy Research Foundation
EPA	United States Environmental Protection Agency
EZ	Ministerie van Economische Zaken (Ministry of Economic Affairs)
GHG	Greenhouse gases
GVE	Groot Vee Eenheid (Dairy Cow Unit)
GWP	Global Warming Potential
HCs	Hydrocarbons
HFCs	Hydrochlorofluorocarbons
ICAO	International Civil Aviation Organization
IEA	International Energy Agency
IHE	International Institute for Hydraulic and Environmental Engineering
IFP	Institut Francais du Petrole
IGCC	Integrated Coal Gasification Combined Cycle
IPCC	Intergovernmental Panel on Climate Change
IVAM	Interfacultaire Vakgroep Milieukunde of the University of Amsterdam
JEA	Japan Environment Agency
KWS 2000	Project 'Koolwaterstoffen 2000' ('Hydrocarbons 2000')
LHV	Lower Heating Value
LNV	Ministerie van Landbouw, Natuurbeheer en Visserij (Ministry of Agriculture, Nature conservation and Fishery)
LPG	Liquified Petrol Gas
LUW	Landbouw Universiteit Wageningen (Agricultural University Wageningen)
MCFC	Molten Carbonate Fuel Cell
MEC	Memorandum on Energy Conservation (in Dutch: Nota Energiebesparing)
NEP	National Environmental Policy Plan 1990-1994 (in Dutch: Nationaal Milieu beleidsplan 1990-1994)
NEPP	National Environmental Policy Plan Plus 1990-1994 (in Dutch: National Milieubeleidsplan plus+ 1990-1994)
n.a.	Not available
NIOZ	Nederlands Instituut voor Onderzoek der Zee (Netherlands Institute for Marine Research)
ODP	Ozone Depleting Potential
OECD	Organization for Economic Co-operation and Development
Q.R.	Quality Rating
RCN	Reststoffen Centrum Nederland
RDF	Refuse Derived Fuel
RSWG	IPCCs Response Strategies Workgroup
SCR	Selective Catalytic Reduction
STAG	Steam and Gas Turbine

abbreviations continued

SVV-II	Structuurschema Verkeer en Vervoer (deel II) (Second Structure Scheme for Traffic and Transport)
TPER	Total Primary Energy Requirement
UNEP	United Nations Environment Program
VROM	Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer (Ministry of Housing, Physical Planning and Environment)
WWTP	Waste Water Treatment Plant

ENGLISH-DUTCH TRANSLATION OF TECHNICAL TERMS

afforestation	herbebossing
animal husbandry	veehouderij
anthropogenic	door de mens veroorzaakt
arable land	landbouwgrond
biogenic	door levende organismen gevormd
bogs	veenmosveen, laagveen
bunker	brandstof-opslagplaats voor internationaal water- en lucht-transport
card board	karton
cast iron	gietijzer
catalyst	katalysator
cereal	graan
cogeneration	warmte/kracht-koppeling (WKK)
coke	cokes
commercial	dienstensector (meestal incl. landbouw)
concentrate	krachtvoer
condensing boiler	hoog-rendement CV-ketel
dairy cow	melkvee
degreasing	ontvetten
district heating	stadsverwarming
ductile iron	nodulair gietijzer
dwelling	woning
effluent	rioolwater
enteric fermentation	vergisting in de ingewanden
feedstock	grondstof
fens	moerasland
fermentation	vergisting
fertilizer	kunstmeststof
flatus gas	darmgas
flared	afgefakkeld
fleet	wagenpark
fodder	veevoeder
freshwater	zoet water
gasoline	benzine
greenhouse horticulture	glastuinbouw
heifer	vaars (kalfkoe)
heterogenous reaction	chemische reactie tussen stoffen in verschillende fasen (bijv. tussen een vaste stof en een gas)
horticulture	tuinbouw

english-dutch translations continued.

incinerator	verbrandingsoven
inland water	binnenwater
insulation	isolatie
jet-fuel	kerosine
lacquer	lak
landfill	vuilstortplaats
leached	uitgespoeld
lead oakum	lood-striktouw
long roughage	lang ruwvoer
lubricants	smeermiddelen
marshes	moeras
manure	mest
methanogenesis	methaanvorming
peat soil	veengrond
porker	mestvarken
power plant	electriciteitscentrale
primary energy	primaire energie (onbehandelde energie, zoals ruwe aardolie)
pseudo ruminant	pseudo herkauwer
pulverized coal	poederkool
retrofitting	renovatie
residential	huishoudens
reciprocating engine	motor
renewable energy	duurzame energie (zon, wind, water e.d.)
root	wortel
roughage	ruwvoer
ruminant	herkauwer
sewage sludge	riool-slib
solvent	oplosmiddel
stoichiometric ratio	verhouding van stoffen in een chemische reactie
stationary	vast (d.w.z. niet mobiel)
town gas	stadsgas
tuber	knol
vented gas	afgeblazen gas (in de buitenlucht)
wetlands	drassig land

CHEMICAL FORMULAS

CFCs	Chlorofluorocarbons
CFC-11	Trichlorofluorocarbon, $CFCl_3$
CFC-12	Dichloro-difluorocarbon, CF_2Cl_2
CFC-113	Trichloro-tetrafluorethane, CCl_2FCClF_2
CFC-22	Chlorodifluoromethane, $CHClF_2$
CH_3CCl_3	Methyl chloroform
CH_4	Methane, methaan
CO	Carbon monoxide
CO_2	Carbon dioxide
H_2	Hydrogen
Halon 1211	Bromochlorodifluoromethane, CF_2BrCl
Halon 1301	Bromotrifluoromethane, CF_3Br

chemical formulas continued

Halon 2402	Dibromo-tetrafluoroethane, $C_2F_4Br_2$
HC-10	Tetrachloride, CCl_4
HC-140a	Methylchloroform, $C_2H_3Cl_3$
HCFCs	Hydrochlorofluorocarbons
HCFC-123	$C_2HF_3Cl_2$
HCFC-124	$CHFClCF_3$
HCFC-132b	$C_2HSF_2Cl_2$
HCFC-141b	CH_3CFCl_2
HCFC-142b	CH_3CF_2Cl
HFC-125	CHF_2CF_3
HFC-134a	$C_2H_2F_4$
HFC-143A	CH_3CF_3
HFC-152A	CH_3CHF_2
N_2O	Nitrous oxide
NMHC	Non-methane hydrocarbons
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_X	Nitric oxides
O_3	Ozone
SO_2	Sulphur dioxide

UNITS

g	Gram
Gg	Gigagram = 10^9 g
Gton	Gigaton = 10^9 ton = 10^{12} kg = 10^{15} g
Ha	Hectare = 10^4 m^2
Kton	Kiloton = 10^3 ton
Mton	Megaton = 10^6 ton = 10^9 kg = 10^{12} g = 1 Tg
Pg	Petagram = 10^{15} g
PJ	PetaJoule electricity = 10^{15} Joule
ppbv	Parts per billion 10^9 by volume
ppmv	Parts per million 10^6 by volume
pptv	Parts per trillion 10^{12} by volume
mld	Milliard (10^9)
Tg	Terra gram = 10^{12} g
ton	Metric ton = 1,000

SUMMARY

Climate change has become an important component of Dutch environmental and energy policies. Human induced climate change has become an important issue. It is caused by the accumulation of a number of radiatively active trace gases in the atmosphere. Until recently policy discussions almost exclusively focused on the most important greenhouse gas: carbon dioxide. This report presents an estimate of the emissions of all trace gases that contributed either directly or indirectly (e.g. precursors of tropospheric ozone) to climate change in the Netherlands in the late eighties. These gases are (with increasing levels of uncertainty in the emissions data): carbon dioxide (CO_2), CFCs and halons, nitrogen oxides (NO_x), volatile organic compounds (VOC), carbon monoxide (CO), methane (CH_4) and nitrous oxide (N_2O). Most attention is given in this report to the last two gases because of the absence so far of any detailed information on the national emissions of methane and nitrous oxide. In Table 1 a summary is given of emissions per gas and their equivalent carbon dioxide emissions.

Table 1: Greenhouse gas emissions in the Netherlands in 1989/1990 (in weight and CO_2 equivalent for a time horizon of 100 and 20 years).

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

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

Because of the relatively small land area of the Netherlands, energy related emissions in industry, energy conversion, transportation and the residential sector dominate the total emissions in terms of equivalent carbon dioxide emissions, as compared to land related natural and agricultural emissions. Interestingly, if we apply the Global Warming Potentials as proposed by the Intergovernmental Panel on Climate Change (IPCC), the energy related ozone precursors CO, NO_x and VOC contribute more than 10% to the total emissions and more than double when a shorter time horizon is chosen. Methane is found to be emitted primarily by ruminants, landfills, natural waters and wetlands and losses during production and distribution of natural gas. Nitrous oxide is thought to be released mainly in fertilized grasslands, inland and coastal waters and transportation.

In the report future developments under existing and possible future policies are reviewed (Table 2). It is concluded that the total contribution in the Netherlands under existing policy is decreasing mainly due to the phase-out of the Dutch production of CFCs regulated under the Montreal protocol by 1988, ahead of the schedule agreed upon internationally. CO_2 emissions are planned to be reduced by 3-5% in the year 2000 as compared to the 1989/1990 level. This can be considered as a first step towards further reductions that are necessary globally to stabilize ambient concentration. Options to achieve additional reductions are briefly reviewed. Emissions of nitrogen oxides, carbon monoxides and VOC are also planned to be reduced by 50% in 2000 from present levels under policies aiming at limiting

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

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

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

acidification and photo-chemical air pollution. Climate change offers an additional reason to pursue and maybe intensify these policies. Although no specific policies exist to limit the emissions of methane, developments in other areas, like waste and livestock management and replacement of old town gas distribution networks, are likely to cause an "autonomous" decrease of the emissions by 10%. For nitrous oxide the reduction seems to depend on the balance between decrease caused by reduced application of nitrogenous fertilizers and growth caused by transportation (application of catalysts). Especially for methane additional measures to limit emissions further (about 20%) seem to be feasible.

1. INTRODUCTION

The problem of climate change has captured a prominent position on the environmental agendas in the Netherlands. This is caused by mounting concern among scientists, policy makers and the general public about the increasing size and scope of environmental degradation. Although many uncertainties still exist about the consequences of the enhanced greenhouse effect, the risk of potential damaging effects has induced the Netherlands to take a precautionary approach and to initiate policies to reduce the causes of climate change. The Netherlands as a small country cannot significantly contribute to the solution of the global problem, but taking action may stimulate others to follow. Furthermore action is believed to contribute to the abatement of many other environmental problems, such as acid deposition, photochemical air pollution, increasing amounts of waste and depletion of the ozone layer. Measures will probably not endanger economic growth and may under certain circumstances even benefit economic development and will surely contribute to the desired shift towards a more sustainable economy (Opschoor et al., 1990). So far discussions in the Netherlands have focused on carbon dioxide emissions from fossil fuel combustion, this being the most important contributor to greenhouse gas emissions at an international level. The phase-out of CFC production is taken care of in the upgraded Montreal Protocol.

Early in 1991 the Dutch Ministry of Housing, Physical Planning and Environment had to report to Parliament about a comprehensive approach to respond to the threat of climate change. To support this activity, this RIVM report aims at giving an overview of all emissions of greenhouse gases in the Netherlands, assessing the implications of existing policies for future emissions of these gases and identifying options for additional measures. Among existing policies are included the measurements as described in policy plans, the most important of which being: the National Environmental Policy Plan, Acidification Abatement Plan, the Memorandum on Energy Conservation and the Second Structure Scheme for Traffic and Transportation. Incidentally these are combined with the best forecast for autonomous future developments in case no policy is defined. Under additional response options are grouped measures which might lead to emission reduction in case an additional policy is formulated.

This report focuses on the emissions of methane and nitrous oxide, which are relatively unknown. After a general overview of the problem of climate change in the second chapter, these gases will be covered in the third and fourth chapters.

The uncertainties about the emissions of carbon dioxide and CFCs are smaller and policies have already been initiated and discussed in detail elsewhere (VROM, 1990a; VROM, 1990b). The contribution of carbon monoxide, non-methane hydrocarbons and nitrogen oxides to climate change is indirect (via ozone formation in the troposphere). For other purposes policies have been implemented. In Chapter 5 these gases will be discussed briefly and the present policies will be evaluated in the perspective of climate change. In the sixth chapter the emissions of greenhouse gases are integrated into equivalent CO_2 emissions by application of so-called Greenhouse Warming Potentials. Finally the report gives a number of conclusions and recommendations for further research. In this chapter the expected development of the Netherlands' GHG emissions is compared with international emissions scenarios; notably those of the Response Strategies Working Group of the Intergovernmental Panel on Climate Change (IPCC). In this context the implications of different options for target setting are also discussed.

2. CLIMATE CHANGE AND GREENHOUSE GASES

2.1. GENERAL OVERVIEW

For a general description of the physical and chemical characteristics of the enhanced greenhouse effect we refer to other literature (Bolin et al., 1986). The most recent consensus document is the report on scientific assessment of climate change by the Science Working Group of the Intergovernmental Panel on Climate Change (Houghton at al., 1990: IPCC, 1990a). The authors are certain that:

- there is a natural greenhouse effect, caused by the trapping of solar radiation in the atmosphere by greenhouse gases, the most important being CO_2. Without an atmosphere the surface air temperature would be several tens of degrees lower;
- emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases carbon dioxide (CO_2), chlorofluorocarbons (CFCs), methane (CH_4) and nitrous oxide (N_2O). Also tropospheric ozone (O_3) concentration, the result of reactions between nitrogen oxides and non-methane volatile organic compounds (VOC), has been increasing. These increases will enhance the greenhouse effect, resulting in an additional warming of the Earth's surface. The most abundant greenhouse gas, water vapour, will increase in response to greenhouse warming.

The authors calculate with confidence that:

- some gases are potentially more effective than others in changing climate, and their relative effectiveness can be estimated. Carbon dioxide has been responsible for over half the enhanced greenhouse effect in the past, and its importance is likely to remain so in the future;
- atmospheric concentrations of the long-lived gases (carbon dioxide, nitrous oxide and the CFCs) adjust only slowly to changes in emissions. Continued emissions of these gases at present rates would commit us to increased concentrations for centuries ahead. Continued increases in emission rates will force us to implement more drastic reductions in the future to stabilize concentrations at a given level;
- the long-lived gases would require immediate reductions in emissions from human activities of over 60% to stabilise their concentrations at current levels; methane emissions would require a 15 to 20% reduction.

Carbon monoxide (CO) is a precursor of O_3 and CO_2, both greenhouse gases. CO also competes with methane for hydroxyl radicals (•OH) in the troposphere. Increasing emissions of CO increase the greenhouse effect by increasing the ozone and carbon dioxide concentration and reduce the atmospheric methane sink and so indirectly contribute to the enhanced greenhouse effect through increased methane abundance. Nitrogen oxides (NO_2) and non-methane hydrocarbons (NMHC) are important precursors of the greenhouse gas ozone (O_3). The main characteristics of key greenhouse gases as affected by human activities are summarized in Table 2.1.

The IPCC Science Working Group also evaluated the effects of a number of emission scenarios developed by the EPA and RIVM for the Response Strategies Working Group of IPCC (IPCC, 1990c). The business-as-usual ('high emissions') case would lead to a rate of increase of the global mean temperature during the next century of about 0.3 °C per decade (with an uncertainty range of 0.2 °C to 0.5 °C per decade); this is greater than temperature

Table 2.1: Summary of characteristics of key greenhouse gases affected by human activities

Substance Atmospheric concentration	CO_2 (ppmv)	CH_4 (ppmv)	CFC-11 (pptv)	CFC-12 (pptv)	N_2O (ppbv)
Pre-industrial (1750-1800)	280	0.8	0	0	288
Present (1990)	353	1.72	280	484	310
Current rate of change per year	1.8	0.015	9.5	17	0.8
in percentage	0.5%	0.9%	4%	4%	0.25%
Atmospheric lifetime	50-200 *	10	65	130	150

* The way in which CO_2 is absorbed by the oceans and biosphere is not simple and a single value can therefore not be given.

source: Houghton, 1990; IPCC, 1990a.

changes which have occurred over the past 10,000 years. The magnitude and distribution of regional climate changes cannot yet be predicted with certainty. The potential effects on ecosystems and economies are large.

2.2. GLOBAL EMISSION SCENARIOS AND NORMATIVE RESPONSE STRATEGIES

Emission scenarios

The emission scenarios of the IPCC Response Strategies Working Group (RSWG) are listed in Table 2.2. They are normative in the sense that the end points in terms of equivalent carbon dioxide concentrations were prescribed by the Steering Committee of the Working Group: a doubling as compared to pre-industrial levels in 2030, 2060 and 2090 respectively and a stabilization at levels 'well below doubling'. Explicitly, the scenarios do not represent policy targets. Nevertheless, for the purpose of comparing national emissions scenarios with proposed global environmental goals the scenarios can be used for a "what if" analysis: what would the climate effect be if all industrialized countries were to follow a similar track as the Netherlands? What would an emission pathway be to comply with environmental goals proposed to date? At the end of this report such a preliminary comparison will be made. In this section we present a brief outline of the scenarios and their assumptions.

Growth of economies and population was taken to be identical for all scenarios. Population was assumed to approach 10.5 mld in the second half of the next century. Economic growth was assumed to be 2-3% annually in the coming decade in the OECD countries and 3-5% in the Eastern European and developing countries. The economic growth levels were assumed to decrease thereafter. In order to reach the required targets, levels of technological development and environmental controls were varied as summarized in Table 2.3. The scenarios are already outdated because they do not encompass the June 1990 London update of the Montreal Protocol, where it was agreed to phase-out CFCs completely. The 2030 doubling/high emissions scenario has nevertheless been named 'business-as-usual', taking into account that in terms of CO_2 equivalents, the overestimation of CFC-emissions is more or less balanced by an underestimation of the fossil carbon dioxide emissions. This underestimation is caused by relatively low assumptions for economic growth and rather optimistic assumptions for the decrease of the energy intensity of economies as compared to national analyses.

Appendix 1 shows the regional distribution of emissions (IPCC, 1990c). While the business-as-usual scenario would lead to a rate of global average

Table 2.2: Emissions scenarios for the response strategies of the Working Group of the Intergovernmental Panel on Climate Change (IPCC, 1990c)

Trace gas and scenario	1985	2000	2025	2050	2075	2100
CO_2 (Pg C)						
2030 high emissions	5.9	7.7	11.5	15.2	18.7	22.4
2060 low emissions	5.9	5.5	6.4	7.5	8.8	10.3
Control policies	5.9	5.6	6.3	7.1	5.1	3.5
Accelerated policies	6.0	5.6	5.1	2.9	3.0	2.7
Alternate accelerated policies	6.0	4.6	3.8	3.7	3.5	2.6
N_2O (Tg N)						
2030 high emissions	12.5	14.2	16.4	17.3	17.3	17.6
2060 low emissions	12.5	13.1	13.9	14.1	14.3	14.6
Control policies	12.5	12.9	13.2	13.0	12.5	12.2
Accelerated policies	12.5	12.9	13.1	12.7	12.5	12.3
CH_4 (Tg CH_4)						
2030 high emissions	540.5	613.9	670.8	899.1	922.0	1062.9
2060 low emissions	540.5	576.8	665.4	723.8	732.4	735.6
Control policies	540.5	557.9	607.7	621.6	562.0	504.9
Accelerated policies	540.7	565.8	583.0	553.0	530.1	502.0
NO_x (Tg N)						
2030 high emissions	50.5	56.2	68.3	80.7	90.5	101.5
2060 low emissions	50.2	50.2	46.1	41.2	41.4	43.8
Control policies	50.2	50.3	46.4	41.9	39.3	39.4
Accelerated policies	51.2	50.5	49.9	43.8	42.9	43.5
CO (Tg C)						
2030 high emissions	537.2	615.6	781.2	881.9	839.1	927.9
2060 low emissions	537.2	427.6	336.1	284.6	279.8	280.9
Control policies	537.2	427.4	336.1	285.4	274.3	270.2
Accelerated policies	540.8	411.1	340.8	287.0	285.0	281.0
CFC-11 (Gg)						
2030 high emissions	287.3	305.1	244.7	251.5	353.0	353.0
2060 low emissions	287.3	302.1	226.7	223.2	223.2	223.2
Control policies	287.3	197.1	10.6	0.0	0.0	0.0
Accelerated policies	287.3	197.1	10.6	0.0	0.0	0.0
CFC-12 (Gg)						
2030 high emissions	361.9	376.0	302.7	314.1	316.1	316.1
2060 low emissions	361.9	372.2	279.1	277.9	277.9	277.9
Control policies	361.9	262.2	10.2	0.0	0.0	0.0
Accelerated policies	361.9	262.2	10.2	0.0	0.0	0.0
HCFC-22 (Gg)						
2030 high emissions	96.9	522.9	1340.4	2681.3	2961.0	2961.0
2060 low emissions	96.9	525.7	1357.2	2707.2	2988.1	2988.1
Control policies	96.9	638.5	1571.9	2927.6	3208.5	3208.5
Accelerated policies	96.9	638.5	1571.9	2927.6	3208.5	3208.5
CFC-113 (Gg)						
2030 high emissions	150.6	132.6	122.0	124.8	124.8	124.8
2060 low emission	150.6	131.4	116.6	116.6	116.6	116.6
Control policies	150.6	29.7	0.0	0.0	0.0	0.0
Accelerated policies	150.6	29.7	0.0	0.0	0.0	0.0

Remark: Slight variation in initial (1985) values is due to minor differences in the way scenarios are specified in the model.

Table 2.3: Main assumptions in IPCC/RSWG emissions scenarios

	2030 doubling high emissions	2060 doubling low emissions	2090 doubling control policies	well below doubling accelerated policies
Energy supply	coal intensive	gas intensive	renewable and nuclear >2050	renewable and nuclear >2000
Energy demand	moderate efficiency	high efficiency	high efficiency	high efficiency
Defores-tation	continuing	reversed	reversed	reversed
CO-control	moderate	strict	strict	strict
CFC-control	Protocol	Protocol	phase-out	phase-out
CH_4, N_2O agricult.	continuing	continuing	controlled	controlled

source: IPCC, 1990c.

temperature increase of about 0.3 °C per decade, according to the Science Working Group the other scenarios would lead to rates of change of 0.2 °C per decade (low emissions), somewhat above 0.1 °C per decade (control policies) and about 0.1 °C per decade (accelerated policies). Two alternative accelerated policies were developed with different time paths leading to a similar final reduction of greenhouse gas emissions and associated climate change.

Climate targets

Although within the framework of IPCC no tolerable levels of change were discussed, elsewhere targets for temperature changes have been proposed. Jäger (1988) suggests that rates of temperature changes below 0.1 °C per decade would allow ecosystems to adapt to the change. Rijsberman and Swart (1990) used a maximum temperature increase of 1.0 °C above pre-industrial global mean temperature to avoid risks of ecosystem damage and potential rapid non-linear response of the biosphere-climate system. They argued that the risk of such damage and response increases rapidly if there is a temperature increase exceeding 2 °C above pre-industrial levels. Targets for sea level rise are also suggested, but these do not lead to stricter emission control requirements than the temperature targets. Comparing these targets with the above mentioned IPCC scenarios, it appears that for an average climate sensitivity of 3 °C for a doubling of CO_2, the proposed targets are only reached with the accelerated policy scenarios.

The assumptions and implications for emissions worldwide and for Western Europe over intervals of 5 years are listed in Table 2.4 and table 2.5 respectively. It must be noted that this figure gives one possible combination of emission scenarios leading to the required target. Other models than the ones used or the application of other assumptions for different climate parameters would give other results. However, we do not believe that this will essentially change the general picture. For the purpose of this report we assume that a policy aiming at preserving the natural resource base of the world economy should aim at controlling

greenhouse gas emissions consistent with this lower emissions pathway. Of course, more work remains to be done to increase the understanding of the vulnerability of ecosystems and the sensitivity of the global climate in order to confirm or adjust the proposed targets. If the resulting climate sensitivity was lower than 3 °C for a doubling of the CO_2 concentration, higher emission levels could be tolerated. However a higher climate sensitivity would require even more strict emission targets to achieve the same results in terms of climate change.

Table 2.4: Implications of accelerated emissions scenario for the globe.

Trace gas	1985	1990	1995	2000	2005	2010	2015	2020	2025	2050	2075	2100
CO_2 (Gt C)[1]	5.99	5.85	5.61	5.59	5.57	5.44	5.35	5.27	5.09	2.91	2.96	2.72
CO_2 (Gt C)[2]	6.0[3]	n.a.	n.a.	4.6	n.a.	n.a.	n.a.	n.a.	3.8	3.7	3.5	2.6
CH_4 (Tg CH_4)	541	542	555	566	573	576	581	583	583	553	530	502
N_2O (Tg N)	12.5	13.0	13.1	12.9	13.1	13.5	13.4	13.0	13.1	12.7	12.5	12.3
NO_x (Tg N)	51.2	50.1	50.0	50.5	49.9	48.0	47.3	47.6	49.9	43.8	43.0	43.5
CO (Tg C)	541	453	427	411	404	376	356	336	341	287	285	281

source: IPCC, 1990c.

1 Total CO_2 including (de-)forestation.

2 RIVM-alternate, adapted for recent emissions data; reflecting Toronto target (IPCC, 1990c).

3 RIVM-alternate data of 1985 is updated according to latest IPCC RSWG data

Table 2.5: Implications of accelerated emissions scenario for Western Europe.

Trace gas	1985	1990	1995	2000	2005	2010	2015	2020	2025	2050	2075	2100
CO_2 (Gt C)[1]	0.85	0.85	0.82	0.81	0.78	0.73	0.70	0.66	0.64	0.40	0.35	0.33
CO_2 (Gt C)[2]	0.85[3]	n.a.	n.a.	0.63	n.a.	n.a.	n.a.	n.a.	0.36	0.33	0.31	0.18
CH_4 (Tg CH_4)	35.6	34.0	36.8	36.4	35.7	34.6	33.8	32.5	31.4	26.3	23.9	21.9
N_2O (Tg N)	0.63	0.68	0.71	0.73	0.85	1.12	1.04	0.71	0.72	0.66	0.61	0.58
NO_x (Tg N)	4.65	4.37	4.14	4.03	3.86	3.27	2.91	2.65	2.77	2.37	2.30	2.38
CO (Tg C)	49.0	44.0	40.3	37.5	37.6	31.3	26.0	19.9	21.0	18.7	18.1	18.0

source: IPCC, 1990c.

1 Total CO_2, but not significant influence deforestation/reforestation expected in first decades.

2 RIVM-alternate, adapted for recent emissions data; reflecting Toronto target (EPA/RIVM, 1990).

3 RIVM-alternate data of 1985 is updated according to latest IPCC RSWG data

3. METHANE

3.1. GENERAL CHARACTERISTICS

The methane concentration in the atmosphere has shown an increase since pre-industrial time from about 0.8 ppmv to 1.72 ppmv at present day (Houghton et al., 1990; IPPC, 1990a). The current rate of change is 0.9% per year, with a particularly marked increase in the second half of the 20th century. It has been observed that the concentration in the northern hemisphere is somewhat higher than in the southern hemisphere. At present the concentration in the atmosphere is greater than ever found in ice cores from the last 160,000 years. The major cause of this large increase is the increasing source strength, of both fossil and biogenic nature, which are mainly anthropogenic (Khalil and Rasmussen, 1985). 20 to 25 percent of the total atmospheric CH_4 emission originates from energy-related sources. The remaining part is of biogenic origin (Wahlen et al., 1989).

Methane is the most abundant and stable hydrocarbon gas in the atmosphere and plays an important role in the chemistry of many species in the troposphere and stratosphere, including ozone (O_3), hydroxyl radicals (•OH) and carbon monoxide (CO). Methane is also a strong absorber of infrared radiation. Its residence time in the atmosphere is relatively short and estimated to be 10±2 years (Cicerone and Oremland, 1988).

Sinks

The photochemical oxidation of methane takes place in the troposphere, except for a minor quantity which is transported to the stratosphere by circulation or diffusion. Estimates of transport of CH_4 range from 5 to 15% (Wahlen et al., 1989; Cicerone and Oremland, 1988). In the troposphere CH_4 is oxidized by hydroxyl radicals (OH) (a sink for CH_4) leading via a complex chain to the formation of carbon monoxide (CO) and finally carbon dioxide (CO_2) (Crutzen and Graedel, 1986).

In the stratosphere the oxidation of CH_4 is an important source of water vapour (IPCC, 1990a). The growth of tropospheric methane in the past two centuries may have increased the water vapour concentration in the stratosphere by as much as 45% and thus increased available water for the formation of polar stratospheric clouds (Blake and Rowland, 1988).

Since OH radicals are also responsible for the removal of carbon monoxide, the system of CH_4-CO-OH radicals in the troposphere is rather unstable. Khalil and Rasmussen (1985) estimated that about 30% of the increase of methane in the atmosphere is caused by the depletion of OH radicals as a result of the marked increase of CO emissions and the remaining 70% by direct emission sources. The products that are formed in the methane oxidation chain strongly depend on the concentration of NO_x in the atmosphere. In low NO_x environments the chain of methane oxidation reactions is an important sink of HO_2 and ozone ($HO_2 + O_3 \rightarrow OH + OH$ prevails above $HO_2 + NO \rightarrow NO_2 + OH$). In high NO_x environments, mostly the industrialized regions and tropical areas where biomass burning takes place, the oxidation of methane contributes substantially to the ozone formation in the troposphere by depletion of OH radicals ($OH + NO_2 \rightarrow HNO_3$)(Cicerone and Oremland, 1988; Thompson and Cicerone, 1986). Another methane sink is the uptake by soils, particularly those of the dry tropics and subtropics (Keller et al., 1986).

Sources

Biogenic methane is produced during microbial decomposition of organic material in an anaerobic environment. This process is called methanogenesis, which is carried out by bacteria belonging to the species of Archaebacter. These methanogens are strictly anaerobic, requiring highly reducing conditions such as prevalent in aquatic sediments, flooded soils and rumen of ruminants. The physiology of the bacteria and the ecology of the anaerobic ecosystem is influenced by physical, chemical and biological factors. Methanogenesis is a very complicated process. Its occurrence and intensity strongly depend on the competitive or complementary nature of the ecosystem composition and the population of micro-organisms in the habitat.

The biogenic methane sources are natural wetlands, wetland rice cultivation, landfills and deposits of solid waste, domestic ruminants, biomass burning, termites, oceans and freshwater systems. Fossil sources and non-biogenic sources are natural gas venting, coal mining and CH_4 hydrate destabilization (in permafrost ecosystem). Additional sources, which are not commonly mentioned (IPCC, 1990d), are animal waste and waste water.

The latest available data on global methane sources and sinks are given in Table 3.1. and in Figure 3.1

Table 3.1: Estimated global sources and sinks of methane (Tg CH_4/yr).

Description	low	high	med.	perc.
SOURCES				
Wetlands	100	200	115	19%
Rice paddies	25	170	110	18%
Animals (enteric fermentation)	65	100	80	13%
Biomass burning *	20	80	55	9%
Oil/gas (drilling, venting, transmission)	25	50	45	8%
Termites	10	100	40	7%
Landfills	20	70	40	7%
Coal mining	19	50	35	6%
Oceans	5	20	10	2%
Freshwater	1	25	5	1%
CH_4-hydrate destabilization	0	100	5	1%
Subtotal	300	965	540	90%
ADDITIONAL SOURCES				
Animal waste **	n.a.	n.a.	35	6%
Waste water **	20	25	25	4%
Total	310	990	600	100%
SINKS				
Removal by soils	15	45	30	
Reaction with OH-radicals	400	600	500	
ATMOSPHERIC INCREASE ***	40	48	44	

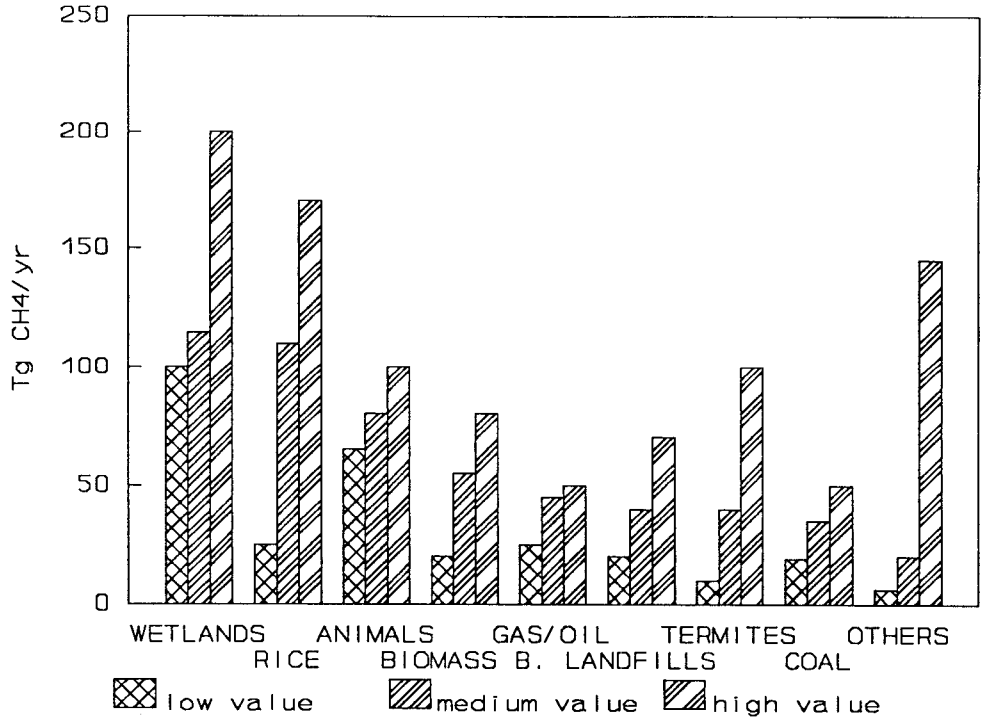
* Medium value (Houghton, 1990; IPCC, 1990a)

** Additional sources (IPCC, 1990d)

*** Sources minus sinks unequal to increase; possibly indicating overestimating sources or missing sinks

source: Houghton, 1990; IPCC, 1990a; IPCC, 1990d.

Figure 3.1: Global sources of methane (Houghton, 1990; IPCC, 1990a)



The annual increase of atmospheric methane is about 44 Tg CH_4. About two thirds of the sources are anthropogenic, the complement is of natural origin. There is uncertainty about the accuracy of the estimates. This is caused by the complexity of the sources and processes involved in the production of methane and the limited amount of measurement data, available. Based on the list of global sources and sinks and literature on sources and emission factors, an inventory has been made of methane emissions in the Netherlands.

Sources of major importance in the Netherlands are enteric fermentation (cattle), landfills (waste deposits), production and distribution of natural gas and natural wetlands. Sources of minor importance are waste water treatment, combustion, oceans and freshwater systems, drinking water production and biomass burning. Terrestrial sinks are area related and not significant in the Netherlands if compared to global terrestrial sinks.

A division is made in this report between methane from fossil sources and methane from biogenic sources. The fossil sources are described in Section 3.2, whereas the biogenic sources are discussed in Section 3.3. Present and future methane emissions under existing policies and future emissions including the impact of additional response options are described in Section 3.4 and 3.5, respectively.

3.2. EMISSION OF METHANE FROM FOSSIL SOURCES

3.2.1. Characteristics

Methane is the lightest hydrocarbon. Dutch natural gas has a methane content of about 83.5%. Other fuels like coal and crude oil contain only a small fraction of methane. LPG consists mainly of liquified propane and/or butane gas. Besides leakage from fuel systems methane is emitted as a combustion product either as a component of unburned fuel or it may be formed in the post flame zone (Barns and Edmonds, 1990).

From a global perspective four broad categories of methane emissions from fossil energy sources can be distinguished:

- leakage from natural gas systems (production, transportation pipelines, distribution systems);
- venting of gas associated with oil production (leakage and venting of natural gas);
- coal production;
- combustion of fossil fuels (especially in small installations e.g. residential and transport sector).

Other energy-related sources are landfills and biomass burning. In this report these sources are considered to be biogenic emissions and they are discussed in Section 3.3. In addition to emissions during normal operating conditions, accidents should be noted as another source of methane. Examples are blow-outs during exploration and exploitation activities and disruptions caused by explosions in pipelines and buildings. However, though the emission per incident may be considerable, the very infrequent occurrences of such incidents in the Netherlands mean that the time-averaged accidental methane emissions are negligible with respect to the normal fossil emission sources (Nielen, 1991).

In the Netherlands coal production has been discontinued since 1974, leaving the other three categories as the major fossil sources of methane. In Table 3.2 an estimation is presented of the total fossil methane emission in the Netherlands for 1988.

In comparison with other industrialized countries, natural gas, which accounts for about 40 mld m^3/yr (1,300 PJ) or about half the total net use of energy in the Netherlands, is deeply embedded in the Dutch economy. In the Dutch residential and commercial sectors natural gas for heating purposes has a penetration of almost 100%. The volume of gas exports is almost equal to the volume of domestic consumption. The relatively large fossil contribution from natural gas sources to the Dutch methane emissions in comparison with other EC countries is a result of the exploitation activities of the large Dutch natural gas resources, especially production and distribution activities.

Table 3.2: Estimation of methane emissions from fossil energy sources in the Netherlands in 1988.

Source	emissions (kton CH_4/yr) average	(range)	perc.
- Oil/gas prod./distribution	150	(102-197)	85%
o.w. gas production	40 - 70		
gas transportation (high pressure)	2 - 12		
gas distribution (low pressure)	60 - 80		
oil production	0 - 35		
- Energy sector (power plants, refineries)	1.5		1%
- Residential	8		5%
- Transportation	8		5%
- Industry	5.2		3%
- Commercial	3.6		2%
TOTAL:	176	(129-224)	100%

source: CBS, 1990a (energy consumption); Nielen, 1991 and Piccot et al., 1990 (emission factors).

3.2.2. Exploration, production and transportation of fossil fuels

Coal mining, a potentially important source of fossil methane, is not carried out in the Netherlands. Under normal handling conditions methane emissions from imported coal stored in ships during transportation and kept in stock on piles in the open-air are very small (less then 0.5 ton/year using an emission factor estimated by Kok (1990).

Production of natural gas (66 mld m_o^3 or 2,100 PJ in 1988) may cause operational emissions:

- production tests and maintenance of production wells;
- leakage from gas treatment plants (cleaning of the raw, wet gas);
- venting or flaring of gas caused by over-pressure safety systems;
- accidental emissions during blow-outs.

A German study indicated that 0.13% (weight) of the produced and treated gas is emitted as methane into the atmosphere, excluding blow-outs (DGMK, 1989). If the same factor is valid for Dutch conditions the estimated methane emission would be 55 kton/yr. It may be questioned, however, whether this German figure is applicable to the Dutch gas exploitation activities, of which the Groningen field, with its very special characteristics, accounts for half of the total production. So far the industry has not made available more accurate estimates for gas production activities on the Dutch territory.

The operation of high pressure transportation pipelines for natural gas also accounts for methane losses:

- leakage caused by corrosion of the pipes;
- gas vented by pneumatic measuring and control systems and valves;
- compressor stations (especially if driven by reciprocating engines);
- maintenance activities on pipelines and compressor stations.

Estimates of the methane emissions range from 2 to 12 kton/yr (Gasunie and Alphatania, respectively, in: Nielen, 1991).

Exploration and exploitation of Dutch oil resources are additional sources of methane. When crude oil is produced it also contains a fraction of natural gas. This associated gas is commonly vented or flared, as it is uneconomical to transport and sell it or to reinject it into the well. According to a German study 0.11% (weight) of the crude oil produced is emitted as

methane (DGMK, 1989). When this factor is applied to the 1988 production figure of 3.9 mln kg crude oil (170 PJ), the resulting methane emission would be 5 kton/yr. Based on the registration of associated gas from oil production wells in the Netherlands, this figure is in the range of 0-35 kton/year (Nielen, 1991), the actual emission level being dependent on the ratio venting/flaring. The amounts of gas which are flared or vented on the Dutch territory are unknown.

3.2.3. Natural gas distribution

For the distribution of the gas to the end users an extensive regional and local low pressure network exists, which is operated by the gas distribution companies. The transportation and distribution pipelines are different in their diameter, gas pressure, length and location of the networks. Methane emissions from these low pressure networks mainly stem from leakages, while maintenance and accidents do not contribute significantly. The limited accuracy in measuring the total amounts of gas sold to consumers and amounts bought from Gasunie, the company responsible for transportation of natural gas in the Netherlands, does not allow for an accurate quantification of gas losses merely by calculating the difference. Factors determining the gas losses are the materials used for pipes and joints, age, level of maintenance and soil structure. As data on these leaks are not available, estimating the methane emission from the number of leaks and the amount of gas lost per leak is also difficult. However, the larger part will be contributed by the lead oakum joints of the oldest cast iron pipes used in city networks. These networks were originally constructed for distribution of (wet) town gas but are less appropriate for dry natural gas. Joints as well as the strength of the pipes are of a lower quality compared to more recent systems in which polyethene is used.

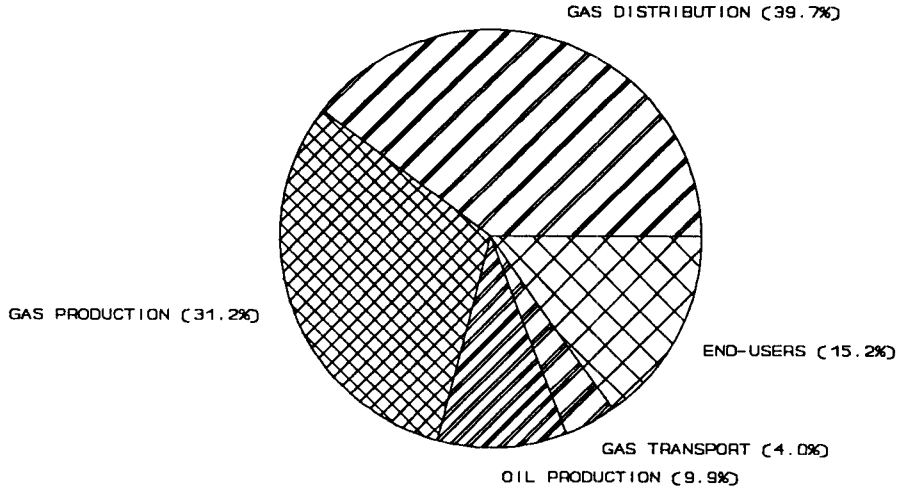
The low pressure distribution network, which had a total length of 93,500 km in 1987, consists of different materials. Table 3.3 gives an overview of these materials and their application. Based on experience VEG-Gasinstituut, the research institute of the Dutch gas distribution companies, estimated the number of leaks per km in iron and in polyethene networks to be 2 to 3 and 0.1 respectively (Nielen, 1991). The total loss of natural gas from the distribution system is estimated by VEG-Gasinstituut using an assumed overall loss factor

Table 3.3: Materials and length of low pressure gas distribution networks in the Netherlands in 1987 (in km).

Pipeline material	Pressure: 8 bar	4 bar	1 bar	100 mbar	30 mbar	Total length
Steel	11,200	700	400	5,800	700	18,800
Ductile iron	1.000	100	1,200	600	1,500	4,300
Cast iron	-	-	400	4,800	6,000	11,200
Asbestos cement	-	-	-	1,100	1,300	2,400
Hard PVC	-	-	400	18,200	3,000	21,600
Non-breakable PVC	-	-	100	23,600	4,500	28,200
Polyethene	-	4,000	300	4,400	700	9,400
Total:	16,200	4,800	2,800	58,500	17,600	96,100

source: Nielen, 1991.

Figure 3.2: Relative contribution from oil and gas production, distribution and end-use to the fossil methane emissions.



of approx. 0.6% of the distributed gas. This corresponds to a methane loss of 74-90 kton/yr (Nielen, 1991). Part of this amount is oxidized by methane bacteria before it is actually emitted into the atmosphere. On the basis of an oxidation figure of 10-20% (Hoeks, 1990) the net methane emission from gas distribution systems may amount to 60-80 kton/yr. The oxidation rate of 10-20%% is uncertain and based on limited number of experiments, more research on this item is needed to quantify more precisely the ratio oxidation versus emission. About three quarters of this amount could stem from the cast iron network if one assumes a constant, material independent leakage per leak and numbers of leaks per km in all networks equal to the numbers for polyethene. Figure 3.2 shows the relative importance of the oil and gas production and distribution activities as sources of fossil methane, using average figures derived from the estimated ranges of emission levels per category. It should be realized that the concern of the gas companies about gas leaks stems primarily from safety concerns and not from economic considerations. In the Netherlands the complete distribution system is checked from the surface for leakages every four years. Any leaks which are detected are usually immediately repaired. The number of leaks found has been steadily decreasing over the years.

3.2.4. Energy conversion processes

In Table 3.4 the methane emissions from the energy sector (dealing with energy conversion processes) are summarized. It should be noted that a small part of the electricity produced by the public utilities is imported. This means that associated emissions are not produced in the Netherlands but abroad, if oil and gas are used as an energy source (in the countries concerned Germany and France). A more detailed overview is given in Appendix 2.

Table 3.4: Methane emissions from the energy sector in the Netherlands in 1988.

Type of conversion	Energy (PJ/yr)	Emission (kton/yr)
Coke manufacturing	115	0
Refineries	2,174 *	0.5
Power plants	499	1.0
District heating	0	0
Municipal waste combustion	14	n.a.
TOTAL		1.5

* Energy content of coal processed.
** Energy content of crude oil processed.

source: CBS, 1990a (energy consumption); Nielen, 1991 (emission factor gas combustion in power plants); Piccot et al., 1990 (other emission factors, adapted to LHV cf. IEA/OECD, 1991).

3.2.5. End-users

The end use can be divided into four basic categories:
- industry (excluding refineries)
- commercial, including services, agriculture
- residential
- transportation

In Table 3.5 a summary is given of the relatively small methane emissions in the various sectors. The main combustion sources are natural gas leaving the exhaust unburned and volatile organic compounds (VOC) in exhaust gases from burning of other methane containing fuels. In Appendix 3 more details for these categories are given. As emission factors for natural gas combustion vary considerably according to the type of combustion (Nielen, 1991; compare with Piccot et al., 1990), considerable uncertainty still exists concerning the strengths of the various sources. However, estimations of the total methane emissions using local emissions factores from the so-called Emission Registration by Nielen (1991) and the mixed approach in this report, using non-gas emission factors of Piccot et al. (1990) give comparable results (within 10%). Combustion emissions from the industry mainly arise from the use of natural gas, which is the main fuel. Process emissions could be another emission source, but no associated emission factors exist to date. Non-energetic - i.e. non-combustion - use of natural gas (as chemical feedstock) will in general probalby not cause methane emissions because it is used in closed systems.

The estimated emission from the commercial sector is very low, the main sources being unburned natural gas used for heating purposes in greenhouses and office buildings and emissions from diesel off-road vehicles and other diesel equipment (mainly agricultural).

Table 3.5: Methane emissions from the end-users in the Netherlands in 1988.

Category of end use	Fuel combustion (PJ/yr)	Emission (kton/yr)
Industry	448	5.2
Commercial	302	3.6
Residential	344	8.4
Transportation *	348	8.1
TOTAL	1,442	25.3

* Excluding international bunkers

source: CBS, 1990a (energy consumption): RCN, 1988 (wood combustion); Piccot et al., 1990 (all emission factors except residential gas combustion, adapted to LHV cf. IEA/OECD, 1991); Nielen, 1991 (emission from industrial and residential gas consumption).

The emission from the residential sector stems from the fraction of natural gas leaving heating systems unburned. Furthermore, some gas is lost in using cooking devices, particularly the flow of gas before ignition. Biomass burning in hearths and multifuel burners, also a renewable source of energy, is probably negligible in comparison with the use of natural gas (Okken, 1982).

Methane emissions in the transportation sector originate mainly from leakage and incomplete combustion. They depend on the methane content of the fuel, the percentage of unburned hydrocarbons and the degree of application of emission control systems. The largest contribution is from the use of gasoline for road transport. Both the emission factor and the amount of gasoline used are high compared to other mobile sources. However, the increasing use of catalysts in gasoline cars - in 1988 still negligible - will reduce the emission factor by a factor 2 (Piccot et al., 1990).

In the transportation sector the definition of fuel used in or by 'the Netherlands' and counted as Dutch emission is important (in particular the bunkers for aircraft and ships). In this report only emissions are counted from activities within the Dutch territory - i.e. unless otherwise indicated. Another method is to take accounting into consideration for all emissions from activities directly related to the Dutch economy (the latter method would include both the emission from the combustion of all fuel loaded by vehicles in the Netherlands, and fuel used abroad to generate imported electricity).

3.3. EMISSIONS OF BIOGENIC METHANE

3.3.1. Methane emissions from wetlands

Methane is produced during microbial decomposition of organic matter under strictly anaerobic conditions. Wetlands are places where such conditions prevail. A review of the processes and the controlling factors responsible for CH_4 formation and oxidation can be found in Oremland (1988). A number of important soil processes and conditions will be discussed here briefly.

Organic matter in soils is decomposed by microbes in consecutive steps in which the available hydrogen acceptors are consumed one after another in a thermodynamically determined sequence of the following processes: aerobic respiration, nitrate reduction, general

fermentation, sulphate reduction and methane fermentation. When inorganic hydrogen acceptors have been consumed, the remaining organic matter will continue to be degraded by microbial reduction processes ultimately leading to the formation of both CO_2 and CH_4. The ratio of the two gases depends on the degree of oxidation of the original material. One of the main pathways in CH_4 formation in nature proceeds via acetic acid, which yields equal amounts of CO_2 and CH_4.

Methane fluxes may correlate with the availability of oxidizable substrate (Delaune et al., 1986), peat depth and nutrient enrichment e.g. from ground water (Harriss and Sebacher, 1981) or nitrogen fertilizer (Cicerone and Shetter, 1981). It appears that nutrient availability and interactions between nitrogen fixing bacteria and methanogenic bacteria are important for CH_4 production. High availability of nitrate or sulphate delay the methanogenesis. Other factors which determine the methane production and oxidation in soils are temperature, depth of ground water and pH. Anaerobic conditions occur in the reduced zone of organic soils.

In the Netherlands various types of organic soils occur. Not all the peat or peaty soils may be important with respect to methane formation. Areas where peat has been exploited and which may now be completely drained and where mineral materials and organic materials have been mixed, may not be anaerobic at present. Therefore these soils have been excluded from the methane emitting area. Stiboka (1985) gives the areas of the various types of organic soils, divided into bogs and fens/marshes (other organic soils). Each type of soil can have several ground water levels. Stiboka distinguishes 5 classes, from high (ground water 0-80 cm) to low (ground water >80 cm to >160 cm). Where more than 1 class occurs within one soil type each class is given an equal area.

Fluxes

Measurements of methane emission from wetland soils in the Netherlands have not been done so far. Data available on methane fluxes are mainly taken from measurements from soils in more or less similar regions. Aselmann and Crutzen (1989) used average emission rates of 15 (1-50) mg CH_4/m^2 per day for bogs, 80 (28-216) mg CH_4/m^2 per day for fens and 253 (137-399) mg CH_4/m^2 day for marshes (see Table 3.6). The large uncertainty in these figures is expressed by the wide range reported. In this analysis a low and a high estimate is presented, with maximum emission factors of 15-80 mg CH_4/m^2 per day for bogs and 80-200 mg CH_4/m^2 per day for fens (other organic soils). These emission factors were used for wetlands with high ground water levels. For deeper ground water levels lower figures were applied, according to relationships between ground water depth and CH_4 emissions reported by Moore and Knowles (1989). The range of emissions for bogs depending on the ground water level is 5 to 15 mg CH_4/m^2 per day in the low estimate and 5 to 80 mg CH_4/m^2 per day in the high estimate for low and high ground water levels respectively. Corresponding figures for fens are 5 to 80 mg CH_4/m^2 per day in the low estimate and 12 to 200 mg CH_4/m^2 per day in the high estimate. To estimate annual emissions a productive period of 360 days is assumed to achieve the maximum possible flux. In reality this period may be shorter, but no exact data were available.

Results

The resulting total emissions for bogs and fens are 40 kton CH_4/yr in the low estimate and 120 kton CH_4/yr in the highest estimate. It must be stressed here that the assumed length of the productive period of 360 days is probably too high, and that these estimates must be regarded as a maximum possible emission. The best forecast indicated as average value is 70 kton CH_4/yr.

Table 3.6: Methane emissions from organic soils per soil type

Type of organic soil	Ground water class	Range of depth (cm)	Area (ha)	Emission factor (mg $CH_4/m^2/d$) low	high	Total emission (kton CH_4/yr) low	high
Bogs/fens	1	0 - 80	± 54,600	15	80	2.9	15.7
(in Dutch: veenmosveen)	2	10/25 -> 80	± 54,600	15	60	2.9	11.8
	3	25/40 -> 50	± 54,600	15	30	2.9	5.9
	4	40/80 -> 80	± 2,900	10	15	0.1	0.2
	5	>80 ->160	0	5	5	0.0	0.0
	6	per.flooded	150	15	80	0.0	0.0
			166,700			8.8	33.6
Other organic	1	0 - 80	± 55,750	80	200	16.1	40.1
soils	2	10/25 -> 80	± 55,750	60	150	12.0	30.1
(fens/marshes)	3	25/40 -> 50	± 46,750	30	105	5.0	17.7
	4	40/80 -> 80	0	15	38	0.0	0.0
	5	>80 ->160	0	5	12	0.0	0.0
			158,250			33.1	87.9
TOTAL (kton, rounded off)						40	120

3.3.2. Methane emissions from surface waters

In sediments which are rich in organic matter sediments methanogenesis may take place. This type of process takes place in the Netherlands in shallow lakes, shallow coastal waters and intertidal zones (Wadden sea), canals, ditches and other water bodies. The processes of microbial decomposition of organic matter which may occur are described in more detail in the section above on methane emissions from wetlands.

There is no information on methane emissions from oceans, rivers and lakes in the Netherlands. It is suggested that methane is also formed in anaerobic gastrointestinal tracts of marine zooplankton and fish and in sediments, especially those from coastal regions (Cicerone and Oremland, 1988).

The total area of water surfaces over 6 m wide is about 340,000 ha (CBS, 1990b). This includes freshwater systems, brackish waters and salt waters of the North Sea. However, since no data are available on flux rates for water in the Netherlands, a single flux rate is used in this analysis. Aselmann and Crutzen (1989), present a figure of 43 mg CH_4/m^2 per day based on 5 measurements reported in literature. However, since there is a strong temperature dependence of CH_4 formation, oxidation and release, measurements in tropical inland waters should be excluded. We assume a range of emissions of about 20-50 mg

CH_4/m^2 per day for Dutch conditions. Using this range the total CH_4 release from Dutch surface inland and coastal waters would be 24 to 60 kton CH_4/yr for a productive period of 360 days. Clearly, this estimate should also be regarded as an upper limit, since in reality the productive period may be much shorter. We assume an average value of 35 kton.

For ditches and canals narrower than 6 m, area data are not available. The total length is estimated at 300,000 to 400,000 km (Higler, 1990). For these water surfaces the CH_4 emission may be higher than for the larger water bodies. In this analysis a flux range is used of 80 to 200 mg CH_4/m^2 per day, to account for larger amounts of carbon present in the sediments of these ditches and canals. We assume an average width of about 2 m. Calculations of the emission from ditches and small canals may be duplicated if they include the contribution of the ditches and canals which are part of the organic soil landscape. These elements are too small to be separated from the land area and we therefore assume that they have been already incorporated already in the emissions from wetlands (foregoing section). Table 3.7 shows the total contribution from small water bodies minus a correction for the emission of methane from ditches and small canals belonging to the wetland landscape. We have assumed that 40% of the small water bodies surface belongs to the "bog/fens" landscape and 40% belongs to the "other organic soils landscape". The remaining belongs to landscapes dominated by mineral soils. The best educated forecast of the total source strength is 11 to 23 kton CH_4/yr.

Table 3.7: Methane emissions from small water bodies in the Netherlands

Perc.	Area (% of total area)	Area (ha)	CH_4-emission low (mg $CH_4/m^2/d$)	CH_4-emission high (mg $CH_4/m^2/d$)	CH_4-emission low (kton)	CH_4-emission high (kton)
Total contribution	100%	70,000	80	200	20.4	51.1
Correction for wetlands:						
Bogs/fens landscape	40%	28,000	15	80	-1.5	-8.2
Other organic soils landscape	40%	28,000	80	200	-8.2	-20.4
				TOTAL (kton)	10.7	22.5

3.3.3. Methane emisions from ruminants, other animals and humans

Managed livestock, in particular ruminants, are important contributors to the increasing abundance of atmospheric CH_4 . The global annual methane release from animals is about 80 Tg CH_4/year (= 80,000 kton/year) (Crutzen et al., 1986). This is about 15 percent of the total annual emission of methane. More than fifty percent of the CH_4 emission from animals comes from between 25 °N and 55 °N (Lerner et al., 1988). High emission rates greater than 5 g CH_4/m^2 are found in small regions such as Bangladesh, the Benelux countries, parts of northern India and New Zealand. Besides ruminants (cattle, sheep, goats) other animals produce methane: pseudo-ruminants (horses, pigs) and wild animals. Humans are also included in this category of sources. To calculate the methane emission in the Netherlands three different references for methane emission per animal are used; Crutzen (Crutzen et al. 1986), IKC (Goossensen and Meeuwissen, 1990) and IVVO (Van der Honing and Van Vuuren, 1991). Both the last two sources are particular to the Netherlands. To calculate the

total emission of methane for the Netherlands of animal population statistics from CBS are used (CBS, 1990f).

Internationally the most frequently used source of methane emission data from animals is Crutzen. His calculations are based on measured relations between feed intake and methane yields.

IVVO generated data for several categories of ruminants based on feed intake and digestion processes. IKC used a standard range of 350 to 550 l CH_4/day (91 resp 143 kg CH_4/yr) for one dairy cow and calculated the emission from all ruminants and sheep and goats based on that specific standard of GVE (1 GVE = 1 dairy cow unit).

Ruminants

The methane is produced by the anaerobic fermentation of organic matter (mainly cellulose) in the rumen, a large fore stomach of the ruminant. Methanogenic bacteria are responsible for the production of methane, which live in the rumen. The rate of methanogenesis is defined as the amount CH_4 produced as a percentage of the gross food energy intake of the ruminants. The range is about 4 to 9 percent (Crutzen et al., 1986). Several factors influence the amount of methane produced. Two important factors are the digestibility of the feed and the level of energy consumed in relation to the required energy for the daily maintenance. For Germany Crutzen calculated that dairy cows produce about 94 kg CH_4/year. Heifers and steers produce about 65 kg/year and animals between 6 and 24 months produce about 51 kg of methane. Calves younger than 6 months do not produce considerable amounts of methane, because of the highly digestible feed they consume. The accuracy of the emission data is 15%. Goossensen and Meeuwissen (1990) used a range of 91 to 143 kg CH_4/yr for dairy cows and a proportional factor for the other cattle types (0.7 for steers; 0.5 for heifers older than 1 year and 0.3 for heifers of less than 1 year). IVVO used 128 kg CH_4/yr for dairy cattle, 55 kg CH_4/yr for steer/bull and 53 kg CH_4/yr for young cattle.

Other domestic and pseudo-ruminants

For other domestic ruminants in the Netherlands like sheep, goats and pseudo-ruminants like horses and pigs, the same approach is followed as for the ruminants. But because of the lack of methane production data per specified age class the average production data per animal type is used. For sheep we used 8 kg/year, for goats 5 kg/year, for pigs 1.5 kg/year and for horses 18 kg/year. Goossensen en Meeuwissen (1990) used 0.1 GVE (35 to 50 l/day) for sheep. No calculations have been made by Goossensen en Meeuwissen for other animals.

Wild ruminants and non-ruminants

Wild ruminants and wild non-ruminants, as they are in natural reserve areas and animal zoos, are of limited importance because of the very low number of animals in this category. In addition there is a lack of reliable data on the methane production per type of animal. The emission of methane from this category is listed in the table as pro memory.

Humans

Humans produce methane in the large intestines. This is partly absorbed in the blood and exhaled through the lungs and partly excreted in flatus gas. The average amount of methane emitted is estimated to be about 50 to 60 g CH_4/year per person (Crutzen et al., 1986).

Results

The results for the different categories are summarized in Table 3.8. The total production of methane in the Netherlands from ruminants, pseudo-ruminants, other animals and humans in 1989 ranges from about 290 to 460 kton CH_4/yr. 270 to 430 kton for ruminants only and about 25 to 30 kton for other animals and humans. The average emission values for ruminants according to Crutzen and IKC is 320 kton and 360 kton CH_4/yr respectively. This is more or less equal to the 360 kton CH_4/yr calculated by IVVO. For further comparison in this study we assumed for ruminants a range of 270 to 430 kton CH_4/yr and an average of 350 kton CH_4/yr. For other animals and humans a range of 25 to 30 kton CH_4/yr. emission from this source was assumed. This amount fits within the minimum and maximum range according to the GVE approach, although it is nearer to the lower end of the range. For more detailed information see Appendix 4.

Table 3.8: Methane emissions from ruminants, pseudo ruminants, other animals and humans in the Netherlands in 1989.

Type	CH4 kton/yr Crutzen low	CH4 kton/yr Crutzen high	CH4 kton/yr 91 kg/yr Goossensen	CH4 kton/yr 143 kg/yr Goossensen	CH4 kton/yr IVVO
Ruminants	270	360	270	430	360
Sheep/goats	5	6	6	10	n.a.
Pigs	18	24	n.a.	n.a.	n.a.
Horses/donkeys	1	1	n.a.	n.a.	n.a.
Other animals	p.m.	p.m.	n.a.	n.a.	n.a.
Humans	1	1	n.a.	n.a.	n.a.

Source: IKC: Goossensen and Meeuwissen, 1990; IVVO: Van der Honing and Van Vuuren, 1991; Crutzen et al, 1986

3.3.4. Methane emissions from manure

A poorly described methane source is animal manure. Methane is produced if animal manure is stored under anaerobic conditions and at temperatures above 15°C (LUW/IMAG/Haskoning, 1987). These conditions occur during storage in basins or silos. In the Netherlands most of the animal manure produced is derived from cattle, pig husbandry and poultry. The total amount of animal manure produced and stored temporarily in the stable or in silos is 52.5 Mton. There are only a few measurements of the emission of methane from animal manure. So far more attention has been given to stimulate the production of methane in reactors with mesophyllic or low temperatures conditions for biogas production.

Research on biogas fermentation has shown that the amount of methane produced depends on temperature, composition of the manure, concentration of ammonia, presence of antibiotics and residence time in reactors. Temperature is an important parameter. Below 15° C the production of methane is negligible. Experiments with low temperature fermentation under current farm management in the Netherlands have indicated that animal manure from

pigs may produce 4.8 to 7.2 kg methane per ton of manure if stored for a certain number of months in the cellar of the stable (calculations based on Zeeman et al., 1987; LUW/IMAG/Haskoning, 1987; Hoeksma et al., 1987; Van Nes, 1990). The estimated emissions from cattle manure amount to 3.6 kg methane per ton of manure. From experiments with storage in silos outside the stable it is concluded that the emission of methane is about one sixth of the stable emission (calculations based on LUW et al., 1987).

Table 3.9: Potential methane production from animal manure in the Netherlands in 1988.

kind of animal	manure ton x1000	manure storage (%)		no. of animals x1000	CH_4 (kg/ton)		total amount of CH_4 (kton)	
		stable	silo	*	stable	silo	stable	silo
Cattle:								
- in meadows	32,436	0	0	1,971	0.0	0.0	0.0	0.0
- in stables	27,485	67	33	1,971	3.6	0.6	65.9	5.5
Fattening steers	2,278	67	33	524	3.6	0.6	5.5	0.5
Fattening calves	1,981	67	33	619	* 1.8	0.3	2.4	0.2
Breeding pigs	7,219	80	20	1,714	4.8	0.8	27.6	1.2
Porkers	12,022	80	20	7,072	7.2	1.2	68.8	2.9
Poultry	1,505	p.m.	p.m.	94,000	p.m.	p.m.	p.m.	p.m.
TOTAL	84,926						170	10
TOTAL excluding meadow:	52,490			total potential CH_4 emission :			180 kton	

* data are based on mesophyllic fermentation

source: CBS, 1990f (number of animals and manure quantitities); LUW et al., 1987 (CH_4 kg/ton yr).

If we consider the present division of storage types of manure in the Netherlands, the potential methane production under described circumstances may total up to 180 kton CH4/year (Table 3.9). This amount is reached where the conditions are optimal for methane formation and depends on how the manure is treated, i.e. residence time and storage conditions are similar to those of the experiments. Considering that "field" conditions are less favourable for methane formation, we propose that the emission of methane from cattle manure is negligible due to the low temperature (average about 15° C) at which it is stored is stored (Hoeksma et al, 1987) with the methane emission from pig manure ranging from 10 to 20% of potential production. The total emission from manure storage is based on these assumptions ranging from 10 to 20 kton CH_4/yr. If we follow the methodology, described in other sources on methane emission from manure (JEA/EPA, 1990), the total emission in the Netherlands might be higher than is assumed here. But because of the difference in manure treatment and the possible effect of the difference in composition of the manure we assume a yearly emission of about 10 to 20 kton CH_4. More information will be available after LUW and IMAG have finished research on the methane production from animal manure storage systems.

3.3.5. Methane emissions from waste water treatment plants

Methane is produced by anaerobic fermentation of sewage sludge in special reactors. The gas produced is used as an energy source for heating, electricity production, and for gas turbines, while the unused gas is flared or vented. After fermentation the non-active sewage sludge is used as fertilizer in agriculture (2.4 million ton) or dumped in landfills or burned (2.1 million ton). The total production of methane from anaerobic fermentation at public waste water treatment plants in 1987 is 17.5 kton, of which 2.5 kton is vented. (BKH, 1990). The amount of methane from landfilled non-active sludge is 10 kton. This amount is considered to be included in the emissions from landfills (see Section 3.3.6).

Finally, another possible source is the stabilized sewage sludge used in agriculture as organic fertilizer. It still contains small quantities of methane (about 3 mg/kg) (Van Andel, 1990), yielding a source of less than 10 ton/yr. The total emission of methane from waste water treatment plants is about 2.5 kton/yr in 1987, and estimated to be about 3 kton in 1990, because of strong increased treatment of waste water since 1987.

Apart from methane carbon dioxide and nitrous oxide are also emitted. Emissions of these gases are discussed in Section 4.3.2. and 5.1.

3.3.6. Methane emissions from landfills

The global emission of methane derived from waste dumps and landfills is estimated to be 40 Tg CH_4/yr (range 20-70 Tg CH_4/yr) (Houghton, 1990; IPCC, 1990a). The release of methane to the atmosphere from waste dumps has greatly increased during the past decades. This source will grow rapidly in the future because of increasing world population and urbanization, particularly in developing countries (Bingemer and Crutzen, 1987). Methane in waste dumps is generated from bacterial anaerobic decomposition of the organic biochemically degradable refuse of municipal and industrial origin. In addition to methane, there is also carbon dioxide production.

The Netherlands is one of the countries in the world with a high refuse production per capita. Part of it is dumped in landfills and the remainder is burned or re-used, composted or fermented in a biogas reactor.

Considering the scarcity of data available on the emission from landfills a theoretical approach is the only way to calculate the magnitude of the source. We based our estimates on the present knowledge concerning waste deposition, waste composition and methanogenesis and oxidation processes in landfills. The process of methanogenesis and oxidation of methane in landfills starts shortly after dumping of the organic matter containing waste. Methanogenesis continues for many decades until all the organic matter is fermented.

Emission calculation

Detailed information is only available for the years 1971 and 1986. We assume that during the second world war no waste was dumped and that the dumping of waste started after 1945. Data for the reamining years were obtained via inter- or extrapolation. With respect to waste composition we assume an organic matter fraction of 17% today and of 18% before 1986 (Beker, 1990).

The emissions have been calculated using the formula for specific gas production.

$$\alpha = 0.8\ k\ P_o\ e^{-kt}$$ (Hoeks, 1983; Hoeks and Oosthoek, 1981).

α = production in m_3 waste gas $ton^{-1}year^{-1}$
P_o = concentration of degradable organic matter in kg/ton refuse
k = degradation rate coefficient (0.0365 $year^{-1}$)
t = time after landfilling (year)

Current production potential of waste gas from material dumped in the past is accounted for by integrating the production potential over time. So far we have considered waste gas potential and not methane emission. Because of some uncertainties with respect to the factors used we applied different minimum and maximum values for the time factor, oxidation percentage and methane concentration of waste gas. To estimate the current emission, we assumed a lower and higher oxidation percentage (10% and 20% respectively of the potential production) and a lower and higher estimation of the methane/carbon dioxide weight ratio (50% and 60% respectively) and a longer and shorter period of methane emission (20 years and 50 years respectively).

In addition to the above mentioned factors, other factors regulate the fraction of the methane which is finally lost to the atmosphere. These factors are moisture content, temperature, pH, particle size, landfill cover etc. These could not be incorporated because of the complexity of processes and the lack of data. In Appendix 5 more information is given on the methodology of the methane emission calculation.

Waste gas extraction

At present methane is recovered successfully at seven waste dump locations. The gas produced is consumed directly or sold to the natural gas distribution companies. The total amount of waste gas collected and flared in 1990 is about 40 kton CH_4 (VAM, 1990).

Results

Based on the model described above the methane production from landfills in the Netherlands is estimated to range from 230 to 360 kton CH_4/yr (mean value 300 kton CH_4/yr). With a present recovery of waste gas of about 40 kton, the net release to the atmosphere amounts to between 190 and 320 kton CH_4/yr (mean value 260 kton CH_4/yr). The emission calculated by VAM (1990) of 210 kton CH_4/yr is about the lowest value.

3.3.7. Methane emissions from other sources

Two very small sources of methane are composting and drinking water production. Both are negligible if compared to other sources like animals, gas production and gas distribution and landfills. But because these sources have so far not been mentioned in international literature on this subject some attention is given to both sources and calculations have been made to estimate the source strength.

Methane emission from composting

During composting of organic material aerobic conditions prevail. Anaerobic conditions only occur to a slight extent leading to the production of small amounts of methane. The process of methanogenesis takes place at micro level within the compost hills.

In the Netherlands two kinds of compost are produced: compost (black earth) and substrate for mushroom-cultivation. Both are produced by specialized enterprises.
Measurements have indicated that during the several stages of the production of mushroom compost small quantities of methane are emitted.

In total the net production is 185 mol CH_4/m^2, which is equal to 4.1 m^3 CH_4/m^2 or about 3 kg $CH4/m^2$ (Op den Camp, 1987). The total production in the Netherlands is 800,000 ton (Proefstation Champignonteelt, 1990). With an average height of the compost hills of 1.5 meter, a density of 1 ton/m^3, and a composting time of one month, the total production is 1 to 2 kton CH_4/yr.

No experimental results are available for compost. The total production in 1987 was 6,486,000 m^3. Because of the difference in composition and production techniques is it unrealistic to use the methane emission data from mushroom substrate and calculate the thane emission from compost. We assume a total amount of about several hundreds of tons of CH_4/yr.

The total estimated methane emission from mushroom substrate and compost is thus about 1.5 to 2.5 kton CH_4/yr.

Methane emission from drinking water production

Water in aquifers contains small quantities of methane. The amounts range from levels below the detection limits (about 0.01 mg/l) to more than 50-60 mg/l.

To produce drinking water of good quality from these aquifers the methane is removed to a very low concentration level. This prevents methane bacteria consuming oxygen from the water and the use of filters which are polluted with bacterial slime.

To release methane several techniques are available. However, the principle of these different techniques is similar. The water is aerated until the methane concentration is low enough. The aeration technique has been applied since the beginning of the eighties, while in other countries this technique has already been used for many decades (Reijnen, 1987).

In Table 3.10 the release of methane from drinking water production in 1989 is shown. The total emission is about 1.5 kton CH_4 (KIWA, 1990). The majority of the drinking water production plants (40 out of 43 plants) produce together one third of the total production. At two plants the production is around 200 ton and in one other plant the production amounts to 625 ton methane.

The methane released comes directly in the atmosphere. Because of the low

Table 3.10: Methane emissions from drinking water plants in the Netherlands in 1989.

Amount of plants	emission category	methane emission (ton)
32	< 20 ton/yr	150
5	20-50 ton/yr	170
3	50-100 ton/yr	200
1	100-200 ton/yr	160
1	200-500 ton/yr	215
1	>500 ton/yr	625
Total (rounded off)		1,500 ton

source: KIWA, 1990.

production in most of the plants, the emission has not been regarded as a problem and gas flaring or exploitation of the gas has not been considered seriously. At only one location gas flaring has been considered, but due to current technical problems associated with the flaring of the gas currently no incinerators have been applied.

3.4. PRESENT EMISSIONS AND FUTURE DEVELOPMENTS UNDER EXISTING POLICIES

3.4.1. Present emissions

In Figure 3.3 and Table 3.11 the current level of the total methane emissions in the Netherlands is summarized, showing the main sources and their contribution to the total amount of methane emitted. The total methane emission ranges from about 710 to 1,230 kton CH_4/yr with an average of 960 kton CH_4/yr. About 18% of the total emissions stem from fossil sources and 82% from biogenic sources. The major sources, totalling about 80%, are enteric fermentation from ruminants (37%), landfills (27%) and oil and gas production and transportation (16%). Minor sources are natural wetlands (7%), oceans, lakes, rivers etc. (6%) and other sources (2%).

Figure 3.3: Fossile and biogenic methane emissions in the Netherlands 1989/1990.

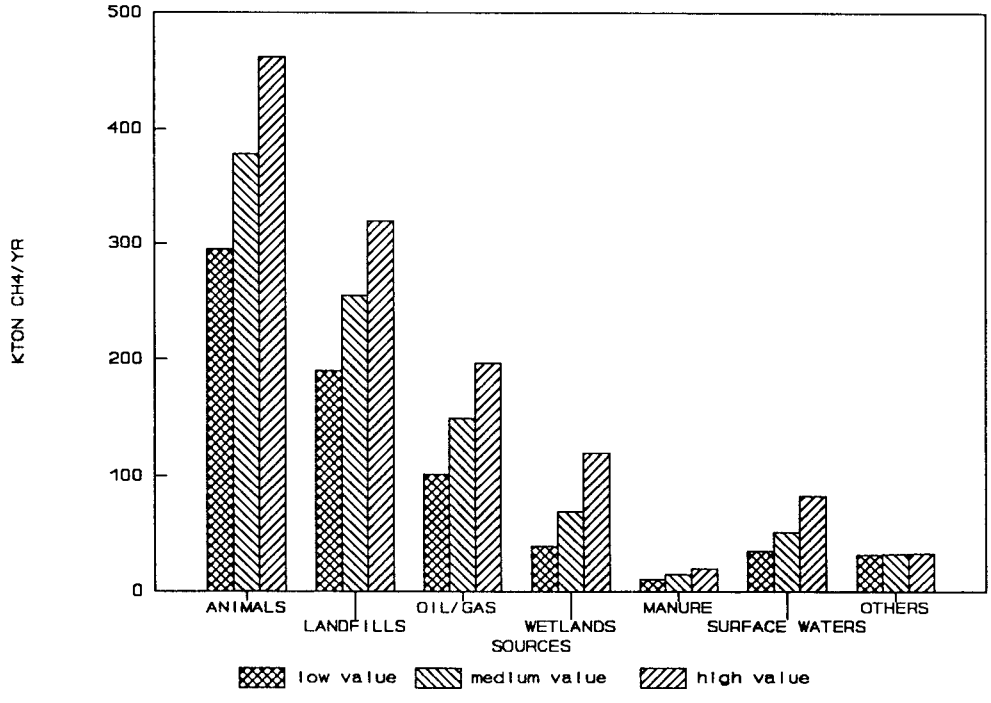


Table 3.11: Emissions of methane in the Netherlands in 1989/1990 (in kton/yr).

Sources	low	high	medium **	perc.
FOSSIL SOURCES				
Oil and gas production o.w.				
- gas production	40	70	55	6 %
- gas transportation	2	12	7	1 %
- gas distribution	60	80	70	7 %
- oil production	0	35	18	2 %
Energy sector (power plant, refinery)	1.5	2	2	0.2%
Residential	8.0	8.0	8.0	1 %
Transportation	8.0	8.0	8.0	1 %
Industry	5.2	5.2	5.2	0.5%
Commercials	3.6	3.6	3.6	0.4%
Total fossil (rounded off) :	130	220	180	18 %
BIOGENIC SOURCES				
Natural wetlands (organic soils) *	40	120	70	7 %
Inland and coastal waters *	24	60	35	4 %
Small water bodies *	11	23	17	2 %
Biomass burning	p.m.	p.m.	p.m.	0.0%
Enteric fermentation o.w.				
- ruminants	270	430	350	37 %
- pseudo-ruminants	5	6	6	1 %
- pigs	18	24	21	2 %
- horses	1	1	1	0.1%
- wild animals	p.m.	p.m.	p.m.	0.0%
- humans	1	1	1	0.1%
Animal manure	10	20	15	2 %
Landfills	190	320	255	27 %
Composting organic waste	1.5	2.5	2.0	0.2%
Water production	2	2	2	0.2%
Waste water treatment	3	3	3	0.3%
Total biogenic (rounded off) :	580	1010	780	82 %
TOTAL (rounded off):	710	1230	960	100 %
o.w.				
- anthropogenic	640	1030	840	87 %
- natural (marked with *)	80	200	120	13 %

** Arithmetical average except for natural wetlands and inland and coastal waters

3.4.2. Future developments of emissions under existing policies

3.4.2.1. Fossil sources of methane

To estimate the future methane emissions from fossil sources it is important to know the development of future energy demand and supply. Table 3.12 gives an indication of the development of energy consumption in the next decade. The data are taken from the Memorandum on Energy Conservation (EZ, 1990b). More detailed data are given in Appendix 6. In the commercial sector gas penetration is expected to increase from 85% in 1990 to 95% in 2010, substituting oil consumption. (Gasunie, 1990). In the public electricity generating sector the share of natural gas will decrease from 45% in 1990 to about 30% in 2000 (SEP, 1990). Further penetration of cogeneration and the use of compressed natural gas (CNG) by buses and cars will increase gas penetration in industry and in the transportation sector. In the residential sector gas consumption will drop due to further insulation and use of high efficiency heating devices. As a result Gasunie (1990) expects that the total gas consumption in the Netherlands will stabilize at the current level. However, it is expected that the export of natural gas in the total period 1990-2010 will increase from 600 to 750 mld m^3 due to developments especially in the electricity sector (shift towards cleaner fuels) and in Eastern Europe.

Furthermore, since the offshore oil fields have passed their peak production rate the volume of oil production will decline. Onshore production will be discontinued as it has become uneconomical at 1989 oil prices (EZ, 1990a). Coal consumption by power plants will increase substantially in the next decade; also the import of electricity will increase in this period (SEP, 1990). Finally, within the next 5 to 10 years most of the gasoline cars will be equipped with a catalyst, thus reducing methane emissions.

As a result of the expected developments, gas production will increase by some 10% and oil production will fade out, with a corresponding effect on methane emissions: ranging from 42-117 kton/yr in 1988 to 46-89 kton/yr in 2000. The large methane emission from gas distribution networks will decrease slowly as a consequence of replacement and maintenance of the old cast iron networks. Quantification of this effect will only be possible when a replacement scheme becomes available. However the number of leaks detected is gradually decreasing, so that a moderate autonomous reduction of this methane source can be expected.

The decrease of gas consumption in power plants in favour of coal will reduce associated methane emissions by 33% and increase emissions from coal by 25%. The total effect of these changes is an emission decrease from 2.0 kton/yr in 1988 to 1.6 kton/yr in 2000.

Industrial gas combustion may show an increase of 10%, causing an increase of the corresponding methane emissions of 230 ton/yr in 2000. Gas consumption in the commercial sector may not change at the same level, while the decrease of energy consumption in this sector will mainly effect the use of oil.

Table 3.12 Tentative scenario for the development of final energy consumption in the Netherlands.

Sector	1989 (PJ)	2000 (PJ)	Increase/ decrease 1990-2000
Power Plants *	325	280	-14%
Industry	1,147	1,310	+14%
Commercial	425	390	-8%
Residential	460	400	-13%
Transportation (excluding bunkers)	370	400	+8%
TOTAL	2,727	2,780	+2%

* Primary energy minus electricity produced by centrally installed power plants.

source: EZ, 1990b: Memorandum on Energy Conservation, Annexe 1, Table 4.

In the transportation sector the relatively large contribution from gasoline fired cars will be decreased by a factor 2 in the next decade due to the increasing penetration of 3-way catalysts: from 5.7 to about 3.0 kton/yr. On the other hand, only a slight increase of energy consumption for this sector is assumed in the MEC for 2000. However, if current rising trends continue, this could in reality almost compensate this reduction.

The total methane emissions from fossil sources will decrease by about 30 kton/yr in 2000 compared to 1988. In Section 3.5.3. the above mentioned data are summarized and discussed in the context of all national emissions of methane in the Netherlands (including biogenic and agricultural emissions).

3.4.2.2. Biogenic sources of methane

Wetlands

The present policy with respect to the management of wetlands is based on prevention of further drainage of the peat and peaty soils and even the raising of water tables in existing agriculturally used wetlands, which may be converted to natural or more extensively used land (LNV, 199a). This may result in an increase of the methane emission from wetlands. Assuming that 50% (± 10%) of the planned increase of nature conservation areas (63,750 ha) will have a higher ground water level then at present (from 4 or 5 to 1, 2, or 3 (see Section 3.3.1), and an average increase of 35 to 120 mg CH_4/m^2 per day the total emission increase is about 4 to 14 kton in a period of 15 years starting in 1990 may be expected.
For 2000 the emissions is assumed to range from 40 to 130 kton CH_4/yr with an average of 75 kton CH_4/yr.

Surface waters

The total area of surface water is not expected to change in the next decades, and it is assumed that the amount of organic material added annually to the surface water change. This implies emissions from this source will remain unchanged.

Ruminants, other animals and humans

The present policy concerning the animal husbandry sector, particularly with respect to cattle, will lead to a reduction of the cattle population in the coming decade. The decrease in heads of cattle is the result of a stable demand of dairy products and meat and an increase of

the production per head of cattle (LNV, 1990b; LEI, 1987; Goossensen and Meeuwissen, 1990). The main determining factor in the total amount of milk cattle is the milk quota. Given the present fixed milk quota a decrease in the amount of milk cattle of 10% (some sources mention 20%) is assumed to occur to compensate the production increase per cattle in the next decade. If no replacement by other ruminants takes place the methane emission from milk cattle will decrease by 10% assuming that there will be no methane emisssion increase due to the production increase. Van der Honing and Van Vuuren (1991), calculated that the methane emission per head of cattle will increase by almost 5% and that the total decrease from this subsector is 6%. This 6% will be realized under the assumption that the milk production increases by 700 kg/year, realized by additional concentrate of 350 kg and no reduction in methane production due to higher digestibility and increase of fodder uptake, and assuming no replacement by other ruminants takes place.
If we assume that the decrease in the cattle population, both dairy/breeding cattle and fattening cattle, will be about 10 to 15 percent in 2000, the methane emissions may decrease by 6% to 9%. The emission of methane from goats and sheeps is assumed to increase equally with the animal population increase of 10 to 20% over a period of 10 years. The remaining animals are assumed to remain at the level of 1990.

Animal manure

The total amount of methane from animal manure, especially from pigs, may decrease as a result of further efforts to diminish the amount of animal manure. Uncertainity still exists concerning the targets. Therefore in the existing policy scenario neither increase nor decrease are assumed. Storage of manure over longer periods (during the winter season), which is part of the policy, might lead to a decrease in emissions as temperatures are lower. However, this is assumed to be a small decrease.

Waste water treatment plants

With respect to the prevention of methane emissions from waste water treatment plants no policies exist to prevent the venting of produced gas.

landfills

Using a model similar to the one described in Section 3.3.6, we calculated the future production of methane in the coming decades (till 2050), based on future waste dumping scenarios. For the future development of waste, especially for dumping in landfills, we had used existing scenarios (Nagelhout et al., 1989). The ratio of waste dumped versus other waste treatments and the organic matter content is assumed to remain at the same level, except for the first scenario.

Scenario 1 involves a phase-out of the dumping of organic material containing waste in 2000. This scenario corresponds with present policy with respect to waste dumping (VROM, 1989b; VROM, 1990a). Scenario 2 depicts a stand-still situation, implying that from 1990 onwards the amount of waste dumped is equal to that in 1990. Scenarios 3 and 4 are based on an annual growth of about 1% and 2% respectively, calculated from 1990 onwards till 2050.

In Table 3.13 and Figure 3.4 the results of the four scenarios are presented. The waste gas production in 1990 from landfills in the Netherlands is estimated to range from 230 to 360 kton CH_4/yr. For the first scenario the emissions in 2000 will be about equal to present emission and for the long term, emissions will decrease to almost zero in the period between

2025 and 2050. For the second scenario the emissions in 2000 are about 90 to 140 kton CH_4/yr higher compared to 1990 emissions data and will stabilize at a level of about 300 to 600 kton CH_4/yr. The third and fourth scenarios show increasing emissions. In 2000 emissions will be about 300-500 and 320-530 kton CH_4/yr respectively and in 2050 the emissions will further increase to 500-1000 and 870-1600 kton CH_4/yr, respectively.

The conclusion is that a stabilization at the 1990 level of the amount of waste produced and dumped will lead to a 50% higher methane emission in 2050 compared to the present situation. Methane production will increase even more if the amount of waste dumped grows annualy with 1 or 2 percent. Figure 3.5 shows the development of the methane emission for scenario 1, the phase-out of dumping organic matter containing waste within one decade.

Collecting waste gas from waste dumps has several advantages. The most important is energy production, decrease in smell from the dump, less damage to the existing vegetation, fewer problems with replantation on the dumps and better safety (fewer explosions due to gas accumulations underground). Besides the above mentioned advantages there are two environmental advantages: firstly the collection of gases from waste reduces the leakage of heavy metals to the soil and ground water below the dumps. If the waste gases are removed the reduction in soil pH is less marked than when this does not take place (Hoeks en Oosthoek, 1981). Secondly the emission of methane to the atmosphere is reduced.

The amount of waste gas recovered is still limited at present, but directions with respect to landfills (Ontwerp Stortbesluit) include regulations that newly designed landfills have to be covered up and methane have to be recovered, using a drainage system. About the effect of the landfill cover, information based on experiments with respect to the methanogenesis proces is lacking but it is assumed that methane formation might increase.

The recovery of waste gas in 1990 is estimated to be 40 kton CH_4/yr, about 15% of the present production (VAM, 1990). The development in the near future strongly depends on the impact of the mentioned direction and its implementation.

According to the environmental action plan drawn up by the energy distribution sector (VEG-Gasinstituut, 1991) and information from NOVEM (1991) the maximum potential recovery might reach an amount of 600 million m^3 waste gas per year (± 230-240 kton CH_4/yr) in 2000. As according to VAM (Woelders, 1990) the production of waste gas after 1993 will diminish due to separate collection of organic waste (so called GFT-component), the extraction might reach its maximum at the end of next decade.

Table 3.13: Calculated methane emissions from landfills (kton CH_4/yr) (not corrected for current recovery of waste gas)

Scenarios	YEAR	1990	1995	2000	2005	2010	2025	2050
SCENARIO 1	minimum	230	240	200	130	60	0	0
DECREASE TO 0 IN 2000	average	300	320	280	220	160	60	0
	maximum	360	400	370	300	250	120	0
SCENARIO 2	minimum	230	270	290	310	310	310	310
GROWTH AFTER 1990 : 0%	average	300	350	400	430	450	490	490
	maximum	360	440	500	550	590	660	680
SCENARIO 1	minimum	230	270	300	330	350	410	520
GROWTH AFTER 1990 : 1%	average	300	360	410	450	490	600	780
	maximum	360	440	510	580	640	800	1050
SCENARIO 1	minimum	230	280	320	350	390	530	870
GROWTH AFTER 1990 : 2%	average	300	360	420	480	550	760	1250
	maximum	360	450	530	610	700	990	1600

Figure 3.4: Projected future methane emission from landfills in the Netherlands in 1990. (not corrected for amount of methane recovered or flared).

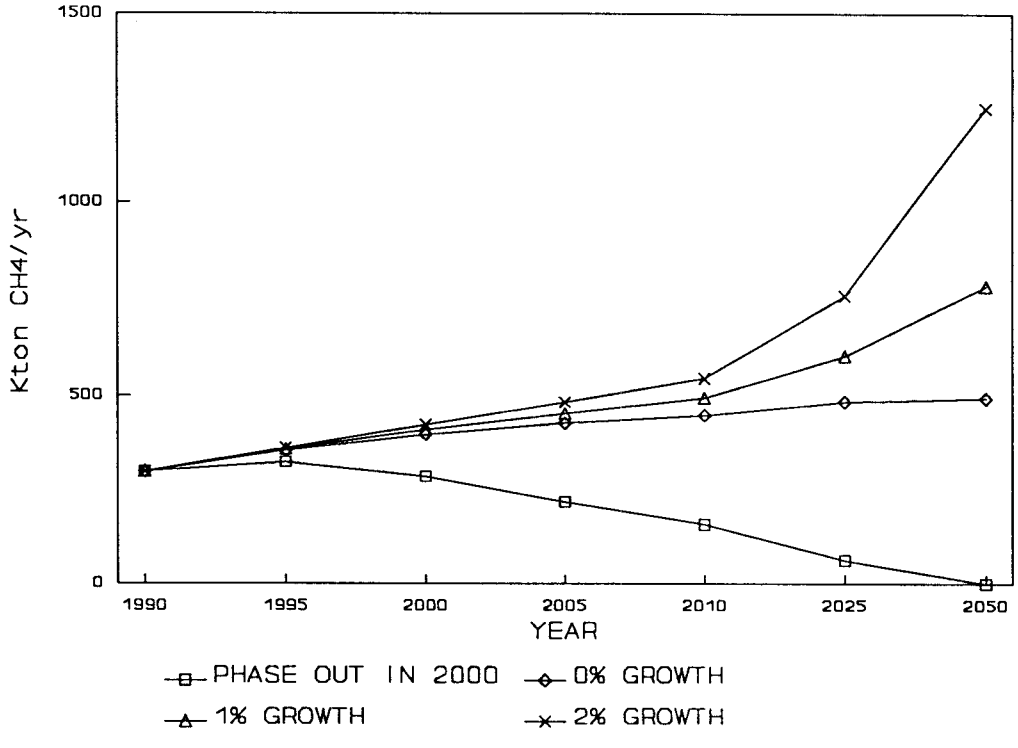
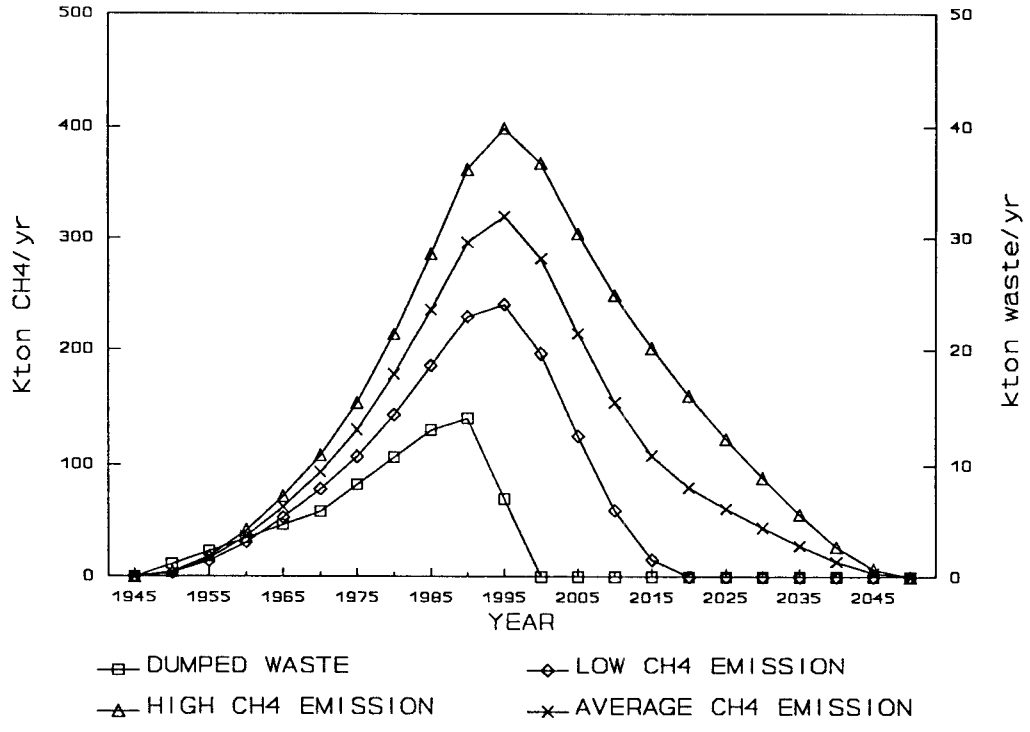


Figure 3.5: Projected future methane emission from landfills in the Netherlands in 1990 for scenario 1: phase out of filling of organic matter containing refuse in 2000.



Within the context of this chapter on existing policies we assume that the impact of the described direction is the autonomous development. For this purpose we assumed an doubling increase in the recovery of methane from waste gas in the next 10 years of 40 kton CH_4/yr to a total recovery of 80 (75-85) kton CH_4/yr in 2000 [1995 level : 60 (55-65) kton CH_4/yr].

Combining production data of methane in landfills and waste gas recovery data for the next decade, the total amount of methane emitted from landfills will decrease from 1995 onwards only if the present policy to phase out the dump of organic matter containing waste is fully implemented and directions are enforced.

Other sources

Composting: The production of compost, both mushroom substrate and black-earth compost, is expected to grow in the future. This growth largely depends on the use of compost in agriculture and the quality of the compost produced in future.

An increasing demand for compost is expected, especially from agriculture and horticulture (Van Onna, 1989), if improvement of the quality (less toxic metals) is realised. This condition seems feasible since more effort is given to the separate collection of organic material and non-organic material. On the basis of this prospect we predict that this methane source may increase by about 1 kton in the next decade. If we compare this very small increase with the amount of methane that would have been produced if the basic material for

composting was dumped instead of used, the amount of methane produced would have been much higher. From this point of view composting is highly preferable if compared with dumping.

Drinking water production: The present emission of about 1.5 kton may increase in the next decades, to about 2.5 kton in 2000. This increase is due to improvement of methane release techniques (100 ton extra), the increase of water consumption (150 ton extra) and the use of new drinking water plants (740 ton extra), yielding a total increase of 1 kton in 2000 (KIWA, 1990).

3.4.3. Projected future emission of methane from fossil and biogenic sources

In Table 3.14 and Figure 3.6 the summarized data for the emissions of methane are given with respect to the business as usual approach. In case information concerning future developments per sector or subsector and related future emission is not available, this is indicated as "n.a.". For part of the sources a certain increase or decrease is assumed in order to get the best prediction with respect to the future development. Although these assumptions are not all exhaustively argumented, they have been introduced as the most realistic sectoral change scenario regarding methane emissions under the effects of existing policies. For the period up to 2000 the tentative energy scenario of Table 3.12 is used to calculate energy consumption.

From the data it may be concluded that for the two major fossil sources (oil and gas production) in this scenario a decrease is foreseen over a period of 10 years. For fossil sources there is an increase of methane emissions in the gas production and industrial sectors, and a decrease in the oil production, the energy conversion and the transportation sectors. The net effect of both is an increase of about 15 kilotons. Assuming a partial renewal of old cast iron gas distribution networks according to the current replacement rate, a reduction of 10 to 20 percent in 2000 may be expected (as assumed in the Table), resulting in a decrease of fossil emissions of 25 to 30 kton.

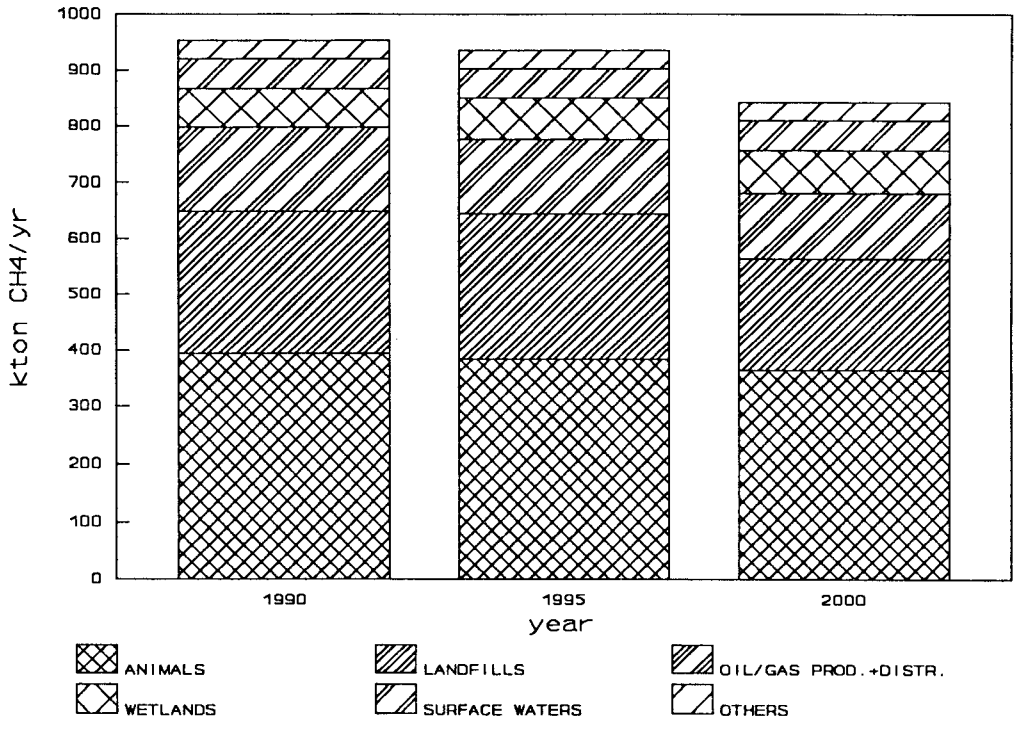
For biogenic sources on the short term an increase is foreseen and on the long term a decrease. The strongest influence in emissions is from landfills, which are presumed to peak in 1995. An increase is expected from landfills (until 1995), natural wetlands, waste water treatment, composting and water production. A decrease is expected to occur in agriculture. Emissions from both cattle (enteric fermentation) and animal waste (pigs and cattle dung) are expected to decrease in time. Both are positive consequences of the animal waste policy.

From the data of the two major biogenic sources (enteric fermentation and landfills) it can be concluded that the 1995 emissions will be about equal to the 1990 emissions of 1,010 kton/yr. In 2000 an emission of about 950 kton is foreseen, which is 5% below the level of 1990. It should be realized however that in Table 3.14 only the average emission values have been used and that the minimum and maximum values range from about 750 to 1,220 kton respectively. Compared to this range the presumed change is almost negligible, though tending to lower emissions.

Table 3.14: Predicted future methane emissions under existing policies 1990-2000 (average values in kton CH_4/yr).

SOURCES	1990 low	1990 high	1990 medium	1995 low	1995 high	1995 medium	2000 low	2000 high	2000 medium
FOSSIL SOURCES									
Oil & gas production/distribution o.w.									
- gas production	40	70	55	42	74	58	44	77	61
- gas transportation	2	12	7	2	12	7	2	12	7
- gas distribution	60	80	70	50	70	60	40	60	50
- oil production	0	35	18	0	18	9	0	0	0
Energy sector (power plants, refineries)	1.5	1.5	1.5	1.3	1.3	1.3	1.1	1.1	1.1
Residential	8.0	8.0	8.0	7.5	7.5	7.5	7.0	7.0	7.0
Transportation	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Industry	5.2	5.2	5.2	5.3	5.3	5.3	5.4	5.4	5.4
Commercial	3.6	3.6	3.6	3.5	3.5	3.5	3.3	3.3	3.3
Total (rounded off):	130	220	180	120	200	160	110	170	140
BIOGENIC SOURCES									
Natural wetlands (organic soils)	40	120	70	41	125	73	42	130	76
Inland and coastal waters	24	60	35	24	60	35	24	60	35
Small water bodies	11	23	17	11	23	17	11	23	17
Biomass burning	p.m	p.m	p.m	p.m	p.m	p.m	p.m	p.m	p.m
Enteric fermentation o.w.									
- ruminants	270	430	350	260	420	340	250	400	320
- pseudoruminants	5	6	6	5	7	6	6	7	6
- pigs	18	24	21	18	24	21	18	24	21
- horses	1	1	1.0	1	1	1	1	1	1.0
- wild animals	p.m	p.m	p.m	p.m	p.m	p.m	p.m	p.m	p.m
- humans	1	1	1.0	1	1	1	1	1	1.0
Animal manure	15	20	15	10	20	15	10	20	15
Landfills	190	320	255	175	345	260	115	295	200
Composting organic waste	1.5	2.5	2.0	2.0	3.0	2.5	2.5	3.5	3.0
Water production	1.5	1.5	1.5	2.0	2.0	2.0	2.5	2.5	2.5
Waste water treatment	2.5	2.5	3.0	2.5	2.5	3	2.5	2.5	3
Total (rounded off):	580	1010	780	550	1030	780	490	970	700
TOTAL (rounded off):	710	1230	960	670	1230	940	600	1140	840
o.w.									
- anthropogenic	640	1030	840	590	1020	810	520	930	710
- natural	80	200	120	80	210	130	80	210	130

Figure 3.6: Projected future methane emission under existing policies in the Netherlands in 1990-2000.



3.5. ADDITIONAL RESPONSE OPTIONS

3.5.1. Fossil sources of methane

Separate efforts are required for a further reduction of the natural gas losses from the gas distribution system. One response option is earlier renewal of the oldest cast iron distribution networks ahead of the original planning or autonomous replacement. This may correspond to either replacement of the joints or the renewal of the complete network. It will be very difficult to achieve further reduction of emissions from leakages. Intensification of the periodic checks of (part of) the network from once per four years to once per year may be considered, although this will probably have a limited effect. It should be noted that the 0.5% loss of gas corresponds to a macro-economic annual loss of tens of millions of Dutch guilders. The second option, related to oil and gas exploration and production, is to prohibit venting of associated, uneconomic volumes of gas. Obligatory flaring of unused gas whenever that is safely possible could sharply reduce this contribution.

A third option is an increase of the level of maintenance of especially residential gas devices, aiming at a reduction of the fraction of unburned gas and associated methane emissions.

A fourth option is lowering the speed limits of road traffic or changing the modal split. When implemented tens of percent of energy could be saved and emissions reduced correspondingly.

Furthermore research into areas of large uncertainties could result in options to reduce emissions on a longer term or in a better quantification of the fossil emission sources. The following issues require research:

- the amount of methane lost in distribution systems, methods to avoid losses and the amounts consumed by bacteria in soils;
- the amount emitted by small and large gas burners, since the emission factors vary considerably;
- the volume of process emissions, especially of non-energetic use of natural gas (chemical feedstock);
- the formation in engines (gasoline and LPG);
- the amount emitted by CNG fired automobiles;

Another point that should receive attention is the definition of "national" methane emission sources, in view of international bunkers, imported electricity (and fuels) and transportation on, in or above international territory. This will greatly facilitate international discussions and agreements on goals for limiting global greenhouse gas emissions.

Quantification of the impact of these options is difficult, due to lack of data. Nevertheless a rough estimate has been made of the effects of the additional response options on methane emissions in order to gain an impression of their effectiveness. Earlier replacement of cast iron gas distribution networks might result in a decrease of emissions of about 50 kton in 2005. Prevention of venting methane during oil and gas production might decrease the emission in 2005 by 30 kton. Improvement of maintenance of gas devices and changes in the transportation sector might save a few kilotons as well. In total an emission reduction of about 80 kton could be achieved by these measures within a period of around 15 years.

3.5.2. Biogenic methane sources

Wetlands and surface waters

A policy to prevent emission from wetlands and surface water is technically impossible and from a nature conservation point of view absolutely undesirable. Therefore no actions exist that may be successful in mitigating emissions from these sources. Monitoring and research for improvement of knowledge on the emission from these natural or semi-natural ecosystems is the most important action that can be taken.

Ruminants and other animals

Two options exist for the prevention of methane emission from ruminants and other animals. One deals with diminishing the methane emissions per animal, the other with the total animal population. Special attention should be given to cattle, responsible for about 90% of the total emission from animals. The net increase or decrease of methane emission per head of cattle strongly depends on the kind of fodder used in the future. The methane production from cattle is largely dependent on the percentage of roughage and the quality of the roughage. The more roughage used, the more methane that is produced by cattle. A diet with a high percentage of concentrate is supposed to reduce the production of methane. It is assumed that the use of roughage with a higher percentage dry matter percentage and long fibres increases the methane production and that higher percentages of fat and flatting decrease the production of methane. (Heeres, 1982).

Improvement of the quality of roughage for more complete digestion and more efficient energy conversion seems to be one of the options that should be considered. As at present only limited data are available concerning the effectiveness of this option, more research is required to analyze the effects of fodder on methane production. Future developments in the use of roughage versus concentrate should be studied. An option with direct results is further reduction of the population of cattle. An extra reduction by 10% will result in about 9% reduction in methane emission derived from animals in the Netherlands. We assume that an additional policy may reduce the cattle and pig population by 10% in 2000, which together with improvement of the quality of roughage may lead to an additional reduction of about 50 kton in addition to the reduction mentioned in Section 3.4.

Animal waste

Two options to prevent emissions from animal waste are feasible. The first is the further promotion of cold and/or thermophile fermentation and the use of the produced gas on farm or centralized. The second option is the prevention of methane emission. Storage of animal waste in silos outside the stable should be promoted. In this respect the temperature of animal waste during storage in cellars and silos is important. Emissions increase with temperature. Below 15 °C emissions do not take place. Considering a combination of both options, a considerable reduction in methane emissions from animal waste is feasible. More research is needed to indicate the exact reduction potential. We assume that a decrease of 3 to 6 kton within 10 years (additional reduction of 20 to 30%) is feasible. This amount also includes the reduction due to reduction of the cattle and pig population (see above).

Waste water treatment

The small amount of methane emitted from fermentation reactors can be reduced to about 1% of the present amount vented. A policy option is compulsory flaring.

Landfills

There are several ways of preventing the release of waste gas into the atmosphere. An integrated approach to prevent the emission seems to be the most successful one. This integrated approach includes several options.

The most fundamental one is the reduction of the dumping of organic material in landfills. This option is effective on the short as well as the long term. If reduction of the dumping of organic material is not a realistic approach on the short term, collection and concentration of organic material in such a way as to make extraction of waste gas feasible should be considered.

Another option is the intensification of waste gas extraction from existing landfills. This not only prevents emission of greenhouse gas, but also prevents further pollution of the landfill area and produces consumable gas. Much more attention should be given to this option, especially in view of the long duration of the methanogenesis proces in landfills. The recovery potential of waste gas from landfills is 600 m^3/yr or 230 to 240 kton CH_4/yr.

The composition of the waste collected and dumped at a waste deposit largely determines the success of collecting waste gas. The policy of the local government with respect to the collection of waste (separated or mixed) should be in harmony with the way the waste is dumped, processed and used. The composition of the waste dumped should be based on knowledge about the most effective composition of the organic components for optimal waste gas production.

Policy makers should be aware of the fact that every million ton of waste of the present composition (about the amount dumped in one month in the Netherlands) dumped produces on the long term a potential amount of 25 kton methane. We assume that response options might lead to a recovery of the potential of 600 million m^3 waste gas per year in 2000. We assume that the range might be 200-240 kton CH_4/yr in 2000. This means that in 2000 the minumum value of the emission is about zero and the maximum emission value is 130 kton CH_4/yr.

Composting

The amount of methane produced during the composting process of compost/black earth and mushroom-substrate is presumably very small. Prevention of anaerobic conditions is the only method which can lead to a decrease of methane. Nowadays composting increasingly takes place in tunnels, which probably reduces the amount of methane that is emitted to the atmosphere.

Water production

To ensure good quality drinking water, methane needs to be removed from untreated ground water. Most of the drinking water services produce very low quantities of methane. These small amounts cannot be collected economically. High quantities (several hundreds of tons) are produced by only a few drinking water services. To prevent the emission from the latter services, the methane produced should be collected and used, or flared. A last option is not to use aquifers with high methane concentrations for the production of drinking water if others are available.

Quantification of response options

From the biogenic sources only a few are potentially suitable for further reduction of methane emissions. Natural sources such as lakes, ditches and wetlands and activities such as composting cannot be influenced and prevention of their emissions is technically difficult. However, some other sources such as cattle, animal waste and landfills, can be influenced.

Especially methane from landfills can be prevented by landfill biogas production for energetic application. Developments in this field should be stimulated and the effect might be a reduction of methane emission of about more than 200 kton on the long term. The substitution of the same amount of natural gas, and the subsequent prevention of associated emissions, is a small secondary positive side effect. Methane from animal waste should be prevented as well. More research is needed to quantify the present emission. We assume that storage of animal waste under emission-reducing conditions might save several ktons. Reduction of the total number of cattle and/or change of fodder could save about 70 to 80 kton, caused directly by lower emission from ruminants and indirectly by lower production of animal waste. Methane produced during the production of water and at water treatment plants may be reduced with a few kton in the coming decade. In total these reductions could reduce emissions by 230 to 270 kton of methane per year (average 250 kton). The time for realization is assumed to be one decade. This quantification is largely unsure. It is based on impact assumptions of policy options. Nevertheless it indicates an order of magnitude of the potential methane reductions due to policy options.

3.5.3. Total impact of response options

From the data on both main sources it can be concluded that if the above mentioned response options are realized a decrease of the methane emission by about 35 percent is feasible. For the fossil sources this is about 45% of a total of 180 kton in 1990 and for the biogenic sources this is about 30% of a total of 780 kton in 1990. This is illustrated in Table 3.15. and Figure 3.7.

Figure 3.7: Future methane emissions with additional response measures in the Netherlands 1990-2000 (in kton).

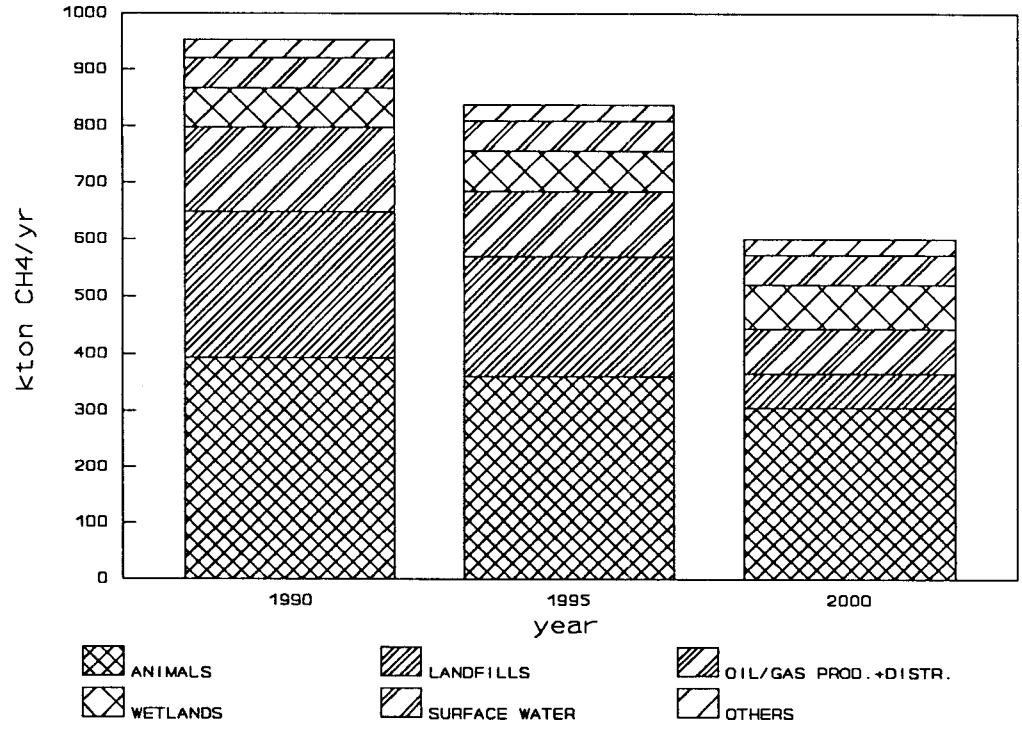


Table 3.15: Projected future methane emissions with additional response measures in the Netherlands 1990-2000. (average values in kton CH_4/yr)

SOURCES	1990 low	1990 high	1990 medium	1995 low	1995 high	1995 medium	2000 low	2000 high	2000 medium
FOSSIL SOURCES									
Oil & gas production/distribution									
- gas production	40	70	55	30	60	45	20	50	35
- gas transportation	2	12	7	2	12	7	2	12	7
- gas distribution	60	80	70	43	63	53	27	47	37
- oil production	0	35	18	0	18	9	0	0	0
Energy sector (power plants, refineries)	1.5	1.5	1.5	1.3	1.3	1.3	1.1	1.1	1.1
Residential	8.0	8.0	8.0	7.5	7.5	7.5	7.0	7.0	7.0
Transportation	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Industry	5.2	5.2	5.2	5.3	5.3	5.3	5.4	5.4	5.4
Commercial	3.6	3.6	3.6	3.5	3.5	3.5	3.3	3.3	3.3
Total (rounded off):	130	220	180	100	180	140	70	130	100
BIOGENIC SOURCES									
Natural wetlands (organic soils)	40	120	70	41	125	73	42	130	76
Inland and coastal waters	24	60	35	24	60	35	24	60	35
Small water bodies	11	23	17	11	23	17	11	23	17
Biomass burning	p.m	p.m	p.m	p.m	p.m	p.m	p.m	p.m	p.m
Enteric fermentation o.w.	0	0							
- ruminants	270	430	350	240	400	320	200	350	270
- pseudoruminants	5	6	6	5	7	6	6	7	7
- pigs	18	24	21	16	22	19	14	20	16
- horses	1	1	1	1	1	1	1	1	1
- wild animals	p.m	p.m	p.m	p.m	p.m	p.m	p.m	p.m	p.m
- humans	1	1	1	1	1	1	1	1	1
Animal manure	10	20	15	7	19	13	4	17	11
Landfills	190	320	255	120	300	210	0	170	60
Composting organic waste	1.5	2.5	2.0	2.0	3.0	2.5	2.5	3.5	3.0
Water production	1.5	1.5	2.0	2	2	2	2	2	2
Waste water treatment	2.5	2.5	3.0	2	2	2	0	0	0
Total (rounded off):	580	1010	780	470	960	700	310	780	500
TOTAL (rounded off):	710	1230	960	570	1140	840	380	910	600
o.w.									
- anthropogenic	640	1030	840	490	930	710	300	700	470
- natural	80	200	120	80	210	130	80	210	130

4. NITROUS OXIDE

4.1. GENERAL CHARACTERISTICS

The concentration of nitrous oxide (N_2O) has increased since pre-industrial times from 288 ppbv to about 310 ppbv (Houghton, 1990; IPCC, 1990a). The current rate of change per year is 0.25-0.31% (Prinn et al., 1990). It is inert in the troposphere and indirectly affects the concentration of stratospheric ozone. In the stratosphere N_2O is oxidized to NO_2 and NO, together indicated as NO_x, which is a catalyst for the destruction ozone.

The major sinks of N_2O are the photochemical decompositon in the higher stratosphere, and the reaction with electronically excited oxygen atoms (O^{1D}) to NO in the stratosphere. Nitrous oxide is removed slowly from the atmosphere because of its long life of 120 -200 years and hence, following a decrease in emissions, it takes decades before a reduction in the concentration is noticed. The observed increase in the atmosphere of the N_2O concentration is assumed to be the result of man's influence on the nitrogen cycle, e.g. fuel combustion, the increased use of fertilizers and the conversion of forests into grassland or arable land. Although little is known about the budget for the N_2O exchange between the terrestrial ecosystem and the atmosphere, it is assumed that 40% of the N_2O emitted is generated from soils (mainly tropical), 20% from oceans, 20% from land clearing and biomass burning and 15% from combustion and the rest mainly from fertilizer. Although not yet confirmed, laboratory research suggests that N_2O could be formed in the atmosphere in the presence of NH_3 (Adema et al., 1990). The latest available data on global nitrous oxide sources and sinks are presented in Table 4.1, and in Figure 4.1. It should be noted here that the most recent data are different from the data used by IPCC (Houghton, 1990)

Table 4.1: Comparison of global estimates of individual sources with results of inverse modelling of atmospheric N_2O (Tg N_2O-N/yr)

Sources	References:	According to References low	high	medium *	According to Prinn et al. low	high
Oceans	(Seiler and Conrad, 1987)	1.0	3.0	2.0	2.5	2.6
Tropical soils	(Bouwman et al., 1991)	2.8	9.3	5.6	3.8	4.8
Temperate soils	(Bouwman et al., 1991)	0.3	4.1	1.4	0.6	0.7
Combustion	(IPCC, 1990)	0.1	0.3	0.2	0.2	3.7
Biomass burning	(Crutzen and Andreae, 1991)	0.2	0.6	0.4	0.1	0.4
Land clearing	(Seiler and Conrad, 1987)	0.2	0.6	0.4 |->	1.6	4.0
Fertilizer	(Eichner, 1990)	0.2	2.1	0.7 |		
TOTAL SOURCES		5	20	11	9	16
SINKS						
Removal by soils					n.a.	n.a.
Photolysis in the stratosphere					8	10
ATMOSPHERIC INCREASE					4	4

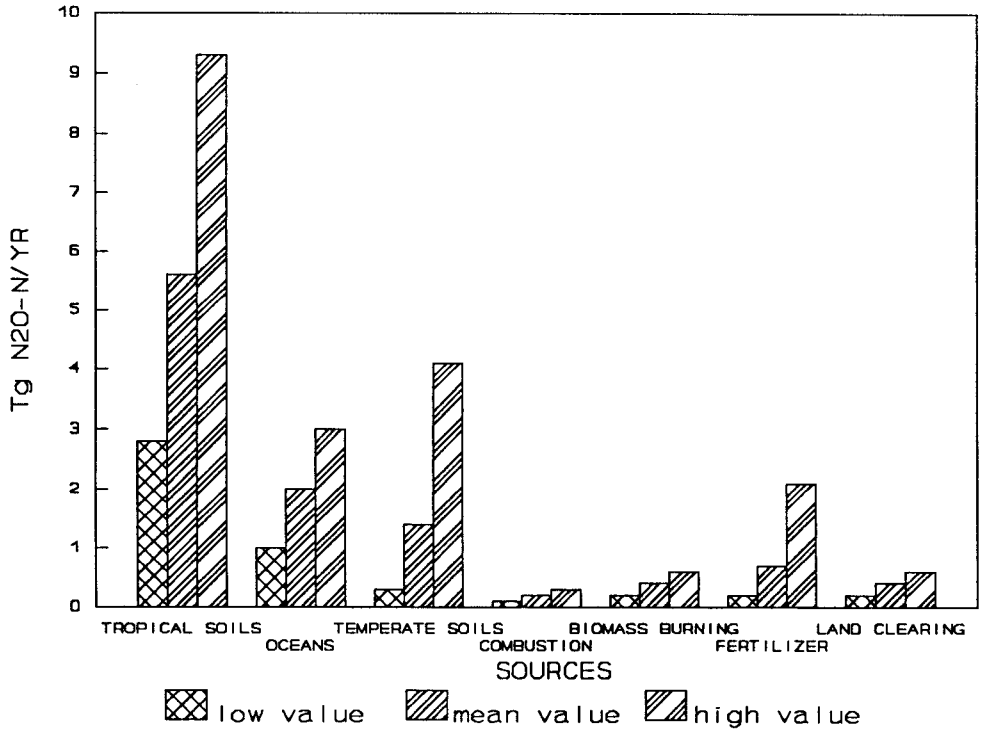
* The sum of individual source estimates does not correspond to the estimate of the total N_2O source strength deduced from inverse modelling by Prinn et al. (1990), illustrating the degree of uncertainty in these estimates.

The sources and sinks of nitrous oxide can be divided into biogenic and fossil sources. The main biogenic processes in which nitrous oxide is formed are denitrification (microbial reduction of nitrate to N_2O) and nitrification (microbial oxidation of ammonium to nitrate). In both cases nitrous oxide is an intermediate component. These processes occur in soils both in tropical and temperate areas (especially in fertilized soils), sediments, oceans, fresh and brackish surface water and waste water treatment plants.
Other biogenic sources of nitrous oxide may be biomass burning, forest fires and ionization processes in the atmosphere through lightning.

The Netherlands, a lowland country with a relative largely area influenced by ground water and flooding, high to very high inputs of fertilizer and a well managed soil water balance, and high energy consumption is expected to contribute substantially to the emission of nitrous oxide from both biogenic and fossil origin.

A problem encountered is that very few investigations have been done on emissions from soils, oceans, lakes and inland waters and waste water treatment plants, notably in the Netherlands. In the following sections often crude assumptions derived from foreign research literature had to be made to gain a quantitative picture of the emission in the Netherlands.

Figure 4.1: Global sources of nitrous oxide (based on individual references)



4.2. EMISSIONS OF NITROUS OXIDE FROM FOSSIL SOURCES

Nitrous oxide (N_2O) is not a constituent of fuels but may be formed when fuel is combusted. Fossil fuel combustion seems to be only a minor source of nitrous oxide emission. A good estimation of this source is difficult. This is due to an artefact in analyses of the emission from stationary combustion sources before June 1988 (formation of N_2O in the gas samples from NO and catalysed by SO_2 in off-line analysed samples). New on-line analyses and critical reexamination of old emission data indicate that N_2O emissions from these sources are in fact much lower than reported previously (De Soete, 1990; Elshout, 1989).

At this moment the reaction mechanism and kinetics of N_2O formation and destruction in the combustion process is not sufficiently well understood. Various formation as well as destruction reactions play a role in the production of N_2O from fossil fuel combustion, whereby the net release depends on a variety of factors such as burner type, excess air, temperature and composition of the fuel (Smart, 1990).

The most important formation mechanisms appear to be gas phase reactions of HCN at temperatures (in stationary combustion sources) of 800-1,000 °C and heterogeneous reactions during combustion or in catalytic emission control systems (SCR of NO_x and 3-way catalysts). Heterogeneous reactions are reactions occurring either between a gaseous and a solid reactant or between two reactants in the gas phase reacting at the gas/solid interface.
During combustion of coal these reactions may occur on the char particles via the formation of oxidized active carbon sites (-CNO). Nitrous oxide may also be formed during catalytic NO_x reduction processes. In 3-way catalysts this may occur under slightly reducing conditions, mainly on noble metal catalysts, and during flue gas after-treatment in selective catalytic reduction de-NO_x processes under slightly oxidizing conditions, mainly on metal oxide catalysts and in the presence of ammonia. Additional favourable conditions for the formation of N_2O are the presence of CO and/or H_2 (engines), an oxygen level not inhibiting NO_x reduction and a temperature in the range 800-1,000 °C (SCR) (De Soete, 1990 and references therein).

Estimates of N_2O from fossil sources are difficult to make because the available reliable emission data are scarce and widely scattered. This is due to the fact that N_2O production largely depends on the prevailing conditions in the reaction chamber and measurements of N_2O are difficult to make, since the application of on-line measurement techniques is required to avoid the artefact completely. Finally, application of NO_x abatement techniques, such as 3-way catalysts, in stationary as well as in mobile sources, tends to increase the formation of nitrous oxide (De Soete, 1990).

In Table 4.2 the estimated emission of nitrous oxide from the various fossil sources in the Netherlands is shown, using the available new emission factors (excluding artefact figures). More detailed information is given in Appendix 7. For a graphical display see Figure 4.2.

The total emission of N_2O from fossil fuels in the Netherlands in 1988 ranges from 1.7 to 6.5 kton N_2O-N per year with an average of 4.1 kton N_2O-N. The transportation sector seems to be the major contributor to the fossil N_2O emissions. The energy sector (conversion) appears to be the second largest source, because of the large volume of coal consumed. However, N_2O emissions from small stationary sources (mainly the residential sector) are estimated by using factors valid for large combustors and are therefore different in reality. This may have to be adapted in time when specific emission data are available for this category. It must be stressed again that the uncertainty in the estimates is very high.

Table 4.2: Estimated emissions of nitrous oxide from fossil sources in the Netherlands in 1988.

Source	Emissions (ton N_2O-N /yr)	Emission range (ton N_2O-N /yr)
Energy sector	740	(240 - 1,180)
Industry	360	(90 - 640)
Commercial	180	(40 - 330)
Residential	180	(10 - 320)
Transportation	2,680	(1,370 - 4,060)
TOTAL (rounded off):	4,100	(1,700 - 6,500)

sources used: CBS, 1990a; De Soete, 1990; Knapp, 1990

Figure 4.2: Nitrous oxide emissions from fossil sources in the Netherlands in 1988.

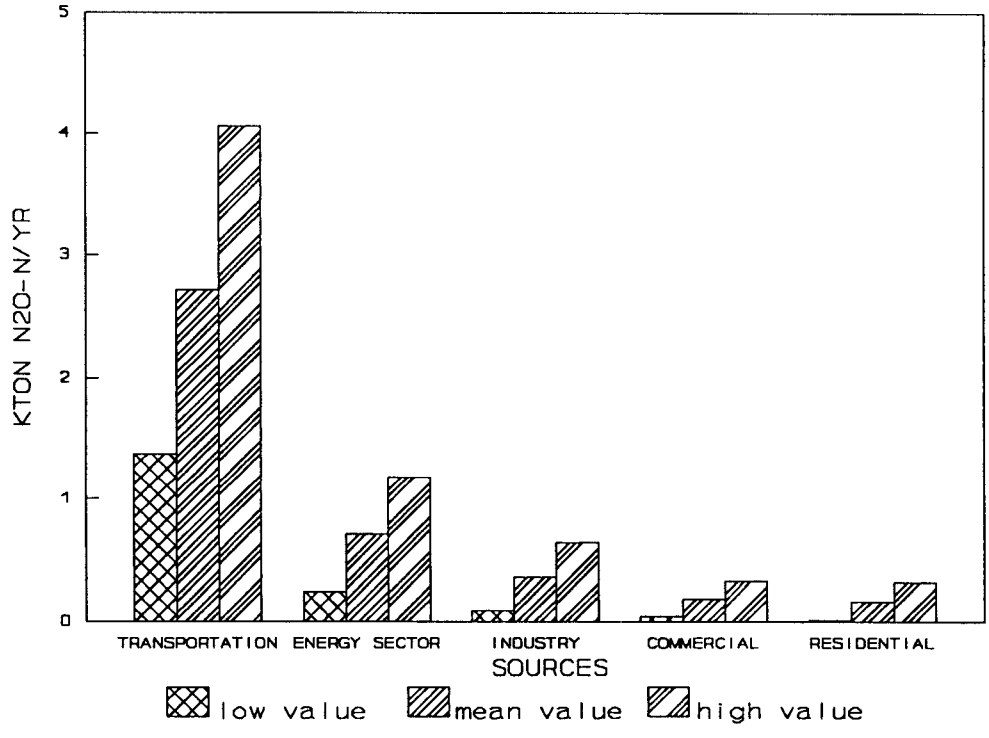


Table 4.3 shows the contribution of the various mobile emission sources. For more details see Appendix 8. The wide range in emission factors illustrates the uncertainty of the available data. It also indicates the strong dependence on the operating conditions of the engine such as load, temperature, type of flame and combustion chamber and lambda value (stoichiometric ratio). Though the low emission estimate of diesel engines is high compared to the low figure for gasoline engines, there are some data indicating that the diesel emission factor may be substantially lower (in the order of 50%) (references in: De Soete, 1990).

Furthermore it should be recalled that the emission data for gasoline fired cars are calculated without (3-way) catalysts, since in 1988 only a small percent of the passenger cars in Europe was equipped with an emission control system. For 1989/1990 the emission might already be higher, due to the increased number of cars equipped with 3-way catalysts.

Table 4.3: Estimated emissions of nitrous oxide from mobile sources in the Netherlands in 1988.

Source	Emissions (ton N_2O-N/yr)	Emission range (ton N_2O-N /yr)
Road (passenger transport) *	1,300	(450 - 2,180)
Road (freight transport)	1,150	(760 - 1,560)
Rail	10	(10 - 20)
Water	220	(150 - 300)
Air	n.a.	

TOTAL (rounded off):	2,700	(1,300 - 4,100)

* without catalyst

sources: CBS, 1990a; De Soete, 1990; Knapp, 1990.

4.3. EMISSIONS OF NITROUS OXIDE FROM BIOGENIC SOURCES

4.3.1. Nitrous oxide emissions from soils

Microbial processes are the major sources and sinks for atmospheric nitrous oxide. The bacterial processes recognized so far in most soil systems are respiratory denitrification, nitrifier or autotrophic denitrification, non-respiratory N_2O production and dissimilatory nitrate and nitrite reduction to ammonia. There is considerable disagreement concerning the relative importance of nitrifier denitrification and respiratory denitrification. Nitrification is a relatively constant process across ecosystems, while denitrification rates are temporally and spatially variable (Firestone and Davidson, 1989). Many researchers have suggested that nitrifiers are the major producers of N_2O in agricultural soils under aerobic conditions (Ryden et al., 1978; Breitenbeck et al., 1980; Bremner and Blackmer, 1981; Klemendtsson et al., 1988) and in semi-arid well-aerated natural soils (Anderson et al., 1988; Parton et al., 1988). In non-agricultural soils the microbial communities may be much more diverse than in cultivated and fertilized soils, and hence, other sources than nitrifiers may, under such conditions, also contribute substantially to N_2O production.

Nitrous oxide emissions of soils show a great spatial and temporal variability due to the occurrence of "hot spots". These hot spots are microsites with high microbial activity and local anaerobic conditions. To include all the spatial variability, a great number of replicates and repetitions of measurements is required whereby the frequency is determined by the weather conditions. As weather conditions may also vary between years, measurements should ideally be made over a number of consecutive years.

Since it was suggested that organic soils, mostly under grassland, are major sources of N_2O (Denier and Swart, 1990), and because no direct measurements were available, a more detailed analysis was done for these types of soils. Below we discuss both quantitative and qualitative aspects of soils and land use, nitrogen supply and leaching in the Netherlands.

Soils and land use in the Netherlands

The total land area of the Netherlands is 3,733,000 ha (CBS, 1990b). The area of cultivated land is about 2,000,000 ha. Of this about 1,100,000 ha is used as grassland. Of the remainder 250,000 ha is used for cereals, 300,000 ha for root and tuber crops, 200,000 for maize (mainly used as fodder), 50,000 for minor crops, 94,000 ha for horticulture and 14,000 ha for intensive horticulture in greenhouses.

Because no information on the distribution of land use over the various soil types was available for this study, some general patterns are assumed: most of the maize cultivation takes place on sandy soils, most agricultural peat soils are used as grassland and most arable land is on mineral soils, mostly well drained. For more information on cultivated and non-cultivated land see Appendix 9.

Nitrogen supply and leaching

The nitrogen applied in agriculture is derived from animal waste and mineral fertilizer. Another source of nitrogen is deposition of ammonium. Data on the use of mineral and organic fertilizers in Dutch agriculture as well as the nitrogen deposition is available per province for the major land-use types; grassland, tuber and root crops (including maize and open horticulture), cereals and other crops. It must be noted that the statistics used are from 1982 (CBS, 1986). Comparison with recent data indicates that the situation may not have changed much (Van Biezen and Hoogervorst, 1989; Kroes et al., 1990). For more information on the input of nitrogen through fertilizer and nitrogen deposition see Appendix 10.

Nitrogen leaching losses were analyzed with the available soil and land use data, to compare and calibrate the value of this approach with other studies, such as Kroes et al. (1990). The levels of nitrogen leached from cultivated soils and non-agricultural land are based on Kolenbrander (1981), whereby the distribution of arable land and grassland over 4 soil texture types was taken from Van Duijvenbooden (1985). The final results of the analysis of the nitrogen input per land use type is given in Appendix 9. For more information on the methodology we refer to Bouwman (1991).

Emissions rates

For grassland on mineral soils and organic soils different equations were used to calculate the amount of nitrous oxide emitted in relation to the net effective input of nitrogen. Net effective input of nitrogen is defined as total N in organic and mineral fertilizer minus NH_3 volatilization. For mineral soils the regression equation is used from Bouwman (1990a) (see Appendix 9), based on statistical analysis of a large number of measurement data. For grassland on organic soils the estimate is based on annual subsidence due to oxidation and on the net effect of an assumed nitrogen supply.

The Dutch grasslands on organic soils are divided into bogs and fens/marshes, followed by a division based on the depth of the ground water table. Assuming that subsidence rates for the bogs are nearly 0.2 cm/yr and for the fens/marshes near to 0.3 cm/yr, a dry matter content of 100-200 kg/m3, and a C% in dry matter of 50%, the loss of carbon from bogs would be 1,000 to 2,000 kg C and 1,500 to 3,000 kg C respectively. Assuming C/N ratios in bogs of 50 and in fens/marshes of 25, the N_2O losses would be 12 to 50 kg N_2O-N/ha per year for fens/marshes and 20 to 40 kg N_2O-N/ha per year for bogs.

Table 4.4: Nitrous oxide emissions from soils (in kton N_2O-N /yr).

Soil texture type	Land use	low	high	average
Mineral soils	grassland	2.8	5.7	4.3
	maize	0.5	1.5	1.0
	other	1.7	2.6	2.2
Organic soils	grassland	3.0	11.8	7.4
	Subtotal agriculture:	8.0	21.6	14.8
	non-agriculture	0.1	0.4	0.3
TOTAL SOILS:		8.1	22.0	15.2

Crops

For non-grassland agriculture the second equation of Bouwman (1990a) is used (see Appendix 9). In this method we assumed that there is no leaching of nitrogen. To arrive at a range, low and high input levels are assumed and the lowest result and highest results of the equation respectively give the extremes. In case of fallow, the nitrogen application is put at zero. For leguminous crops an average emission of 2-4 kg N_2O-N/ha per year was taken. For other non-agricultural land uses the emission rate is assumed to be 0.25 to 0.75 kg N_2O-N/ha yr.

Results

The total amount of nitrous oxide emitted by soils according to the above mentioned methods is 8.1 to 22 kton N_2O-N/yr (see Table 4.4). The annual emission range for grasslands on organic soils is 3.0 to 11.8 kton N_2O-N/yr, which means that more than 50% of the N_2O from soils comes from organic soils with a grass cover. It must be noted however that in organic soils of the bog type (poor organic soils with low pH, which cover about 50% of the total peat land area), the nitrification may be inhibited, and therefore, the estimated N_2O fluxes may be too high.

4.3.2. Nitrous oxide emissions from inland and coastal surface waters

Only few measurements have been made in surface waters in the Netherlands. However, to match the N_2O production in these waters with the mass balance calculations for inland waters emission rates of 6 to 12 kg N_2O-N/ha per year were used. These emissions seem to be high, but such high rates have been measured in other parts of the world (Seitzinger, 1988). However unpublished results show that the N_2O flux for the Wadden sea may amount to only 0.042 kg N_2O- N/ha per year (Kieskamp, 1990).

For inland and coastal waters and the waste water treatment plants gross denitrification rates were used to estimate the N_2O production, since no literature on measurement data are available yet. In Table 4.5 the sources of nitrogen in surface and coastal waters are given, adapted from CBS (1990b). The estimate of N_2O production is based on 25% nitrogen denitrification in inland waters and coastal waters, and a fraction of 5% of N_2O in the gaseous denitrification products. The estimated emission from inland waters is 0.7 to 2.2 kton N_2O-N/yr and this estimate is lower than the figure based on emission rates of 6 to 12 kg N_2O-N/ha per year (see above). The estimated emission from coastal water is 2.2 to 2.8 kton N_2O-N/yr. The

Table 4.5: Sources of nitrogen in waters (in kton N).

Source	Amount
Soils (by leaching)	70
Deposition on water surface	13
Industries	19
Effluent waste water treatment plant (WWTP)	37
Households and other sources	8
TOTAL:	147

source: CBS, 1990b

total amount of N_2O-N from inland and coastal waters (including the effluent of waste water treatment plants) is 2.9 to 5.0 kton N_2O-N/yr.
In waste water treatment plants the nitrogen and phosphorous-containing sewage from households and industries is purified. The nitrogen available as NO_3 - and NH_4+ is removed by nitrification and denitrification. The produced nitrogen is emitted as N_2 except for a small quantity, which is released as N_2O, an intermediate gas product during denitrification. Few measurements of the N_2O emission are available, but a high percentage of the denitrification products may be nitrous oxide. (Wahlen, 1990).

According to statistical data the total influent of the waste water treatment plants (mechanic and biologic treatment) is 75 kton N/yr and the effluent is 30 kton N/yr. In the treatment plants the production of sludge is 264 kton, containing 12.8 kton N. The annual amount of nitrogen removed by waste water treatment plants is thus about 45 kton N/yr. In systems such as water treatment plants with relatively high concentrations and constant supply of nitrogen sources, the N_2O fraction in gaseous losses may be elevated. Assuming an N_2O-fraction in nitrification and denitrification products of about 5% to 10% (Svensson, 1990), the amount lost at the waste water treatment plant itself is 1.6 to 3.2 kton N_2O-N/yr. BKH (1989) reported a total emission of 0.9 kton N_2O-N/yr (1.4 kton N_2O/yr), which is lower than the amount we calculated. This is caused by a lower estimated N_2O fraction during denitrification and nitrification. Recent developments in the treatment of waste water have led to newly designed plants in which the level of nitrogen removal is much higher than in the present water treatment plants. In the near future we foresee that higher amounts of nitrogen will be removed by subsequent denitrification and nitrification, possibly leading to an increase in nitrous oxide emissions.

More research is needed to quantify the increase and find solutions for reducing the emission of N_2O from waste water treatment plants.

4.4. PRESENT EMISSIONS AND FUTURE DEVELOPMENT UNDER EXISTING POLICIES

4.4.1. Present emissions

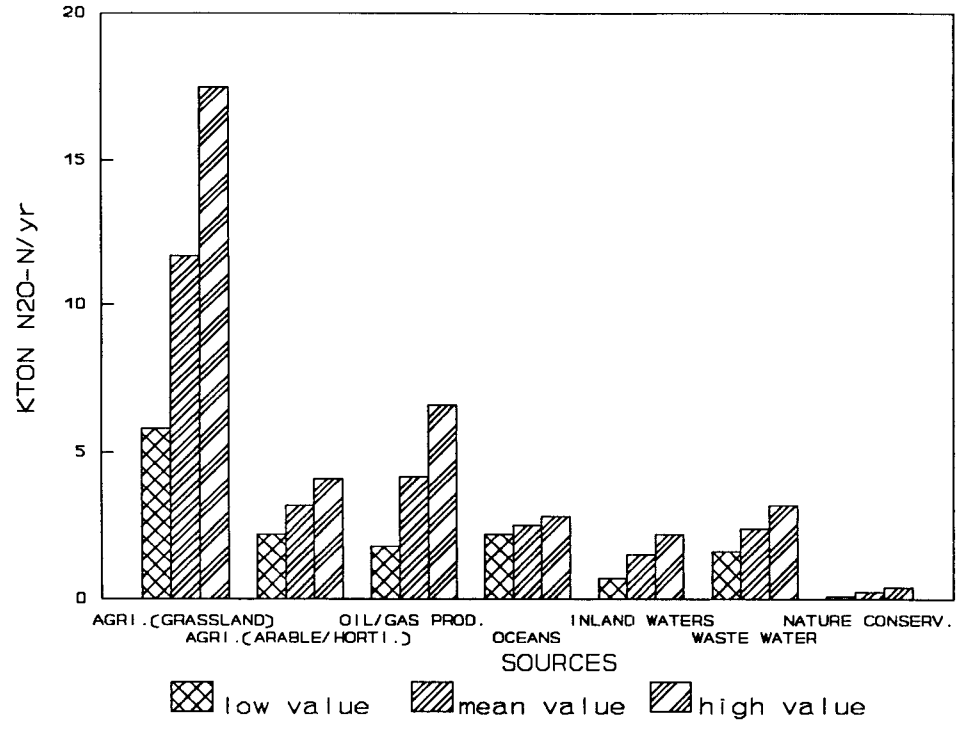
In Table 4.6. all the sources and their contribution to the total amount of nitrous oxide emitted in the Netherlands are summarized. About 15% of the emissions of nitrous oxide is of fossil origin and about 85% is of biogenic origin. Major sources are the grasslands on organic and mineral soils (29% and 17% respectively), the coastal and inland waters (10% and 6% respectively), fossil fuel combustion (16%), of which transportation is the most important

combustion source, fodder maize and other arable/horticulture (13%) and waste water treatment plants (9%). In Figure 4.3 the results are presented in graphical form.
It should be stressed that the N_2O emission results have a large uncertainty and should be interpretated carefully.

Table 4.6: Emissions of nitrous oxide in the Netherlands in 1988-1990 (in ton N_2O-N /yr).

Sources	low	high	medium	perc.
FOSSIL SOURCES				
Energy sector	240	1,200	740	3%
Industry	90	640	360	1%
Commercial	40	330	180	1%
Residential	10	320	180	1%
Transportation	1,400	4,100	2,700	10%
Total fossil sources (rounded off):	1,800	6,600	4,200	16%
BIOGENIC SOURCES				
Grassland, mineral soils	2,800	5,700	4,300	17%
Grassland, organic soils	3,000	11,800	7,400	29%
Maize (fodder)	500	1,500	1,000	4%
Other arable/horticulture	1,700	2,600	2,200	9%
Natural	100	400	250	1%
Inland waters	700	2.200	1,500	6%
Coastal waters	2.200	2.800	2,500	10%
Waste water treatment	1,600	3,200	2,400	9%
Total biogenic sources (rounded off):	12,600	30,200	21,600	84%
TOTAL (rounded off):	14,400	36,800	25,800	100%

Figure 4.3: Sources of nitrous oxide in the Netherlands



4.4.2. Future emission development under existing policies

4.4.2.1. Fossil sources of nitrous oxide

Further developments in the energy consumption pattern following the tentative scenario of Appendix 6 will only have a moderate effect on nitrous oxide emissions. Conventional power plants will emit about 25% more due to the higher volume of coal consumed, while on the other hand emissions from the use of natural gas will drop by 33% in this sector (SEP, 1990). The consumption pattern of the other sectors does not change considerably. However, the application of emission control systems such as catalytic reduction of NO_x could give a substantial increase of N_2O emission.

Lack of data on stationary full scale and emission-controlled combustion facilities make it difficult to make projections for the energy sector. Fluid bed combustion (FBC) appears to have a relatively high emission factor of 100-200 g N_2O-N/GJ. A large scale introduction of this technology will increase emissions. However, some data available from coal fired plants indicate that application of SCR and flue gas desulphurization techniques will not necessarily increase N_2O emissions from these plants (Spoelstra, 1990).

In the transportation sector first results from studies on cars equipped with a 3-way catalyst indicate that N_2O emissions could be multiplied by a factor 3 to 5 for new catalysts and by a factor of seven or more for relatively old catalysts (over 20,000 km). There is growing evidence that these figures are correct (De Soete, 1990 and Prigent, 1990). Hence the N_2O emission of mobile sources, especially passenger cars, will increase substantially in the near future: from 1-4 kton to 3-15 kton per year (emission factors: De Soete, 1990). In

addition to this, current trends suggest that the energy consumption in the transportation sector could grow much more in the next 10 years than the 8% officially quoted in the Structure Scheme for Traffic and Transportation (SVV-II) and the NEPP, increasing the emission of N_2O accordingly.

4.4.2.2. Biogenic sources of nitrous oxide

Soils and land-use

It is presumed that the supply of nitrogen to areas under agriculture will decrease in the next decades as a result of the manure application policy, which regulates the level of fertilization and the period of animal waste application.

This will lead to a decrease in both the emission of ammonia and leaching of nitrate to the ground water, thus leading to a reduction in the emission of nitrous oxide. Based on data with respect to nitrogen supply in agriculture a nitrous oxide reduction of about 40% (±10%) in 2000 may be achieved (LNV, 1990b), leading to an emission ranging from 4.0 to 15.1 kton N_2O-N/yr in 2000 (medium value 8.9 kton N_2O-N/yr.

For nature conservation areas the deposition of ammonia is the main source. If the target of reduction of ammonia deposition of 70% (±10%) in 2000 is reached, the nitrous oxide emission may be also 70% (±10%) lower, giving a negligible emission of 0.02 to 0.2 kton N_2O-N/yr in 2000.

Because of the uncertainties with respect to the feasibility of the decrease in nitrogen supply in the agricultural sector, this reduction should be considered to be dependent on the effectiveness of the policy.

Inland and coastal surface waters and waste water treatment plants

To get information on the increase or decrease of emissions the total input of nitrogen is the key to the answer. Because of the strong relation between the soils and surface water with respect to the nitrogen cycle it is sufficient to know the change in input to the soil-surface water system. The total supply of nitrogen to inland and coastal waters is 147 kton and the emission of nitrous oxide is estimated at 2.2 to 5.0 kton N_2O-N/yr.

For two sources, soils and deposition, an input reduction of nitrogen to inland and coastal waters is assumed, corresponding with the reduction in agriculture (40% ±10%) : 28 kton nitrogen from soils and 9 kton from deposition. This will lead to a total decrease in nitrogen supply of 37 kton over a period of 10 years and a reduction of N_2O emissions of 0.5 to 1.5 kton N_2O-N in 2000 based on the same method of calculation as presented in Section 4.3.2. The reduced future emission of nitrous oxide from surface coastal and inland water will amount to 2.4 to 3.5 kton N_2O-N/yr in 2000.

The input from waste water treatment plants is expected to increase, due to increasing inputs from households and other sectors. The change in treatment technology due to regulations will lead to lower levels of nitrogen in the effluent. This does not drastically influence the direct emission of nitrous oxide. However the relative contribution of the different sources will change. The future input of N from households and other sectors is uncertain. We assume an increase of several percent per year, which may cause an increase of about 20 to 30% in 2000, amounting to an increase of 1 kton in 10 years. The projected future emissions from WWTPs thus range from 1.9 to 4.2 kton.

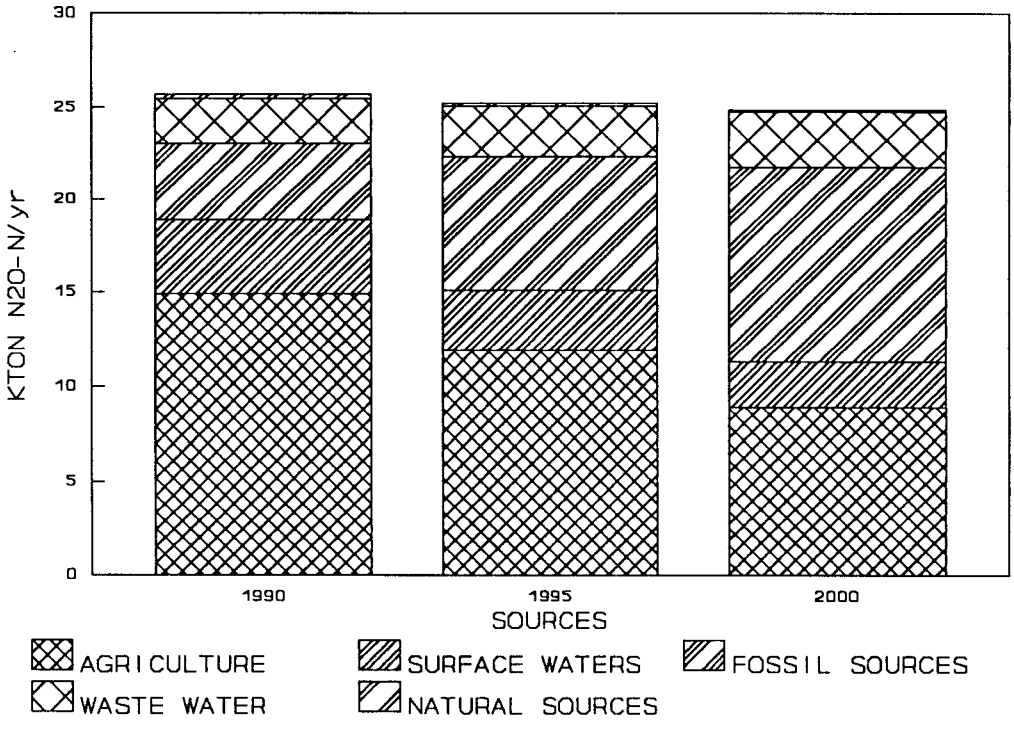
4.4.2.3. Future emissions of nitrous oxide from fossil and biogenic sources

In Table 4.7 and Figure 4.4 the projection of the emissions of nitrous oxide for 1990-2000 under existing policies is presented. In the period 1990-2000 the total emission may decrease by about 4 kton, mainly caused by the expected decrease in the emissions from soils under agriculture and the lower leaching of nitrogen from soils to surface and ground water. The emission from fossil sources, may increase due to the higher emissions by catalysts from the transportation sector. However the increase is based on assumptions and on a limited amount of research data on the subject.

Table 4.7: Projection of emissions of nitrous oxide in the Netherlands 1990-2000 under existing policy (ton N_2O-N/yr).

	1990 low	1990 high	1990 medium	1995 low	1995 high	1995 medium	2000 low	2000 high	2000 medium
FOSSIL SOURCES									
Energy	240	1,180	740	240	1,180	740	240	1,180	740
Industry	90	640	360	90	640	360	90	640	360
Commercial	40	330	180	40	330	180	40	330	180
Residential	10	320	180	10	320	180	10	320	180
Transportation	1,400	4,100	2,700	2,300	10,200	5,800	3,200	16,200	9,000
Total (rounded off):	1,800	6,600	4,200	2,700	12,700	7,300	3,600	18,700	10,500
BIOGENIC SOURCES									
Grassland, mineral soils	2,800	5,700	4,300	6,000	18,400	11,900	4,000	15,100	8,900
Grassland, org.soils	3,000	11,800	7,400						
Maize (fodder)	500	1,500	1,000						
Other arable/horticulture	1,700	2,600	2,200						
Natural	100	400	250	60	280	170	20	160	80
Inland waters	700	2,200	1,500	2,200	2,500	3,200	1,500	3,500	2,400
Coastal waters	2,200	2,800	2,500						
Waste water treatment	1,600	3,200	2,400	1,800	3,700	2,700	1,900	4,200	3,000
Total (rounded off):	12,600	30,200	21,600	10,100	24,900	18,000	7,400	23,000	14,400
TOTAL (rounded off):	14,400	36,800	25,800	12,800	37,600	25,300	11,000	41,700	24,900

Figure 4.4: Projected future emissions of nitrous oxide under existing policies in the Netherlands in 1990-2000



4.5. ADDITIONAL RESPONSE OPTIONS

4.5.1. Fossil sources of nitrous oxide

Since the availability of N_2O emission data is very limited and data on systems with NO_x emission control techniques are even more scarce, a good estimation of the current and future energy related N_2O emissions and possible response options is not yet possible. Further research is therefore recommended, especially on systems with emission controls, to establish good emission factors and to establish the conditions to minimize N_2O emissions simultaneously with the application of emission reducing technologies for other substances. Emphasis on catalyst equipped cars is strongly recommended, since current policy will result in a complete transition of the car fleet within the next decade.
In the future also other fuels such as CNG will be used more intensively in this sector. An evaluation of the consequences for N_2O emissions will assist in developing emission projections for this sector.

An obvious way to reduce the emission is the reduction of the consumption of fossil energy products. In R&D efforts to increase fuel efficiency of combustion systems sufficient attention should be given to the level of N_2O formation, which appears to be very dependent on conditions in the combustion chamber. Another option is further research to decrease the emission of N_2O from cars equipped with a catalyst by optimizing process conditions. If these options prove to be effective, a reduction of several kilotons (2 to 4 kton in 2000) of nitrous oxide may be feasible.

4.5.2. Biogenic sources of nitrous oxide

Information about additional options to reduce the emission of N_2O from soils, inland and coastal water and waste water treatment plants is not available. Process technology and microbiology might give solutions for further reduction of nitrous oxide emissions from treatment plants, stabilization may be feasible in 1995. The bulk of nitrogen inputs however is emitted to water and atmosphere by the agricultural sector. A faster implementation of regulations on nitrogen fertilizer use, both mineral and organic, may strongly influence future emissions, but more study is required. We assume that 10% additional reduction from soils and water sources may be feasible.

4.5.3. Future emission of nitrous oxide from fossil and biogenic sources

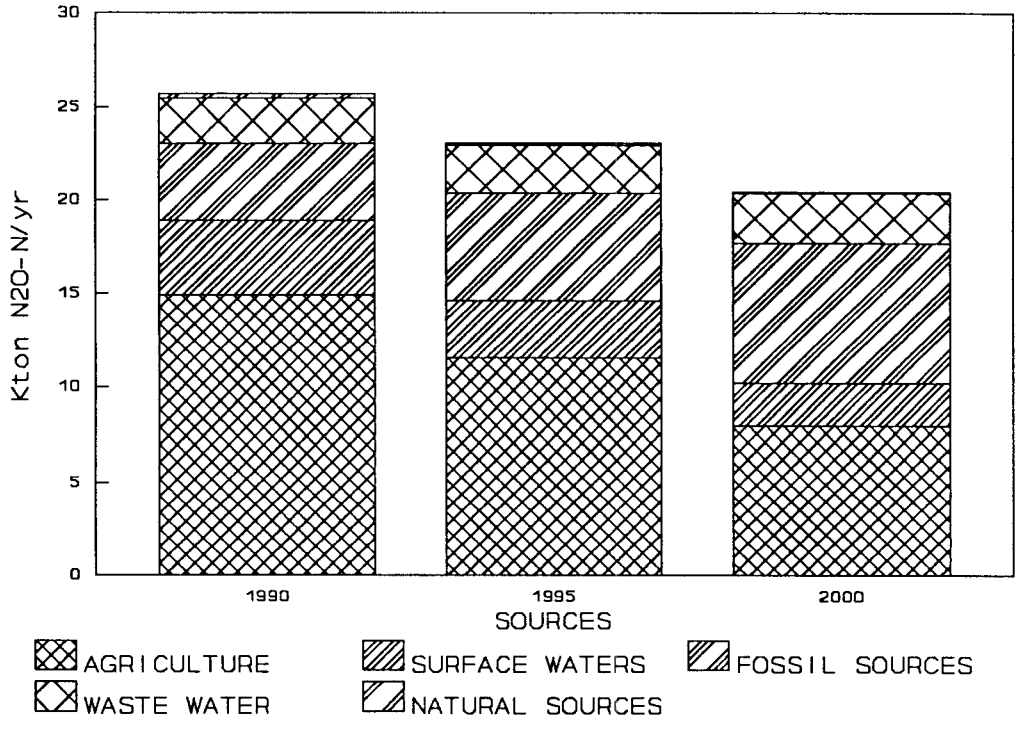
In Table 4.8 and Figure 4.5 a projection is shown of the emissions of nitrous oxide, based on the application of additional response options. Compared to the business as usual option in the next decade till 2000, the total emission might decrease by another 5 kton. This is mainly due to the measures to stabilize the emissions from waste water treatment plants after 1995. After 2000 the emission might stabilize due to a stabilization of the emissions from fossil sources, especially from the transportation sector.

The emissions in the period from 2000 on to 2010 might decrease to a level of about 12 kton if the targets to develop a more sustainable agriculture with almost closed nitrogen cycles are achieved.

Table 4.8: Projected emissions of nitrous oxide with additional response measures in the Netherlands 1990-2000 (ton N_2O-N /yr)

	1990 low	1990 high	1990 medium	1995 low	1995 high	1995 medium	2000 low	2000 high	2000 medium
FOSSIL SOURCES									
Energy	240	1,180	740	240	1,180	740	240	1,180	740
Industry	90	640	360	90	640	360	90	640	360
Commercial	40	330	180	40	330	180	40	330	180
Residential	10	320	180	10	320	180	10	320	180
Transportation	1,400	4,100	2,700	700	9,200	4,300	0	14,200	6,000
Total	1,800	6,600	4,200	1,100	11,700	5,800	400	16,700	7,500
BIOGENIC SOURCES									
Grassland, mineral soils	2,800	5,700	4,300	5,800	17,600	11,500	3,600	13,600	8,000
Grassland, organic soils	3,000	11,800	7,400						
Maize (fodder)	500	1,500	1,000						
Other arable/horticulture	1,700	2,600	2,200						
Natural	100	400	250	60	270	160	20	140	70
Inland waters	700	2,200	1,500	2,100	2,500	3,100	1,300	3,200	2,200
Coastal waters	2,200	2,800	2,500						
Waste water treatment	1,600	3,200	2,400	1,700	3,500	2,600	1,700	3,700	2,700
Total (ton):	12,600	30,200	21,600	9,700	23,900	17,400	6,600	20,600	13,000
Total :	14,400	36,800	25,800	10,800	35,600	23,200	7,000	37,300	20,500

Figure 4.5: Projected future emissions of nitrous oxide with additional measures



5. OTHER GREENHOUSE GASES

5.1. CARBON DIOXIDE

5.1.1. Characteristics

Carbon dioxide is the most important greenhouse gas with the largest radiative effect because of its significant concentration. The atmospheric concentration increased from 280 ppmv in pre-industrial time to 353 ppmv at present with a current rate of change per year of 1.8 ppmv or 0.5% (Houghton et al., 1990). CO_2 is relatively homogenous throughout the troposphere because the troposphere is mixed on a time scale of about 1 year. Carbon in various forms of carbon (CO_2, carbonates, organic compounds) is cycled between various reservoirs of atmosphere and biosphere (aquatic ecosystems, terrestrial ecosystems, sediments etc.). The average time it takes before a CO_2 molecule goes from atmosphere to biosphere is about 4 years. The largest fluxes occur between atmosphere and terrestrial biota and ocean surface water. The time it takes for the atmospheric CO_2 level to adjust to a new equilibrium is of the order of 50-200 years.

5.1.2. Biogenic carbon dioxide

Studies on non-fossil C-fluxes for the Netherlands are executed or currently done by several research institutes such as NIOZ and IHE and by the Agricultural University at Wageningen. Subjects are the aquatic and semi-aquatic ecosystems (IHE), changes in the balances of non-fossil carbon in Dutch coastal waters (NIOZ) and carbon fluxes of terrestrial systems (LUW).
In this report the contribution of sinks or sources of carbon dioxide, both quantitative and qualitative, of the several natural, semi-natural and agricultural ecosystems is not incorporated. For more information on these subjects we refer to the studies of these institutes mentioned in the reference and a reconnaissance report on the consequences of climate change on rural areas by LNV (1990c). Carbon dioxide and waste, an item which deals with prevention of the use of fossil energy sources through recovery and use of energy from fermentation processes e.g. in landfills and waste water treatment plants. This subject is discussed in Chapter 3, especially in Sections 3.4.2.2 and 3.5.2. For CO_2 fixation by forestation and agricultural crops we refer to the results of a project on forestry and climate change in the Netherlands (DHV et al., 1990). They concluded that under the present forestry policy (increase with 40,000 ha in 2000) the equivalent CO_2 fixation might be about 2.6 Mton CO_2 over a period of 10 years, which is only a fraction of the yearly fossil CO_2 emission. Addititional measures might lead to higher CO_2 fixations but it still remains a limited fraction if compared to the fossil emission.

5.1.3. Fossil carbon dioxide

In comparison with other industrialized countries most of the energy consumption in the Netherlands relies very heavily on natural gas (1,300 PJ of 2,700 PJ total primary energy requirement (TPER) in 1988). In almost all sectors, except for refineries and transportation, natural gas is very deeply penetrated. The Dutch energy economy is further characterized by a high consumption by refineries and basic chemical and basic metals industry.

For the definition of CO_2 emissions it should be noted that a considerable amount of energy (440 PJ in 1988) is not combusted but used as chemical feedstock (naphtha, bitumen, natural gas) for the production of plastics, lubricants, asphalt, ammonia, fertilizers etc. (CBS, 1990a). Burning of the plastics, lubricants and asphalt at the end of their life cycle will release the carbon content ultimately as CO_2, usually within a decade or so. Storing/dumping in landfills causes CO_2 release to spread over centuries.

Another matter of definition of national emissions is the fuel consumption by ships and aircraft via international bunkers (260 PJ in 1988), the import of electricity (20 PJ in 1988) and the correction for the average yearly temperature. Electricity imports are generally not considered as part of the inland CO_2 emissions, since the associated fuel combustion is located abroad. For the calculation of the energy-related CO_2 emission of the Netherlands a definition is needed of the activities considered, the possible correction factors for the release time (prompt or including delayed/potential emissions), the average annual temperature (to standard number of heating degree-days of the Netherlands) and finally emission factors for the various fuels. In addition to the prompt CO_2 emission by fossil fuel combustion of approximately 150 Mton/yr about 10% is fixed in carbonaceous non-energetic materials. Most of these products (about 75%) are exported as bulk polymers and raw polymers. Part of the inland consumption is burned for energy purposes, thus releasing CO_2 (Okken et al., 1989). Another additional 10% originates from bunker fuels. A comparison between two different methods to calculate the national CO_2 emission budget is shown in Table 5.1.

Table 5.1: Different methods for calculating CO_2 emissions in the Netherlands (Mton in 1985).

Activity/source	Method A *	Method B **
- Inland combustion of fossil fuels	147	147
- Carbon contained in non-energetic petrochemicals (potential emissions)	18	
- Combustion of MSW, RDF, waste lubricants for energy generation		1
TOTAL:	165	148
- International bunkers (ships, aircrafts)	18	18
- Imported electricity (calculated as being generated by gas) ***	3	3
TOTAL including bunkers and imports of electricity:	186	169

* Includes emissions from carbon contained in non-energetic petrochemicals.
** Excludes this potential source, but includes the CO_2 actually emitted by waste combustion for energetic purposes.
*** Mentioned here to illustrate the size of this contribution in CO_2 equivalents if generated domestically.

source: Okken et al., 1989 (except for imported electricity).

For the definition of national environmental policies in the Netherlands up to now method A has been used; that is including the potential emissions from all petrochemical materials which are produced in the Netherlands and exclusive of international bunkers and of imported electricity. In this report this approach has been adopted too for emission projections unless stated otherwise.

Between 1985 and 1988 the CO_2 emission increased by 10% (see Table 5.2). The main factors responsible for this increase were:

- an increase in the electricity demand by 12% and the substitution of natural gas by coal (partly compensated by more co-generation and more imports);
- an increase of the refinery production of 28%, possibly magnified by a shift of conversion towards lighter products to meet market demand (flexicoker/hycon);
- intensified greenhouse horticulture, consuming 45% more fossil energy;
- increase in the transportation sector 15% (compensated partly by a higher efficiency per vehicle-km);
- a doubling of the estimated combustion of waste from non-energy petrochemical sources, although this was partly used to substitute part of the fossil fuel required for electricity generation (some 10% of the total potential emissions from this source);
- bunkering in general increased by 7% (the bunkering of jet-fuel, though accounting for a minor part as compared with bunkering by seaships, did increase by 50%).

The CO_2 emission decreased only in the residential sector, where a reduction of 4% was achieved, after correction for the number of so-called standard heating degree-days (Okken et al., 1989).

Table 5.2: Sectoral CO_2 emissions of the Netherlands in 1985 and 1988 (temperature adjusted to standard number of heating degree-days).

Sector	Emissions (Mton/yr) 1985	1988	Share 1988	Growth 1985-1988
ENERGY CONVERSION				
- power plants	30.8	35.2	19%	14%
- refineries	9.8	13.2	7%	35%
- coke factories	1.1	1.2	1%	9%
- waste combustion ***	0.8	1.5	1%	88%
INDUSTRY				
- combustion	36.6	37.4	21%	2%
- non-energetic use **	18.0	23.0	13%	28%
COMMERCIAL				
- greenhouse horticulture	5.0	7.4	4%	48%
- others (public and commercial services)	12.7	12.9	7%	2%
RESIDENTIAL				
- residential	23.4	22.4	12%	-4%
TRANSPORTATION				
- inland transport	23.1	24.9	14%	8%
- international bunkers	18.0	19.1	-%	
OTHERS				
- miscellaneous	1.4	1.6	1%	14%
TOTAL (exclusive bunkers, import) ***	161.9	179.2	100%	11%
- import electricity (gas) *	2.7	2.9		7%
TOTAL (inclusive bunkers, import) ***	182.8	201.2		11%

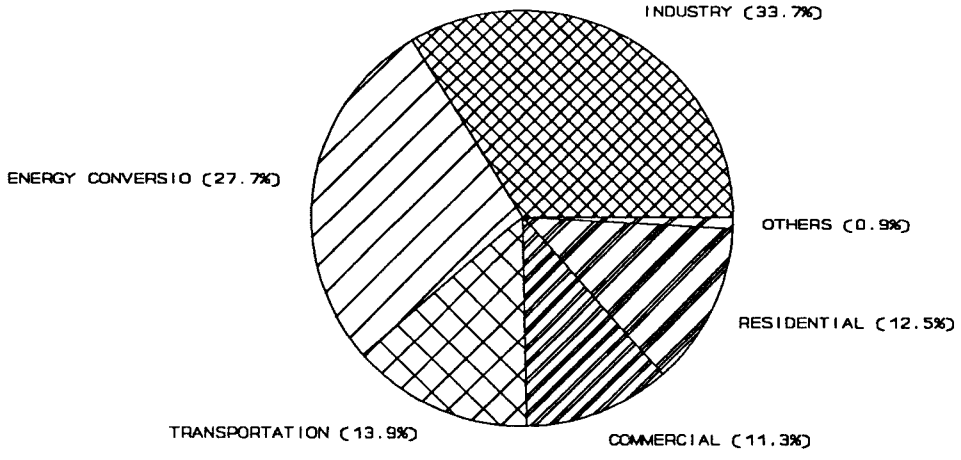
* Included only to illustrate possible CO_2 emissions generated abroad associated with this level: if this electricity was produced domestically it had been included in the Dutch CO_2 budget.

** Potential emission from non-energetic petrochemical products, of which in fact about 75% are exported as bulk materials and a fraction is burned when the material has become waste.

*** Waste combustion is not included in the total, since this is already part of the potential emissions of carbonaceous materials.

sources: Boonekamp et al., 1989; Tiemersma et al., 1989.

Figure 5.1:Fossil CO_2 emissions per sector in the Netherlands in 1988



The relative contribution per sector in the Netherlands for 1988 is shown in Figure 5.1.

The current policy of the Dutch government with respect of CO_2 emissions has been integrated into the National Environmental Policy Plan Plus (NEPP) (VROM, 1990b). The targets are firstly to stabilize CO_2 emissions in 1994/1995 at the 1989/1990 level, which is estimated to be 182 Mton per year, and secondly to realize an absolute reduction in 2000 of 3 to 5% resulting in a level of 173-177 Mton per year. More specific policy measures in the fields of energy consumption and transportation are dealt with in separate policy documents of the competent ministries, i.e. the Memorandum on Energy Conservation (MEC) of the Ministry of Economic Affairs (EZ, 1990b) and the Second Structure Scheme for Traffic and Transportation (SVV-II) of the Ministry of Transportation (V&W, 1990).

The emissions are determined by the total energy consumption, the fuel mix, waste treatment, and correction factors. Energy consumption depends on the volume of activities, structural changes in the economy and the energy efficiency. Changing in the fuel mix is a long term development in the Netherlands, as there are only few dual firing installations in the end-use sector. The infrastructure does not allow for fast changes (e.g. gas used in the residential sector and oil products for the transportation sector).

Currently only a small fraction of the waste of petrochemical non-energy products is combusted. An increase of electricity production by cogeneration may increase the overall energy efficiency of the energy conversion considerably.

Furthermore the application of gas fired Steam and Gas Turbines (STAGs) to replace pulverized coal power plants may decrease the emission of carbon dioxide considerably as a result of a higher efficiency and a lower carbon content.

5.1.4. Future developments under existing policies.

In Table 5.3 and Figure 5.2 the projections of CO_2 emissions until 2000 are shown according to the NEPP. The target of the NEPP and the MEC is to stabilize the emission on the 89/90 level (i.e. 182 Mton/yr) ultimately in 1995 and to achieve an absolute reduction of 3 to 5% in 2000 (i.e. 173-177 Mton/yr), which is also dependent on the economic and international development. For more information see Appendix 11.

With respect to the development "without NEPP" this means a reduction of CO_2 emissions of 17 Mton in 1995 and 38-47 Mton in 2000. Savings for 1995 and 2000 are, respectively, 2.5 and 6-7.5 Mton from energy conservation in the transportation sector, 1.5 and 4-5 Mton from waste treatment, 3 and 14-15 Mton from fuel switching and 10 and 14-20 Mton by energy conservation in other sectors. On average this means a doubling of the energy conservation rate to 2% per year. Table 5.4 summarizes the expected contribution to the CO_2 emission reduction of the various sectors and the type of measures to be implemented, according to the MEC.

In industry it is estimated that in 2000 50% of the then existing installations and buildings will have been built and installed after 1990 and will have a 25% higher energy efficiency. Based on earlier experience, the level of conservation subsidies for adaptations of existing apparatus is expected to generate an increase of energy efficiency of 4% annually.

The 30% conservation in agriculture is expected mainly from greenhouse horticulture: application of energy saving plants (10%), more cogeneration (10%), closed greenhouses and CO_2 fertilization (5-10%), and from more economic techniques for the treatment of manure for the whole sector (5%).

Table 5.3: Historical trends and projected emission of CO_2 in the Netherlands (in Mton/yr) (see also Appendix 11).

Source	Historic trend*				Level projections				
	1988	share	growth 85-88	89/90	1994 auton.	94/95 NEPP	2000 auton.	2000 NEPP	2010 def.
Energy sector	50	28%	+19%			-1.5		-12.5	
Industry ***	60	34%	+2%			-1.5		-1.5/-2.5	
Commercial	20	11%	+14%			-10.0		-17/-20**	
Residential	22	12%	-4%						
Transportation	25	14%	+8%	26.5	29	-2.5	29.5	-6.5/-7.5	20.7
Waste combustion ***	2	-%	+88%			-1.6		-3.5/-4.5	
TOTAL ***	177	100%	+10%	182	195	182	220	173-/177 (NEPP)	

* Adjusted to standard number of heating degree-days.

** Contribution from all stationary combustion sources.

*** Total excluses waste combustion, since this is already included in potential emissions from the industrial sector.

source: Boonekamp et al., 1989; VROM, 1989b (NEP); VROM, 1990a (NEPP); EZ, 1990b (MEC).

Table 5.4: Contribution of measures to the reduction targets of the Memorandum on Energy Conservation for 2000 per sector (percentage of projected sectoral demand).

Sector	Total	New buildings, new appliances	Adaptations, retrofitting	Behaviour
Industry (incl. feedstock)	20%	12	4	4
Agriculture	30%	30	0	0
Commercial buildings	30%	12	8	10
Residential buildings	25%	11	8	6
Transportation (surface)	20%	15	0	5
Others (incl. power plants)	20%	10	5	5
TOTAL (all sectors):	20%	12	4	4

source: EZ, 1990b (MEC).

In the period 1990-2000 about 20% of the commercial buildings will be have a 35% higher energy efficiency than that of existing buildings. In addition 5% may be contributed by more cogeneration in this sector. Conservation subsidies will increase energy efficiency by the insulation of the remaining 80% buildings by 10%.

To realize a conservation of 25% in the residential sector, space heating should become 30% more efficient and 25% by the use of electricity. In 2000 13% of the houses built after 1990 will be 55% more efficient. In 40% of the houses, heating equipment will be replaced by heating equipment with 13% increased efficiency, part of which will be realized by cogeneration plants. Furthermore currently existing houses will have a share of 87% in 2000 and will save 10% by better insulation.

In the transportation sector the planned increase of energy efficiency per vehicle-km is 20%, which will be realized partially by a shift towards economy cars (i.e. smaller and thus lighter cars). In addition, public road transport, bicycles, rail and water transport should get a greater share (modal split) of transportation kilometres.

Finally waste treatment should result in a CO_2 emission reduction of 1.6 Mton/yr by means of:

- prevention of waste of synthetic materials (0.35 Mton);
- recycling of paper and cardboard (0.5 Mton);
- dry digesting of organic waste and manure (0.35 Mton);
- recycling of glass (0.1 Mton) and ferro metals (0.3 Mton).

Table 5.5 and Figure 5.2 show CO_2 emission projections resulting from the NEPP policy. In Figure 5.2 this is compared with the autonomous economic, demographic and technical developments.

The existing afforestation objective is to expand the Dutch forest area by 25,000 hectares between 1988 and 2000 (about 8% of the present forest area). In addition to the energy-related measures mentioned above an effort will be made to supplement this afforestation objective by several thousands of hectares in the next decade (VROM, 1990b).

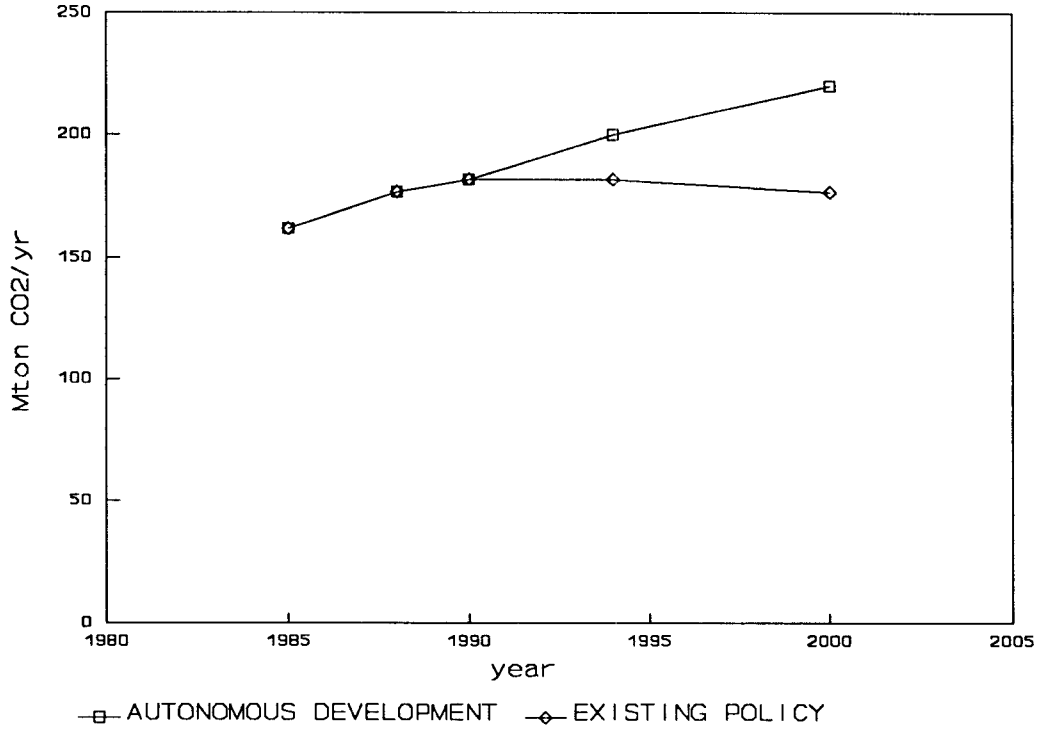
Table 5.5: Future CO_2 emissions in the Netherlands: NEPP scenario (in Mton/yr).

Sector	1988	1995	2000	2010
Energy sector	50	n.a.	n.a.	n.a.
Industry **	60	n.a.	n.a.	n.a.
Commercial	20	n.a.	n.a.	n.a.
Residential	22	n.a.	n.a.	n.a.
Transportation (surface) ***	25	26.5	23	20.7
Waste combustion ****	2	n.a.	n.a.	n.a.
TOTAL (excluding waste combustion) ****	177	182	179-177	142 *

* Assuming an annual decrease of 2%.
** Including potential emissions fixed in non-energetic materials (23 Mton in 1988).
*** Exclusive of air and water transport
**** Waste combustion is not included in the total, since this is already part of the potential emissions of carbonaceous materials.

source: VROM, 1990b (NEPP); EZ, 1990b (MEC).

Figure 5.2: Predicted future CO_2 emission per sector in the Netherlands in 1988.



5.1.5. Additional reponse options

One of the most important technically feasible additional measures, because of high potential and the long lasting impact, is the introduction of higher insulation standards for new buildings and additional energy saving measures for buildings applied at each renovation project which is subsidized by the government. Stringent energy efficiency standards could be applied to all new installations. Energy consumption by traffic can only be reduced against currently increasing trends if either the energy efficiency increases sharply - which is unlikely - or the number of vehicle-km is reduced substantially. This applies to passenger as well as to freight transport. Water and rail transport could be stimulated strongly. Other feasible measures such as thermic solar energy systems (solar boilers), currently on the brink of market introduction, could be stimulated more strongly. Solar energy is one of the few renewable energy sources ready for large scale introduction in the Netherlands.

In general special attention should be paid to those sectors which have a low replacement rate such as the building sector, since measures in these sectors have a very long term impact (positive or negative) (AER, 1990).

An analysis was made of various options for energy saving in the Netherlands in 2000 by the University of Utrecht (Blok et al., 1990). The estimate of the conservation potential for energy saving, including some structural measures and autonomous savings, is about 40% of a projected demand of 3,600 PJ in 2000. The main contributions are from:

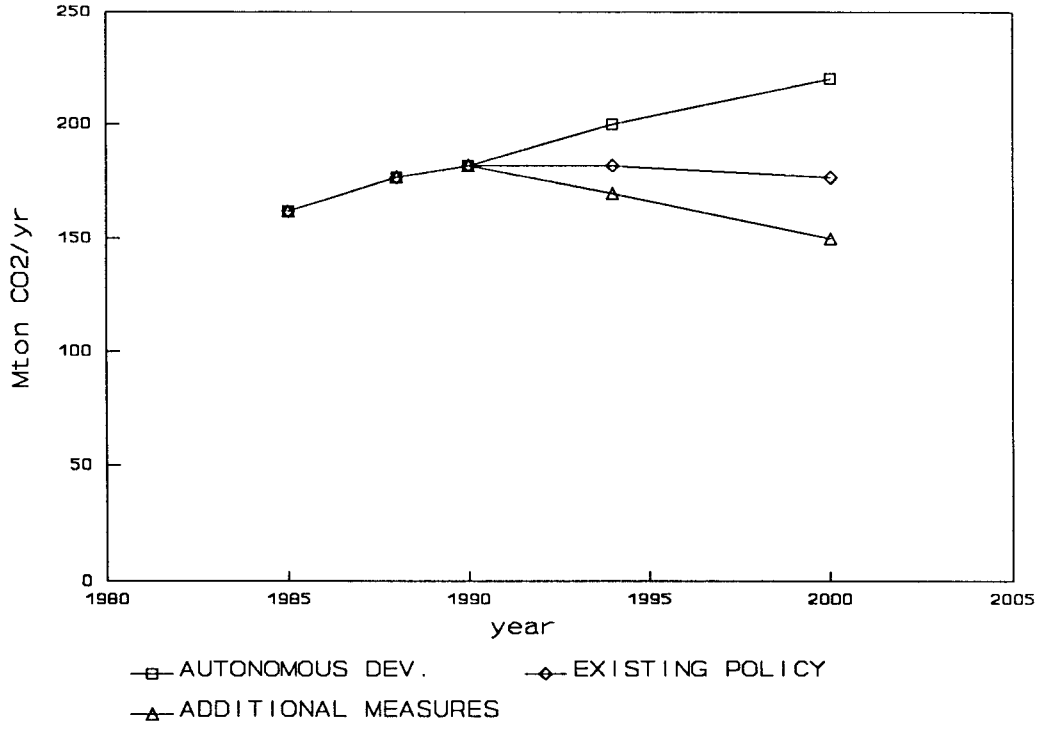
- Residential sector: (special) double glazing, balanced ventilation systems, additional insulation in existing dwellings, high efficiency condensing central heating boilers and energy savings in hot water production and electrical appliances could result in overall savings of 54% of the projected demand (CO_2 reduction 25 Mton/yr);
- Cogeneration: application in chemical industries (boiler steam), greenhouses, food and drugs industries, houses and other buildings could result in savings of 115 PJ primary energy (CO_2 reduction of 12 Mton/yr);
- Transportation: a further shift of the modal split, introduction of CVT, recovery of braking energy of city buses and trucks, more efficient screw propellers/shape of ships could result in overall savings of 26% (CO_2 reduction of 9 Mton/yr);
- Office buildings: double glazing, ventilation heat recovery, additional insulation, condensing boilers, cogeneration and optimizing heat and light control can reduce demand by about 50% (CO_2 reduction 6 Mton/yr);
- Greenhouse horticulture: application of a variety of measures to increase the production per m^2 (assimilation lighting, biological changes), to reduce the energy consumption per m^2 (substrate cultivation, computer controlled growth optimization, insulation and others) and a more efficient energy supply (condensing boilers, heat pumps, external carbon dioxide supply for fertilization, geothermal heat and biogas) would result in reductions of the so-called specific energy demand by 65% (CO_2 reduction 6 Mton/yr).

The associated CO_2 emission reduction of these and other measures is estimated to be 97 Mton/yr or 40% in 2000, based on an estimated demand for primary energy of 3,600 PJ.

Figure 5.3 shows the future CO_2 emission in the Netherlands, i.e. autonomous development, NEPP scenario and additional response options. The estimated associated reduction of Blok et al. (1990) would be about 90 Mton based on a projected autonomous emission of 220 Mton CO_2/yr in 2000 and assuming the same reduction percentage of 40% for this scenario. Another extensive study of the energy savings potential in the Netherlands for 2015 by MT-TNO (Melman et al., 1990) estimates the technical energy savings potential in

2015 to be 30% based on present activity levels and currently available technology, and about 40% including likely technological developments. If only all presently used energy technology were replaced by the best technology already used, then the savings would be in the order of 20%. These figures are in line with the estimates made by Blok et al. (1990). If the difference in economic growth and scenario structure between the NEPP/MEC and the CPB-middle scenario used by Blok is taken into consideration, the total emission in 2000 is estimated to be about 150 Mton, assuming an efficiency improvement increase from 20 to 35%.

Figure 5.3: Predicted future CO_2 emissions in the Netherlands autonomous development, NEPP scenario and additional response options by Blok et al. (1990)



Specific additional long term options aiming at 2010 and 2030, which have been identified by Boonekamp et al. (1989) using a optimization model, are:

- Alternative automotive fuels, i.e. substitution of oil products by CNG (notably for buses, trucks and vans), bio-fuels and electricity (mainly city cars). CNG could have a penetration of 30% in road transport in 2020/2030 and is cost-effective under a 50% reduction constraint (CO_2 reduction 3-8 Mton/year);
- Heat pumps could penetrate in space heating up to 50% reducing CO_2 emission by 7-12 Mton/year, depending on the supply (gas-engine, electricity or gas-absorption);
- Additional renewable energy, i.e. notably photovoltaic solar (to complement gas-fired cogeneration during summer when there is no heat demand for space heating), wind energy (first onshore and on a longer term offshore) and geothermal energy (used for district heating and in greenhouses) could realize an emission reduction of 7-14 Mton/year in 2030;

- Fuel cells for industrial cogeneration (notably MCFC), now in the development stage, could contribute another 3 Mton/year of CO_2 emission reduction;
- Recycling of waste materials (notably the recovery of plastics from MSW and controlled biogas production from the organic fraction in MSW and from manure) can reduce emissions by 4 Mton/year;
- CO_2 removal from Integrated Coal Gasification Combined Cycle (IGCC), the fertilizer industry and gas fired power plants could prove to be cost-effective and feasible from about 2000 onwards, when the first depleted small gas fields will be shut down and could be used for CO_2 storage.

A tentative estimate of the total CO_2 emission reduction achieved by implementation of these options is 10-12 Mton/year in 2010 and 35-40 Mton/year in 2030, taking into account possible interactions of the potentials of these measures. This is based on an estimated demand for primary energy of 3,570 PJ in 2010 and 4,075 PJ in 2030.

Further reductions would require major changes of lifestyles and restructuring of the economy.

5.2. HALOCARBONS

5.2.1. Characteristics

Chlorofluorocarbons (CFCs) and halons have received much attention from researchers and policy makers because of their relation to the global issue of the destruction of the stratospheric ozone layer. CFCs are hydrocarbons with one, two or three carbon atoms, which are fully halogenated with chlorine and fluorine. Halons are hydrocarbons containing one or two carbon atoms, which are fully halogenated with bromine, chlorine and fluorine. HCFCs refer to partially halogenated CFCs with at least one chlorine atom; fluorocarbons or HFCs are hydrocarbons with one or two carbon atoms, which are partially halogenated, exclusively with fluorine. Because of their high ozone depleting potential (ODP) and the long atmospheric lifetime of 60-400 years (and associated long impact) the use of the most important CFCs and halons is regulated by the so-called Montreal Protocol and its update of June 1990 (VROM, 1990b), aiming at a complete phase-out of these CFCs and also of carbon tetrachloride (CCl_4 or HC-10) and methylchloroform (CH_3CCl_3 or HC-140a) in 2000 and 2005, respectively. The last two substances are added mainly because of the high consumption rate. The scheduled phase-out will be accomplished partially by a temporary transition towards HCFCs (30%) and HFCs (10%), which have lower ODPs and much shorter atmospheric lifetimes of 2 to 20 years, and partially by a transition to other substances (30%) and by savings (30%).

Apart from the depletion of the ozone layer CFCs and halons, notably the regulated substances, play a significant role in global warming due to their high global warming potential (GWP). Appendix 12 gives an overview of regulated CFCs/halons and alternatives, their GWP and ODP relative to CFC-11 and their consumption (= potential emission).

It is difficult to estimate the actual annual emission of halocarbons, because the atmospheric emission of these gases may be delayed for some years. This depends on the specific end-use: during use of halocarbon containing devices (e.g. aerosol dispensers) or when it is broken to pieces at the end of the life cycle (e.g. refrigerators).

The consumption of CFCs and halons in the Netherlands is defined as the quantity of production minus destruction by means of an approved technology plus the bulk import and minus the bulk export volume. This definition is in accordance with the definitions used in the Montreal Protocol, which assigns the consumption to the country where the halocarbons are produced.

This definition means that importation of appliances containing CFCs or halons are not counted as Dutch consumption and export is not excluded. For the greenhouse effect this is only of minor concern because of the long lifetime. However, for the estimation of the current contribution relative to other greenhouse gases it does cause some problems. In this report we will use the term potential emission for the consumption of CFCs, to account for the delay of the actual emission to the atmosphere. This does not completely correspond to Dutch future emissions, since the definition of Dutch consumption does not take account of the location where CFCs confined in appliances enter the atmosphere, but only a limited amount of data is available in this sector. However, with respect to time one may assume that the actual emission of CFCs in a specific year is approximately equal to the consumption at that time. The difference will be small when the increase or decrease of annual consumption is small or moderate. At European level the import and export of CFCs are about equal.

The consumption of CFCs and halons is partially energy related and partially related to other uses. A division of the end-use can be made into six major categories, each having a

characteristic delay time between production and emission. This is shown in Table 5.6, which also gives an impression of the range of applications of the individual types of halocarbons. CFC-11 is extensively used as aerosol in spray cans and as a blowing agent in manufacturing plastic foams, whereas CFC-12 is the main CFC used in spray cans and as a cooling agent in refrigerators. CFC-113 is generally used as a solvent in the electronics industry for precision cleaning and to "deflux" printed circuit boards. A small amount is also used for other purposes such as dry cleaning. Most of the CFC-113 production is emitted promptly (assumed to be within a year). CFC-115 is predominantly used in hermetically sealed refrigerators.

Table 5.6: Applications and world consumption of CFCs and halons in 1986 (in kton) and their emission delay time (in years).

Application form	CFC 11	CFC 12	CFC 113	CFC 114	CFC 115	halon 1211	halon 1301	halon 2402	Tot. appl.	Emissions delay
Aerosols/open cell foams	183	162							345	<1
Closed cell foams	153	51							204	10
Hermetically closed refrigerators		219		11					230	12
Non-herm. closed refrigerators	34	9		4	15				62	4
Solvents			182						182	<2 (85%)
Fire extinguishers						18	11	1	30	10
Others	25	32							57	?
Total consumption	395	473	182	15	15	18	11	1	1,110	

sources: Den Elzen et al., 1990 [based on EPA (1988) and UNEP(1989)].

Because of the large quantities produced, methylchloroform (CH_3CCl_3 or HC-140a) is an important substance, although the ODP is rather low compared to CFC-11. Currently it is mainly used in the Netherlands as a cleaning solvent of metal fabricates (54%), solvents of paint and glues (27%), as aerosols (8%), for cleaning of electronic fabricates (7%) and precision cleaning (1%).

Until 1989 the very large non-feedstock uses of carbon tetrachloride (CCl_4 or HC-10) were neglected (UNEP, 1989). Although the main use of HC-10 will continue to be chemical feedstock for the production of CFC-11 and 12, it may also be used as a solvent, for metal degreasing, as a dry cleaning agent and for other purposes. The non-feedstock use of HC-10 has been reduced or prohibited in many countries due to its toxicity.
Halons are extensively used in fire protection applications because of their exceptional specific fire fighting properties. It is estimated that more than 70% or 150 kton are banked to provide stand-by fire protection, being a potential environmental threat.

5.2.2. Further developments under existing policies

In accordance with the Montreal Protocol and its revision of June 1990 the Dutch CFC Action Programme aims at phasing out the consumption of fully halogenated CFCs and halons completely in 2000, with an intermediate goal for 1995 to reduce the CFC and halons consumption by almost 100% (VROM, 1990b). An overview of this programme is given in Table 5.7 and Figure 5.4 and Figure 5.5. More detailed information is presented in Appendix 13. This programme will be implemented in close co-operation between industry and government. It is a few years ahead of the phase-out schedule agreed upon in the Montreal

Table 5.7: Phase-out schedule of CFCs, halons, carbon tetrachloride and methylchloroform consumption in the Netherlands.

Application form	Halo-carbon (code)	Emiss. delay (yr)	Stored quant. (kton)	Consumption (ton) in: 1986	1990	1992	1994	1995	1998
CFCs:									
Aerosols/sterilization	11,12	<1	-	4,700	2,600	951	6	6	0
Cooling	11,12,115	4-12	5	800	600	150	60	0	0
Foams	11,12	<1	50	6,360	5,100	3,050	300	0	0
Solvents	113	<1	-	1,400	1,080	480	200	50	0
TOTAL CFCs:				13,260	9,380	4,631	566	56	0
HALONS:									
Fire extinguishers	1211,1301		3	445	300	100	10	0	0
OTHERS				year:	1990	1992		1995	1998
Carbon tetrachloride	10				1,000	500		150	0
				year:	1989	1992	1995	2000	2005
Methylchloroform	140a				6,400	6,400	4,480	1,920	0

source: VROM, 1989b; VROM, 1990b; WB, 1991

Protocol and the EC-regulation 3322/88 (phase-out CFC in 1997 and halons in 1999). One must realize, however, that a phase out of inland CFC production does not necessarily mean a phase-out of emissions as well: the actual CFC emission from the Netherlands could be higher: CFC containing products will release it in the course of time and new CFC containing products could be imported. It is unknown what currently the net export/import in the Netherlands is. In addition to Dutch agreements on CFC reductions, three European agreements exist on the usage of CFCs for cooling purposes, as aerosol and for the production of synthetic foam (VROM, 1990b). As long as non-ozone depleting and more environmentally suitable alternative substances and technologies are not available, transitional substances with a low ODP will replace the banned CFCs and halons, e.g. HCFCs and HFCs. Additional emission control systems, recovery and recycling should be employed to minimize emissions to the atmosphere.

However, it is expected that in the Netherlands only 40% of the mentioned CFCs will be replaced by HCFCs and HFCs; the other 60% are expected to disappear through conservation measures (30%) and replacement by other alternatives (30%) (VROM, 1990b). Since the ODP of HCFCs is very small relative to the ODP of CFCs, the reduction of the total ODP will be substantial. By a transition to HCFCs, the GWP will be also reduced, because the atmospheric lifetime of HCFCs is much shorter than CFCs (2-20 years for HCFCs in contrast to 60-400 years for CFCs). However scenario calculations indicate that the application of HCFC-22 or similar compounds as a substitute for the eliminated CFCs does have important greenhouse implications, especially if the demand further increases after the completion of the substitution process (Den Elzen et al., 1990).

The substitutes for CFCs which are currently being considered are HCFCs 22, 123, 124, 134a, 141b, 142b and HFC-143a and 152a. These compounds exhibit the specific

Figure 5.4: Phase out of CFCs, halon, methylchloroform and carbon tetrachloride consumption per application form in the Netherlands.

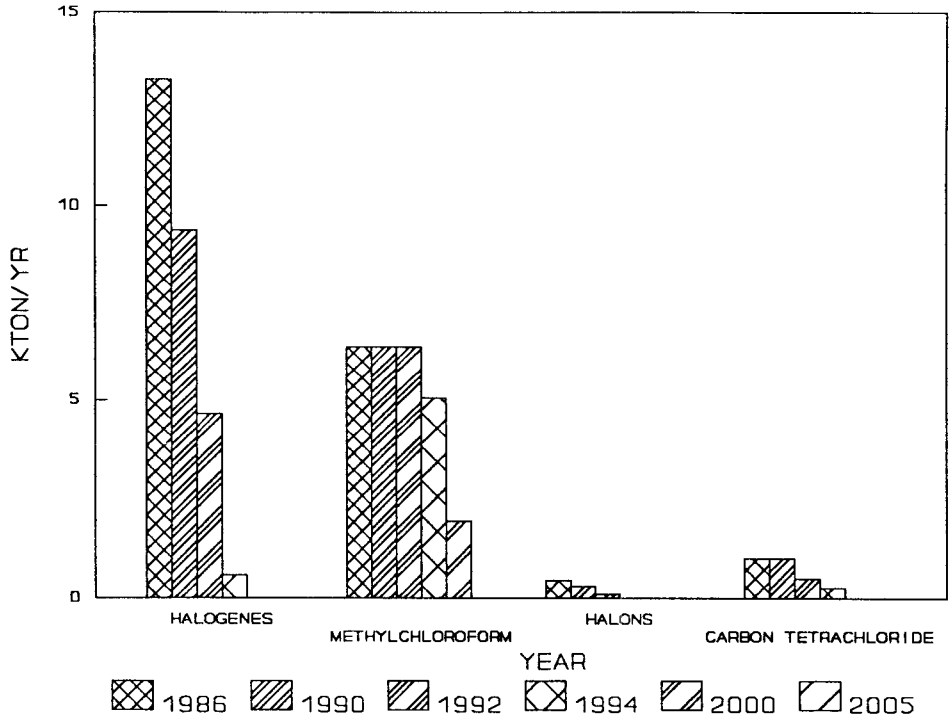
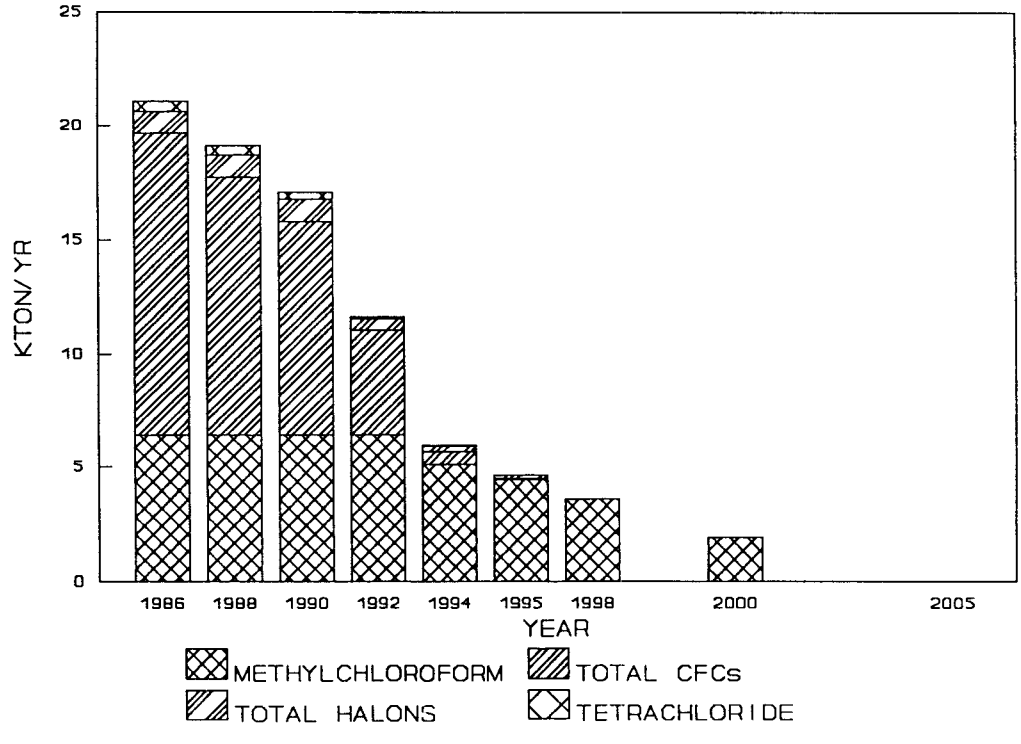


Figure 5.5: Phase out schedule of CFCs, halon, methylchloroform and carbon tetrachloride.



properties of the regulated halocarbons and they are currently being evaluated with regard to their performance, safety, energy efficiency and economics. Some alternative compounds are still in a research phase, but it is expected that production will start soon (Den Elzen et al., 1990).

5.2.3. Additional response options

In new refrigeration and air-conditioning equipment the use of substitutes is already feasible. However, in equipment which is already in use CFCs generally cannot be substituted as these systems are not designed for this mode of operation. For this category only control measures on leakages is a suitable option. For foam production it is technically feasible to reduce the CFC consumption by 60-70% by 1993 with a virtual phase out by 1995, depending on the availability of the substitutes. All solvent applications of CFC-113 can be phased out by 2000 as there are various alternative options available (HCFCs as well as non-fluorocarbons). At present it is technically feasible to replace the CFCs used for aerosols by low-GWP/zero-ODP substitutes. In industrialized countries replacement can start on the short term, while in the developing countries implementation may take place within some years (Den Elzen et al., 1990).

It is not yet clear which alternatives will replace the currently used halocarbons. Therefore the GWP remaining after the elimination of the regulated CFCs can only be estimated. The most important greenhouse gases among the substitutes are HCFC-22 and other HCFCs with a similar, relatively low, GWP. However, if the consumption of HCFC-22 and other alternatives with a similar GWP continue to increase substantially after the completion of the substitution, process calculations will still show a great enhancement of global warming (Den Elzen et al., 1990). Therefore the application of other alternatives with zero GWP and ODP is preferred. If the application of e.g. HCFCs and HFCs with still lower GWPs than CFC-22 is not yet feasible, the intermediate period during which HCFC-22 and similar halocarbons are used should be kept as short as possible.

Frequently used alternatives for CFCs and Halons other than HCFCs which have global warming potential are hydrocarbons. Although these hydrocarbons have low GWPs, the consequence of a total phase-out of CFCs and halons is an increase of the contributions from other trace gases, such as VOC.

As additional policy measures to strengthen the existing CFC Action Programme the following actions could be considered:

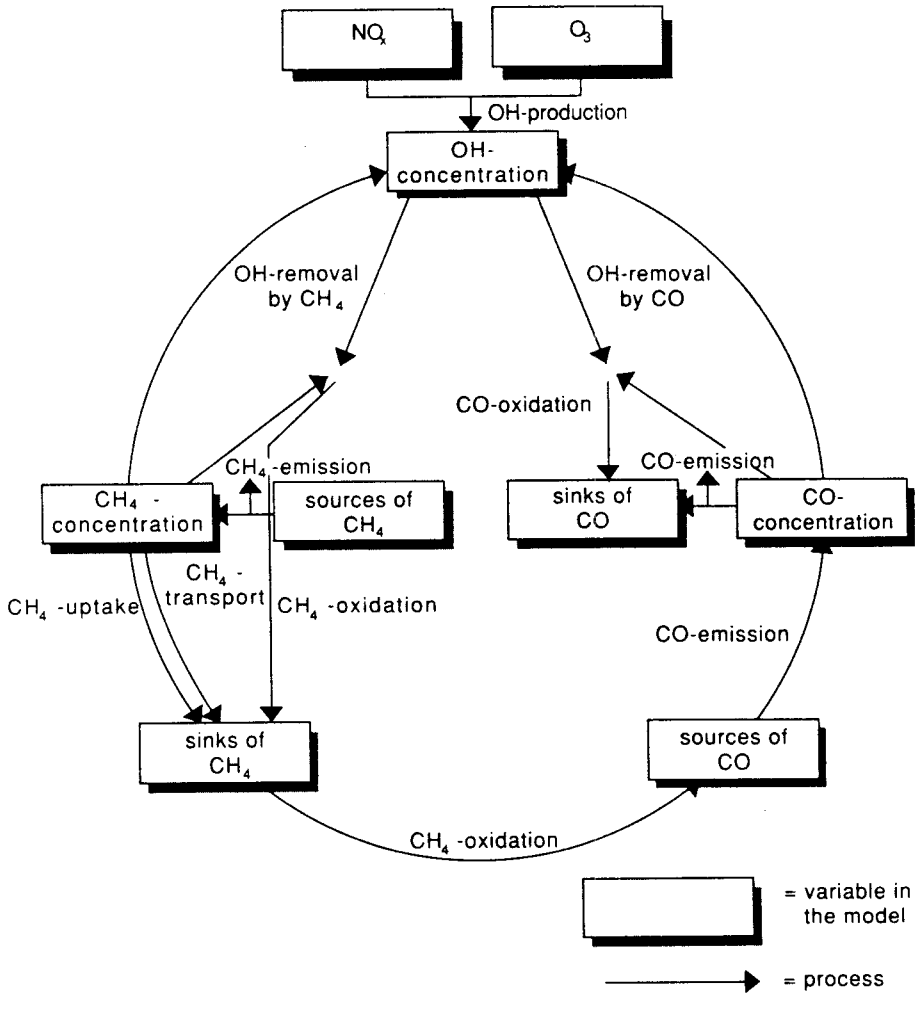
- increased research efforts to identify alternatives for carbon tetrachloride and methylchloroform and consequently a quick reduction programme for these compounds, which is currently being studied; phase-out of methylchloroform in 2000 and of tetrachloride is assumed in 1995
- increased attention for recycling possibilities of the halocarbons with non-zero GWP/ODP still used in appliances (regulation on design, waste treatment etc.);
- stimulation of substitutes with zero GWP/ODP to replace HCFCs after a short transition period. Stabilization of HCFC in 2000 at the level of 1990 is assumed.

5.3. EMISSIONS OF CARBON MONOXIDE

5.3.1. Characteristics

In a chain of reactions in the stratosphere in which NO_x plays an important role as catalyst, organic compounds, including carbon monoxide and methane, are oxidized to CO_2 and O_3. Increase of the CO concentrations leads to a decrease in OH-radicals, which leads to lower CH_4 sinks. Decrease of CO concentrations leads to higher sinks for methane in the troposphere. In environments with a high NO_x concentration the oxidation of CO leads to O_3 while in an environment with a low NO_x concentration O_3 is reduced. Figure 5.6 illustrates the complexity of these interactions. It depicts the CH_4-CO-OH module within the IMAGE-model, developed at RIVM and used for the emission scenario's of the IPCC Working Group 3 (Rotmans, 1990). The processes are highly interdependent and therefore the CH_4-CO-OH system is presented as a cycle.

Figure 5.6: Representation of the CH_4-CO-OH interactions as modelled in IMAGE (Rotmans, 1990)



The emission of carbon monoxide (CO) stems mainly from the transportation sector, notably gasoline fired cars (about 70%). In Table 5.8 the emission data are shown per type and per sector. More detailed information is given in Appendix 14.

Other combustion sources account for about 20% and process emissions contribute another 10%. Incomplete combustion is the main factor determining the amount of CO and VOC in exhaust gases. For car engines the CO content may reach levels up to 2%, especially when a sub-stoichiometric combustion ratio is used. Application of a catalyst will reduce this percentage considerably (Piccot et al., 1990).

Table 5.8: Emissions of carbon monoxide in the Netherlands in 1988.

Type and sector	Emissions per type (kton CO/yr)	(%)	Emission per sector and type (kton CO/yr)	%
COMBUSTION EMISSIONS	985	88		
- Energy sector			4	0
- Industry			153	14
- Commercial			3	0
- Residential			79	3
- Transportation			795	71
PROCESS EMISSIONS	129	12		
- Energy sector			2	0
- Industry			126	11
- Commercials			2	0
TOTAL (rounded off):	1,110	100%	1,110	100%

source: CBS, 1990d; CBS, 1990e.

In Table 5.9 the contribution of the various means of road transportation is presented. The emission factor of carbon monoxide from gasoline fired cars is 18 g/km within city limits (6-8 g/km elsewhere), whereas heavy trucks have a factor of 16 g/km within city limits (and 2-5 g/km elsewhere). Motorbikes have the highest emission factor of 40 g/km (CBS, 1990d). The basic metal industry is the second largest source of CO with emissions from combustion and from other processes. In the steel making process large quantities of carbon monoxide are formed by reactions in the basic oxygen furnace. These emissions can be controlled by means of either an open hood with combustion at the mouth of the furnace and then venting to gas cleaning devices or by a closed hood, ducting all emissions to a gas cleaner and consequently either flaring carbon monoxide or using it for energetic applications. In the Netherlands the former process has been used uptill now. Emissions of carbon monoxide also occur during coke production.

5.3.2. Further developments under existing policies

The application of 3-way catalysts in gasoline fired vehicles will reduce carbon monoxide emissions from the transport sector considerably: 60 to 95% (Piccot et al., 1990). However, complete penetration will take about a decade. A 95% reduction would result in an emission level for this category which is comparable to current emission levels of categories such as diesel vehicles and motorbikes. A consequence of the reduction of CO emissions is an increase of CO_2 emissions. In Chapter 6 this consequence is considered while calculating the contributions of the greenhouse gases. Specific policy measures for a reduction of

Table 5.9: Carbon monoxide emissions in the transportation sector in 1988 (in kton), excl. rail, water and air transport.

Category	Vehicle type	Total	Fuel type		
			gasoline	diesel	LPG
Passenger transport	Passenger cars	580	527	34	19
	Buses	5		5	
	Motorbikes	29	29		
	Mopeds	15	15		
	SUBTOTAL:	629	571	39	19
Trucks	Light trucks	47	35	11	1
	Heavy trucks	24		24	
	SUBTOTAL:	71	35	35	1
Others	Special vehicles	9	6	3	
	Tractors	13		13	
	SUBTOTAL:	22	6	16	0
TOTAL:		722	612	90	20

source: CBS, 1990d

CO emission from the basic metal industry are not foreseen. However, in the middle of 1991 techniques with a higher rate of recovery of CO will be applied to enlarge energetic application of the combustible gases which are produced, thereby reducing CO emissions by about 35% (i.e. an emission reduction of about 30 kton/yr) (N.N., 1991). The results are given in Table 5.10 and Figure 5.7.

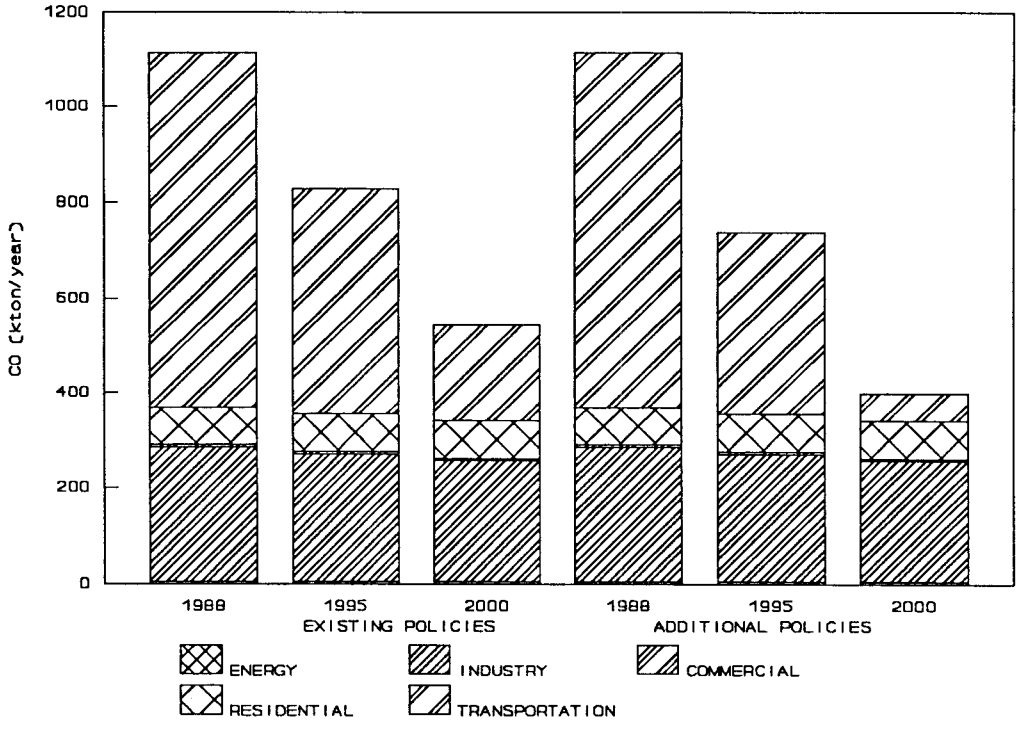
5.3.3. Additional response options

Options to achieve a faster reduction of CO emissions are: obligatory regular inspection and maintenance of vehicles without a catalyst, with special attention for the tuning of the engine in order to reduce the amount of unburned gases. Other options are regular checks of burners (notably in the residential sector) and (additional) control measures in the basic metal industry. The results of additional measures are given in Table 5.10 and Figure 5.7.

Table 5.10: Projected future emission of carbon monoxide emissions under existing policies and with additional measures for 1988-2000 (in kton CO).

	existing policies			additional measures		
Sector	1988	1995	2000	1988	1995	2000
Energy	6	6	6	6	6	6
Industry	279	265	251	279	265	251
Commercial	5	5	5	5	5	5
Residential	79	79	79	79	79	79
Transportation	745	474	203	745	384	58
Total (rounded off)	1110	830	540	1110	740	400

Figure 5.7: Present and future carbon monoxide emissions in the Netherlands under existing policies and additional measures.



5.4. THE OZONE PRECURSORS NO_x AND VOC

5.4.1. Characteristics

The formation of tropospheric ozone is the result of a photochemical reaction between nitrogen monoxide (NO) and nitrogen dioxide (NO_2) and non-methane volatile organic compounds (VOC). The more reactive organic substances react within a few hours close to the emission source (on a regional or national scale), while the less reactive compounds will spread further before ozone formation occurs. This ozone formation should not be confused with the stratospheric ozone layer, which is being depleted. Direct emission of ozone formed as a result of electric discharges and high temperatures, e.g. by photocopiers, can be neglected.

The highly reactive tropospheric ozone acts both as a GHG and as one of the compounds in the atmospheric boundary layer which have a negative effect on vegetation and materials (building structures). Other compounds which affect vegetation and building structures are SO_2, NO_x and NH_3. In addition to these harmful effects high ozone levels also have negative effects on human health. To avoid this the ozone concentration level at surface level should be near the natural background concentration. The formation of ozone can be reduced by limiting the emission of the precursors NO_x and/or VOC (Slooff et al., 1989). For reduction of O_3 during smog episodes (peak concentrations) VOC-emission reduction is the most effective. For reduction of long-term O_3-concentration NO_x reduction is not very effective. Reduction of VOC emissions may be the most effective in this respect.

Anthropogenic VOC emissions are associated with the use of petroleum products (storage, loading and unloading of tanks), the manufacture of chemical products, solvents in paints and lacquers, agriculture and incomplete combustion. Table 5.11 shows that the transportation sector accounts for about 40% of the VOC emissions (unburned hydrocarbons in exhaust gases). For more details see Appendix 15. Mobile sources also give the largest contribute most to anthropogenic NO_x emissions. In the category off-road transport the main sources are inland water transport and agricultural vehicles. Process emissions including evaporation of VOC account for 46% of the total VOC emissions. For NO_x emissions the second most important emission source is stationary combustion.

Table 5.11: Sectoral VOC and NO_x emissions in the Netherlands in 1988 (in kton of VOC and NO_2).

Source/sector	VOC	%	NO_x	%
Natural emissions	15	3%	n.a.	-
Transportation (surface)	202	41%	345	62%
Stationary combustion sources	24	5%	191	34%
Process emissions (excl. agriculture)	225	46%	24	4%
Agriculture	24	5%	n.a.	-
TOTAL:	490	100%	560	100%

sources: VROM, 1989b; CBS, 1990e (natural and agriculture: 1985 figures).

The major industrial sources of VOC are the chemical industry, painting enterprises, the metal-working industries, petroleum industry and the printing industry.

During combustion NO_x is formed through oxidation of nitrogen present in the fuel (fuel NO_x) and predominantly by conversion of nitrogen in the combustion air by reactions with

hydrocarbon fragments or with oxygen in the air (called prompt NO_x and thermal NO_x, respectively) (Odgers et al., 1986). The major process emissions of NO_x are from the fertilizer industry, predominantly from the production of nitric acid.

5.4.2. Further development under existing policies

Reduction of NO_x and VOC emissions from both mobile and stationary combustion sources and from products is one of the targets of the Acidification Abatement Plan (AAP) (VROM, 1989c). This plan and the Hydrocarbon 2000 project (in Dutch: "KWS 2000") (VROM, 1989a), which aims at a reduction of process emissions of VOC, are strengthened for NO_x in the NEPP (VROM, 1990a).

Reduction of VOC and NO_x from mobile sources

The emission targets of the NEPP for road transport are summarized in Table 5.12. Reduction of emissions by the transportation sector, important for both NO_x and VOC emissions, can be achieved by measures focusing at road traffic, such as decreasing the increase of vehicle-kilometres, application of 3-way catalysts, cleaner engine techniques and more energy efficient cars.
For stationary sources NO_x reduction targets in the NEPP are 52-54% as compared to 1980 levels.

Table 5.12: Emissions targets for NO_x and VOC in road transport (kton of VOC and NO_2 /yr).

Source / compound	Emissions limit in:			
	1986	1994	2000	2010
Passenger cars - NO_x	163	100	40	40
Freight trucks - NO_x	122	110	72	25
TOTAL NO_x :	285	210	112	65
Passenger cars - VOC	136		35	35
Freight trucks - VOC	46		30	12
TOTAL VOC:	182		65	47

source: VROM, 1990a (NEPP).

Reduction of VOC from stationary sources and products

In 1986 the Hydrocarbons 2000 project was started, aiming at a reduction of VOC process emissions (including products) to about 50% of the 1981 level of 240 kton per year, to be achieved in 2000 (VROM, 1989a). This project is restricted to industry (including refineries), small enterprises and households. The reduction strategy was developed by using a flexible and balanced approach, whereby targets were set and adjusted in the course of time according to international and technical developments and according to the outcome of consultations of the target group.

The implementation plan consists of measures of which the application is respectively certain, conditional or uncertain. The first group will certainly be implemented (unconditionally). The second type will be implemented as soon as specific technical, environmental or economic conditions are met. The third type of measures may be implemented, depending on

whether or not a positive decision is taken when more information is available. A large number of possible measures dealing with the "petroleum network" and the "paint or solvent network" have been identified:

- process improvements in the chemical industry;
- change to the usage of low-solvent paints, ink etc.;
- reduction of the VOC content of household products;
- intensified maintenance of installations in the chemical and petrochemical industry;
- reduction of filling and breathing emissions of fixed roof tanks by installation of internal floating roofs;
- application of vapour recovery systems during loading/unloading of ships, tank cars and trucks;
- the application of thermal incineration systems for exhaust gases in specific industrial sectors.

Table 5.13 shows the emission targets based on these measures. More details are given in Appendix 16. VOC emission reduction from stationary combustion sources, a minor source with respect to the other sources, is not considered for inclusion in this policy programme because of its low cost-effectiveness. The main sources of this type are the residential and

Table 5.13: Sectoral VOC emissions in the Netherlands according to "KWS 2000" including combustion and natural sources (in kton VOC).

Sector	Historic emission			Projected emissions for 2000			
	1981	1985	1988	Auto-nomous	Certain reduct.	Condit. reduct.	Uncert. reduct.
PROCESS EMISSIONS (acc. KWS 2000)*							
- Energy sector	34	33	32	29	23	8	8
- Industry	142	125	124	120	101	74	61
- Commercial	23	25	25	25	25	19	15
- Residential (households)	31	32	32	30	30	23	16
- Transportation	10	10	10	10	10	6	2
Subtotal:	240	225	223	214	188	129	102
COMBUSTION AND OTHER SOURCES							
- Natural	15	15	15	15	15	15	15
- Agriculture	24	24	24	20	n.a.	n.a.	6
- Transportation (surface)	212	201	203	n.a.	n.a.	n.a.	80
- Stationary combustion sources	27	29	24	n.a.	n.a.	n.a.	10
Subtotal:	278	269	266				111
TOTAL (rounded off):	518	494	491				240

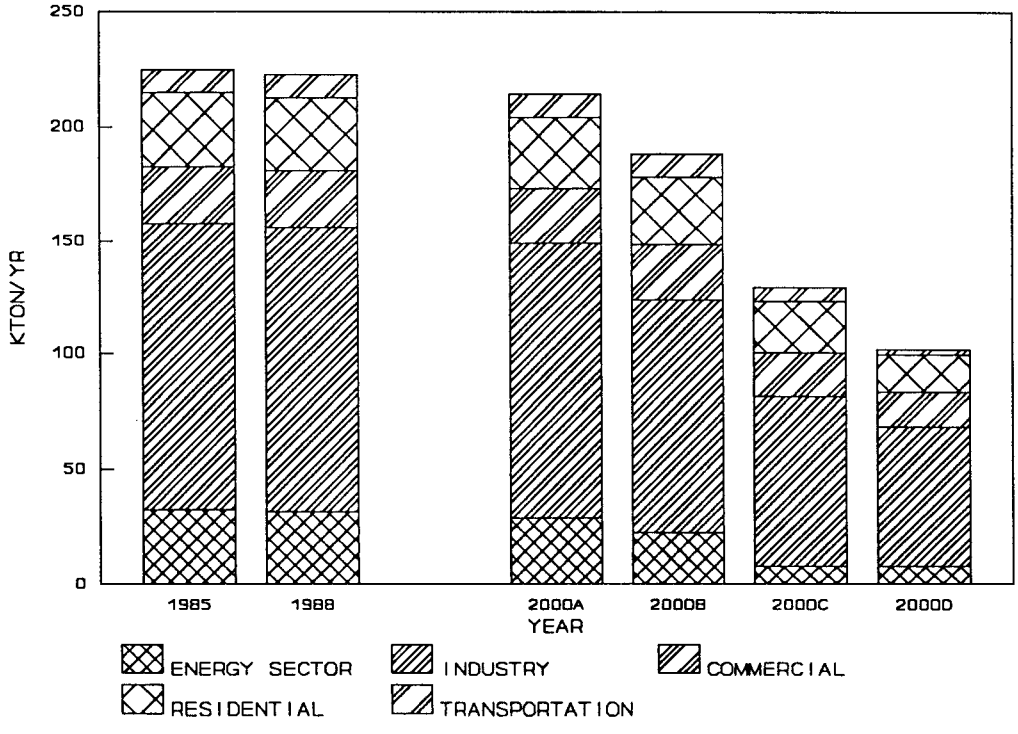
Remark: Target NEPP for 2000 (uncertain reduction) is 194 kton VOC/yr. This corresponds with the sum of KWS 2000 target for process emissions of 102 kton VOC, the targets for surface transport, stationary sources and agriculture.

* Figures for 1988 are interpolations between 1985 and 2000.

source: VROM, 1989a; VROM, 1990a (NEPP); CBS, 1990c and 1987.

commercial sectors. Emission reduction of VOC from agriculture is also not specifically considered within the "KWS 2000" project since policy measures regarding manure treatment is part of another environmental framework.

Figure 5.8: Projected future emissions of VOC according to "KWS 2000"
2000a = autonomous development
2000b = certain reduction
2000c = conditional reductions
2000d = uncertain reduction



Reduction of NO_x

Policy measures for reduction of NO_x in the framework of the Acidification Abatement Plan aim at reducing the 1980 level of 548 kton/yr by 50% in 2000. Table 5.14 shows the targets of the Acidification Abatement Plan as amended by NEPP (1990a). The targets should be realized by means of energy conservation, reduction in the increase of vehicle-kilometres and the application of new technologies, such as low NO_x burners/turbines, combustion modifications on boilers, 3-way catalysts in gasoline cars, low NO_x diesel engines and deNO_x techniques in power plants (SCR). In addition and parallel to the technological development stricter emission standards will be implemented for mobile as well as stationary sources (VROM, 1989c). In an international context, the implementation of lower emission standards is stimulated for car engines as well as for aircrafts, by the EC and CAEPI, respectively (VROM, 1989c).

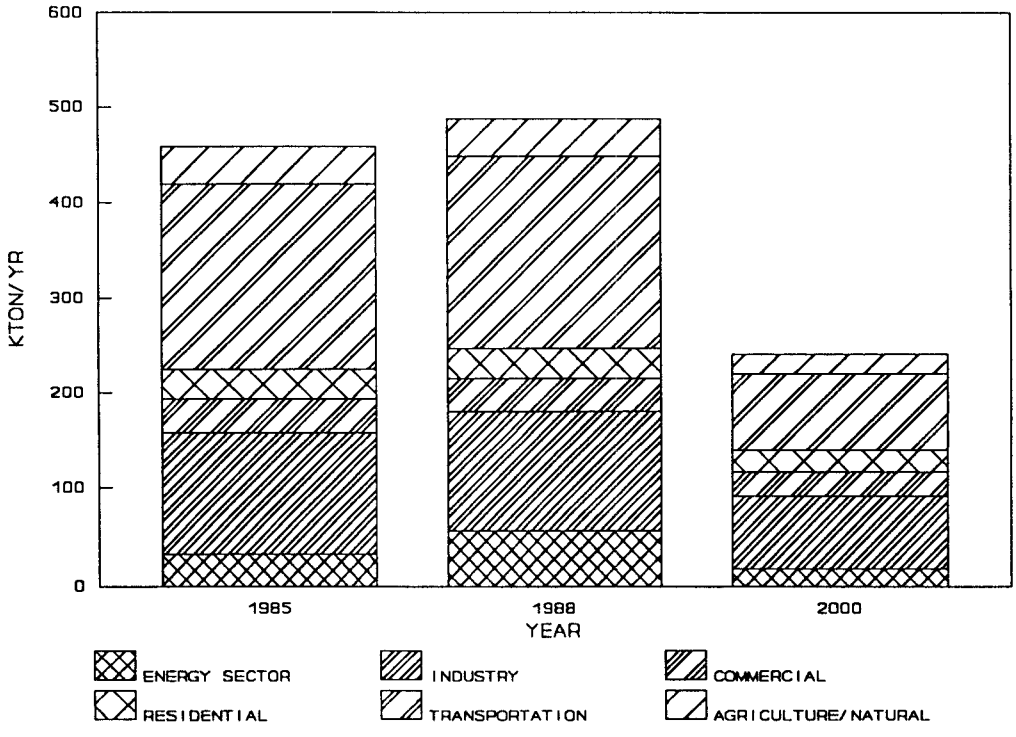
Table 5.14: Sectoral NO_x emissions in the Netherlands (in kton NO_2).

Sector	1980	1985	1988	1994*	2000*
Power plants	80	82	88	55	30
Industry, incl. refineries	86	83	84	57	26-29
Residential	25	24	19	17	11
Transportation	277	272	299	210	112
Others (mobile and stationary)	80	83	70	83	62-63
TOTAL:	548	544	560	422	238-242

* Target of AAP

sources: VROM, 1990a (NEPP); VROM, 1989c (AAP); CBS, 1990c

Figure 5.9: Realized total emissions of VOC in 1985, 1988 and predicted future emissions in 2000 under existing policies.



5.4.3. Additional response options

The emissions of NO_x, VOC and CO will be substantially reduced by existing policy regarding acidification and air pollution in cities.

Additional options for emission reduction of VOC are the following technically feasible measures:

- reduction of vapour losses due to daily temperature changes from cars and trucks (in stand-still position) of about 25 kton/yr by 80 to 90%, by application of active carbon canisters (VROM, 1989a); this also reduces filling losses (4 ton/yr) (VROM, 1989b);

- reduction of VOC in unburned gases from space heaters by more frequent checks of gas burners, especially in the residential sector (estimated current VOC emission: 10 kton/yr).

Other policy measures may include:
- development of strategies for reduction of new VOC sources used in industry, small enterprises and households;
- priority to international coordination with respect to VOC measurements and conditons.

Implementation of the first measure is also discussed at the level of the EC. In addition to the existing KWS 2000 project one could consider to increase the number of demonstration projects to remove the technological barriers which are most important for the realization of the so-called uncertain VOC emission reduction.

Regarding NO_x emissions the determining factors are the type of fuel, the burner type and combustion conditions in general (temperature, air/fuel ratio etc.). As the transportation sector will remain the major source of NO_x, an additional response option is a better control of the combustion process in engines, which will lead to a further decrease of emissions. This option includes:
- frequent performance check of cars, especially those not equipped with a catalyst;
- (stronger) stimulation of cars with relatively low emissions.

In addition to these options, energy conservation and changing of the modal split, other measures to reduce NO_x emissions. These measures will then also contribute to a further decrease of VOC emissions.

6. EQUIVALENT CO_2 EMISSIONS

6.1. INTRODUCTION

In the previous chapters an inventory has been made of the individual emissions of greenhouse gases in the Netherlands. It is interesting to consider the total radiative effect of these emissions. In order to do this we need the concept of Global Warming Potential (GWP). The global warming potential of a gas is the warming effect of an instantaneous emission of 1 kg of each gas relative to CO_2. The GWPs are dependent on the chosen time horizon, because the cumulative radiative absorption of an emitted gas is dependent on the atmospheric lifetime of the gas. Furthermore they will vary in the course of time, as the lifetime and radiative absorption per molecule changes in the atmospheric composition. However, over a period of some decades, which is important for policy making, the associated variations appear to be acceptably small.

Different models and different methods give different GWPs, especially for methane where uncertainties and time dependency are the highest. To show these differences in Table 6.1 presents the GWPs proposed by IPCC (1990a), RIVM (Rotmans et al., 1990) and Lashof and Ahuja (1990). The longer the time horizon selected, the more uncertain the values become. Although the total warming commitment of present emission is important, both for policy making and for the biosphere, it may be more important to assess the more immediate impact of an emission. In order to reflect both views an intermediate time horizon of 100 years has been chosen to calculate the current and future equivalent CO_2-emissions in the Netherlands. Both anthropogenic and non anthropogenic emissions have been taken into account. The trace gases in the Netherlands are for almost 100% of anthropogenic origin, except for methane and nitrous oxide, which are for 85 to 90 % of anthropogenic origin. In this study the GWPs proposed by IPCC have been used for reason of comparison between other national greenhouse gas budget studies. The CO_2 emissions are based on the approach of potential emissions. The actual emissions from the Netherlands territory are in fact lower; approximately three quarters of the carbon contained in petrochemical non-energetic products are exports, thus not producing CO_2 in the Netherlands on the medium or long term. In addition only part of the remaining quarter is converted into CO_2 by municipal waste combustion. The actual CO_2 emission level in which this correction is included is therefore smaller: about 15 Mton of CO_2 less per annum. This correction would also affect the relative importance of individual GHGs as mentioned above. This should be taken into account in the discussion of the relative contribution tot the total CO_2 equivalent emissions.

6.2. CURRENT CONTRIBUTION OF GREENHOUSE GASES TO EQUIVALENT CO_2 EMISSIONS IN THE NETHERLANDS

In Tables 6.2 and 6.3 the current equivalent CO_2 emissions are shown for a time horizon of 100 and 20 years respectively. In each table the gases with a direct effect (including indirect effects on CO_2 and water vapour) and the precursors of tropospheric ozone are indicated separately.

CO_2 is by far the most important greenhouse gas at present if only the direct effect is considered using an intermediate time horizon of 100 years. It accounts for 70% of the equivalent emission in 1989/1990, CFCs together contribute 19% and methane and nitrous oxide 5% (see Figure 6.1). With respect to the precursors of ozone, NO_x is the most important

gas with a contribution of 64%, followed by CH_4 with a contribution of 22% and VOC contributing 11%. (see Figure 6.2)

When direct and indirect effects are considered together, then CO_2 is the most important gas (62%), followed by CFCs (17%), NO_x (8%), CH_4 (7%) and N_2O (4%). Rather surprisingly nitrogen oxide (NO_x) is ranked in third place contributing almost 8% to the equivalent emissions, equal to methane and more than nitrous oxide (see Figure 6.3).

Table 6.1: Global warming potential of greenhouse gases considering different time horizons (in kg of each trace gas relative to 1 kg of CO_2).

Compound		IPCC (1990a)			Rotmans et al. (1990)		Lashof et al.(1990)
Time horizon (years):		20	100	500	100	1,000	1,000
Direct effect:							
CO_2		1	1	1	1	1	1
CH_4 *		63	21	9	34	14	10
N_2O		270	290	190	370	270	180
CFC-11		4,500	3,500	1,500	3,600	1,600	1,300
CFC-12		7,100	7,300	4,500	8,000	5,000	3,700
CFC-113		4,500	4,200	2,100	4,100	2,200	
CFC-114		6,000	6,900	5,500	6,800	5,700	
CFC-115		5,500	6,900	7,400	6,700	7,700	
Halon 1211			** 5,800				
Halon 1301			5,800				
HCFC-22		4,100	1,500	510	1,500	550	410
HCFC-123		310	85	29			
HCFC-124		1,500	430	150			
HCFC-141b		1,500	440	150			
HCFC-142b		3,700	1,600	540			
HFC-125		4,700	2,500	860			
HFC-134a		3,200	1,200	420			
HFC-143a		4,500	2,900	1,000			
HFC-152a		510	140	47	1400	580	
CCl_4		1,900	1,300	460			
CH_3CCl_3		350	100	34			
CF_3Br		5,800	5,800	3,200			
Indirect effect:							
CH_4	(->O_3)	24	8	3			
CH_4	(->CO_2)	3	3	3			
CH_4	(->H_2O)	10	4	1			
Total CH_4:		37	15	7			
CO	(->O_3)	5	1	0			2.2
CO	(->CO_2)	2	2	2			
Total CO:		7	3	2			
NO_x	(->O_3)	150	40	14			
NMHC	(->O_3)	28	8	3			
NMHC	(->CO_2)	3	3	3			
Total NMHC:		33	11	6			

* Including indirect effects.

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

In Table 6.3 (page 86) the data are presented in relation to a shorter time horizon of 20 years, in order to reflect the more immediate concerns and perspectives of policy makers. The contribution of compounds with very short lifetimes such as nitrogen oxide and short lifetimes such as methane to the total equivalent emissions increases drastically at the expense of the gases with longer lifetimes such as carbon dioxide, nitrous oxide and CFCs.

With a shorter time horizon of 20 years the importance of methane would increase to and that of carbon dioxide would decrease.

CO_2 is by far the most important greenhouse gas at present if only the direct effect is considered using an intermediate time horizon of 20 years. It accounts for 65% of the equivalent emission in 1989/1990, CFCs together contribute 18%, methane 13% and nitrous oxide 4% (see Figure 6.4). With respect to the precursors of ozone, NO_x is the most important gas with a contribution of 67%, followed by CH_4 with a contribution of 18% and VOC contributing 11%. (see Figure 6.5). When direct and indirect effects are considered together, then CO_2 is the most important gas (45%), followed by NO_x (21%), CH_4 (14%), CFCs (13%), VOC (4%), N_2O (4%) and CO (4%) (see Figure 6.3).

Table 6.2: Equivalent potential CO_2 emissions from anthropogenic and non anthropogenic sources in the Netherlandsin 1989/1990 for a time horizon of 100 year.

Trace gas	Emission average (kton)	Uncertainty estimation (%)	GWP (100 year)	Equiv. emission (kton)	Relative contribution Direct effect excl.CFCs	Direct effect incl.CFCs	Prec. ozone	Direct + CFCs + precursor
Direct effect (including CFCs and indirect effect via H_20 and CO_2)								
CO_2	182,000	2%	1	182,000	87.9%	71.1%		62.5%
CH_4	960	30%	12	11,400	5.5%	4.5%		6.5%
N_2O **	40	50%	290	11,600	5.6%	4.5%		4.0%
CO	1,110	10%	1	1,100	0.5%	0.4%		0.8%
VOC	490	10%	2	1,000	0.5%	0.4%		1.7%
CFC-11	2.9	10%	3,500	10,100		3.9%		3.5%
CFC-12	3.3	10%	7,300	24,300		9.5%		8.4%
CFC-113	0.9	10%	4,200	3,900		1.5%		1.3%
CFC-115	0.03	10%	6,900	210		0.1%		0.1%
Halon-1211	0.15	10%	5,800	870		0.3%		0.3%
Halon-1301	0.15	10%	5,800	870		0.3%		0.3%
HC-10	1.0	10%	1,300	1300		0.5%		0.4%
HC-140a	6.4	10%	100	640		0.2%		0.2%
HFC	1.6	10%	1,700	2,700		1.0%		0.9%
HCFC	4.8	10%	800	3,800		1.5%		1.3%
					100 %	100 %		
Indirect effect (precursors of O_3)								
CH_4	960	30%	8	7,600			21.7%	*
CO	1,110	10%	1	1,110			3.1%	*
NO_x	560	10%	40	22,400			64.0%	7.7%
VOC	490	10%	8	3,900			11.1%	*
							100 %	100 %

* Indirect effects of CH_4, CO and VOC are included in direct effects.

** Nitrous oxide in kton N_2O (not in kton N_2O-N, as in chapter 4)

Figure 6.1: Relative importance of greenhouse gases in equivalent CO_2 for a time horizon of 100 year; direct effect including CFCs.

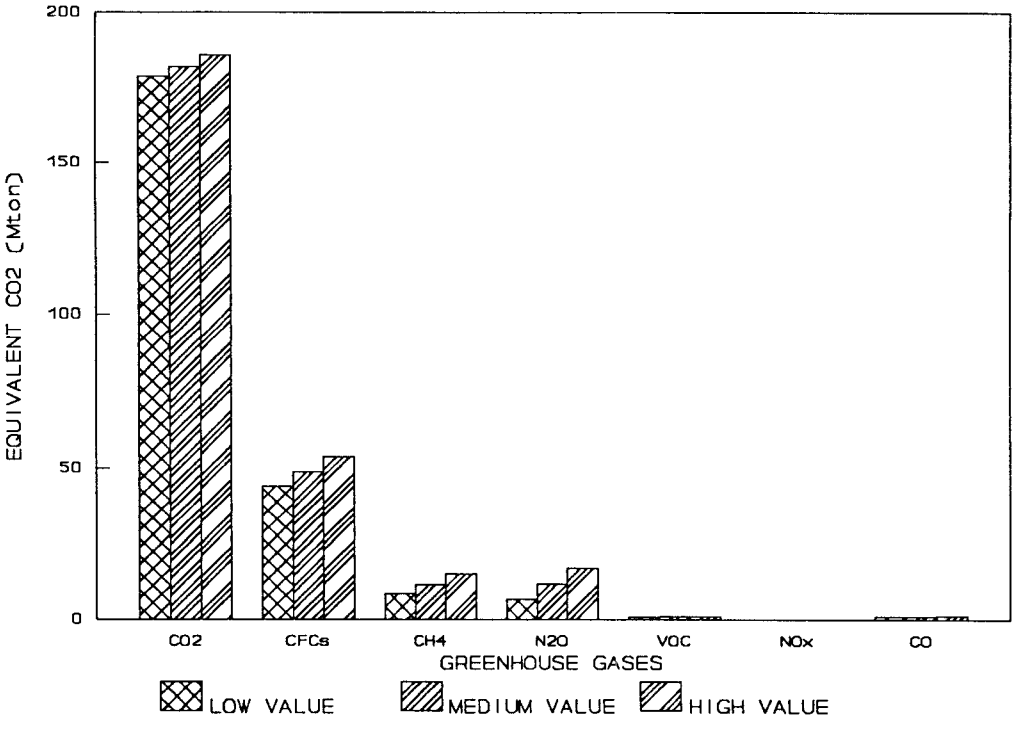


Figure 6.2: Relative importance of greenhouse gases in equivalent CO_2 for a time horizon of 100 year; precursors of ozone.

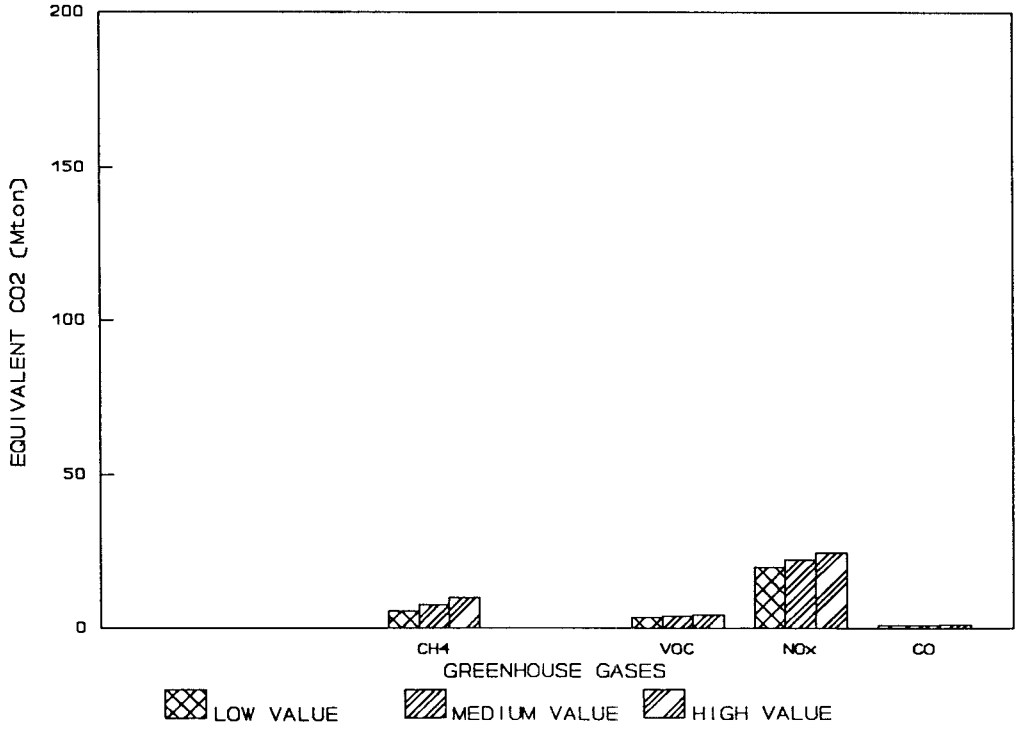
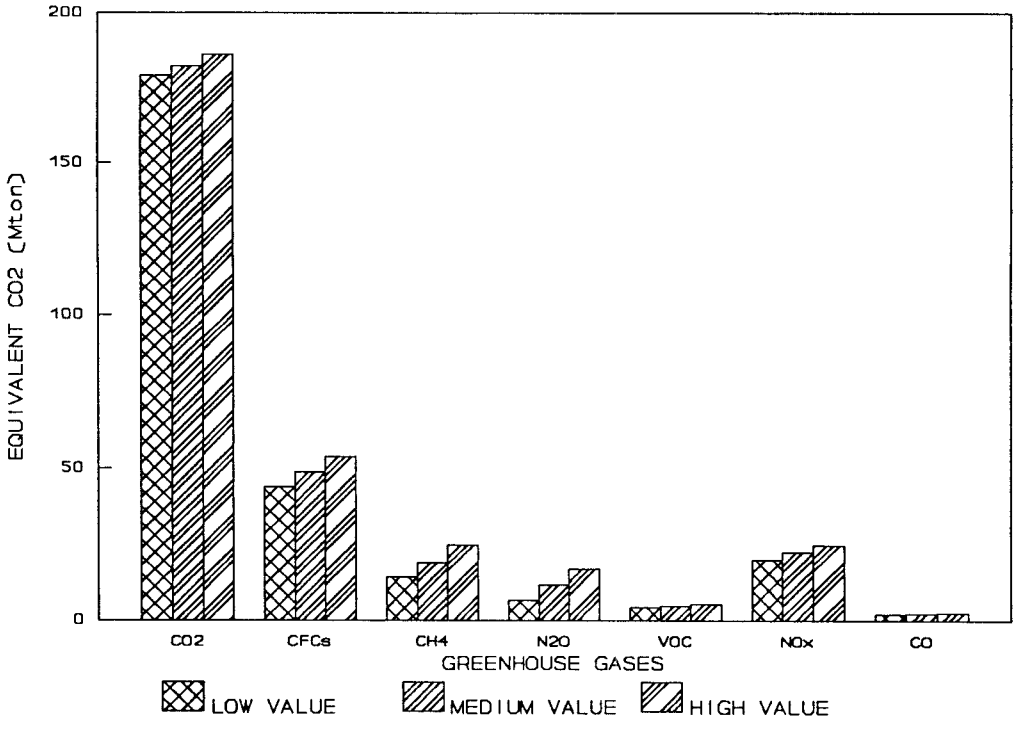


Figure 6.3: Relative importance of greenhouse gases in equivalent CO_2 for a time horizon of 100 year; direct effect plus precursors of ozone and CFCs.



The relatively short atmospheric lifetime of methane and nitrogen oxides and the availability of emission control measures offer opportunities for effective abatement of equivalent carbon dioxide emissions.

From this perspective it can be observed that the Netherlands has relatively high emissions of nitrogen oxides, in particular due to the intensive traffic and the energy intensive economy in general. This causes the nitrogen oxides to contribute almost 20% to the equivalent emissions. The GWP of NO_x, however, is very uncertain and should therefore be handled with the utmost care, since the GWP figures for the indirect contributions are even more uncertain than GWPs of other gases. However it does emphasize, the importance of the precursors of ozone as a greenhouse gas in the Netherlands.

Table 6.3: Equivalent potential CO_2 emissions from anthropogenic and non anthropogenic sources in the Netherlands in 1989/1990 for a time horizon of 20 years.

Trace gas	Emission average (kton)	Uncertainty estimation (%)	GWP (20 year)	Equiv. emission (kton)	Relative contribution Direct effect excl.CFCs	Direct effect incl.CFCs	Prec. ozone	Direct + CFCs + precursor
Direct effect (including CFCs and indirect effect via H_20, CO_2)								
CO_2	182,000	2%	1	182,000	78.8%	64.5%		44.6%
CH_4	960	30%	38	36,100	15.6%	12.8%		14.4%
N_2O **	40	50%	270	10,800	4.7%	3.8%		2.6%
CO	1,110	10%	1	1,100	0.5%	0.4%		1.6%
VOC	490	10%	2	1,000	0.4%	0.4%		3.6%
CFC-11	2.9	10%	4,500	13,000		4.6%		3.2%
CFC-12	3.3	10%	7,100	23,700		8.4%		5.8%
CFC-113	0.9	10%	4,500	4,100		1.4%		1.0%
CFC-115	0.03	10%	5,500	170		0.1%		0.0%
Halon-1211	0.15	10%	5,800	870		0.3%		0.2%
Halon-1301	0.15	10%	5,800	870		0.3%		0.2%
HC-10	1.0	10%	1,900	1,300		0.5%		0.3%
HC-140a	6.4	10%	350	640		0.2%		0.2%
HCF	1.6	10%	1,700	2,700		1.0%		0.7%
HCFC	4.8	10%	800	3,800		1.3%		0.9%
					100 %	100 %		
Indirect effect (precursors of O_3)								
CH_4	960	30%	24	22,800			18.1%	*
CO	1,110	10%	5	5,600			4.4%	*
NO_x	560	10%	150	84,000			66.7%	20.6
VOC	490	10%	28	13,700			10.9%	*
							100 %	100 %

* Indirect effect of CH_4, CO and VOC are included in direct effects.

** Nitrous oxide in kton N_2O (not in kton N_2O-N, as in chapter 4)

Figure 6.4: Relative importance of greenhouse gases in the Netherlands for a time horizon of 20 years; direct effect including CFCs.

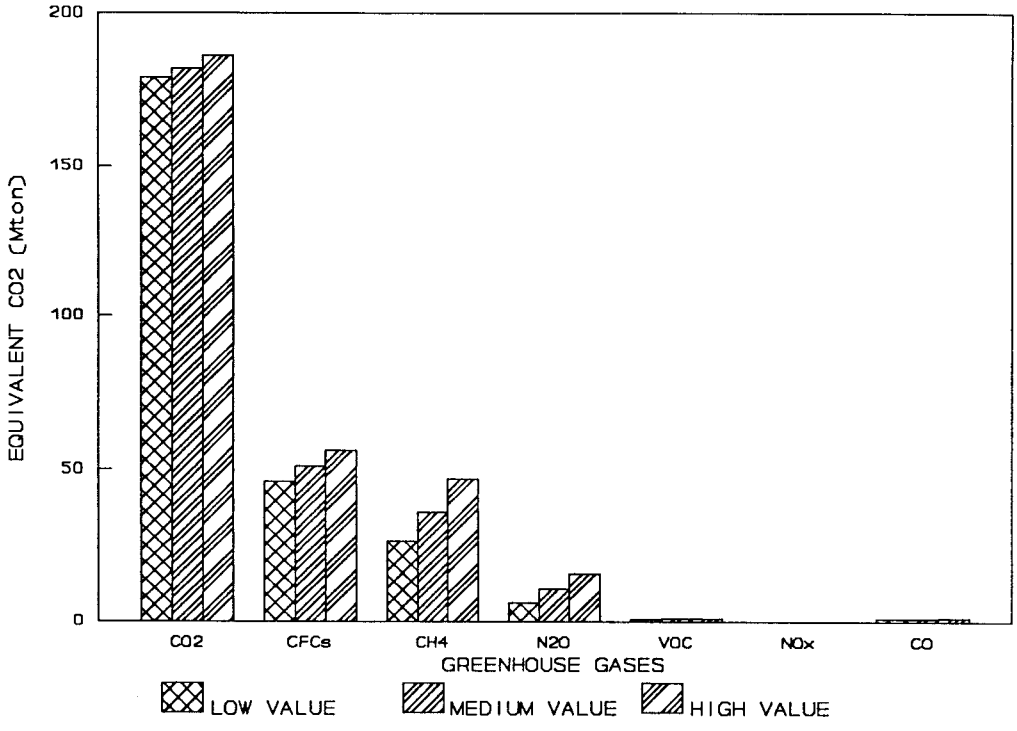


Figure 6.5: Relative importance of greenhouse gases in the Netherlands for a time horizon of 20 years; precusors of ozone.

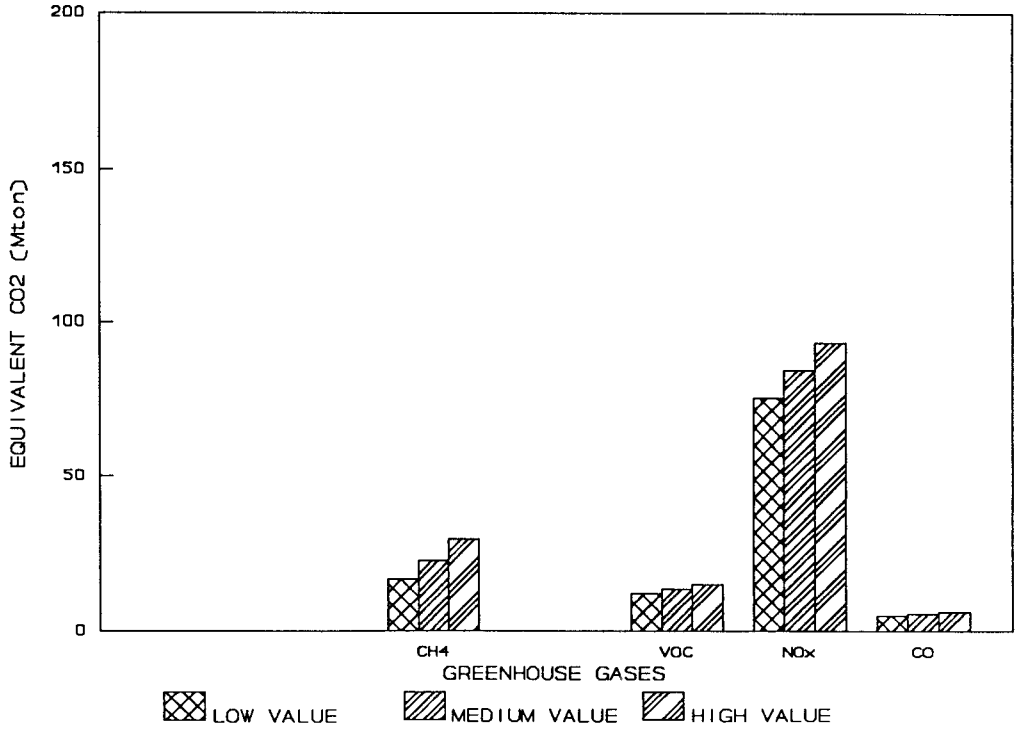
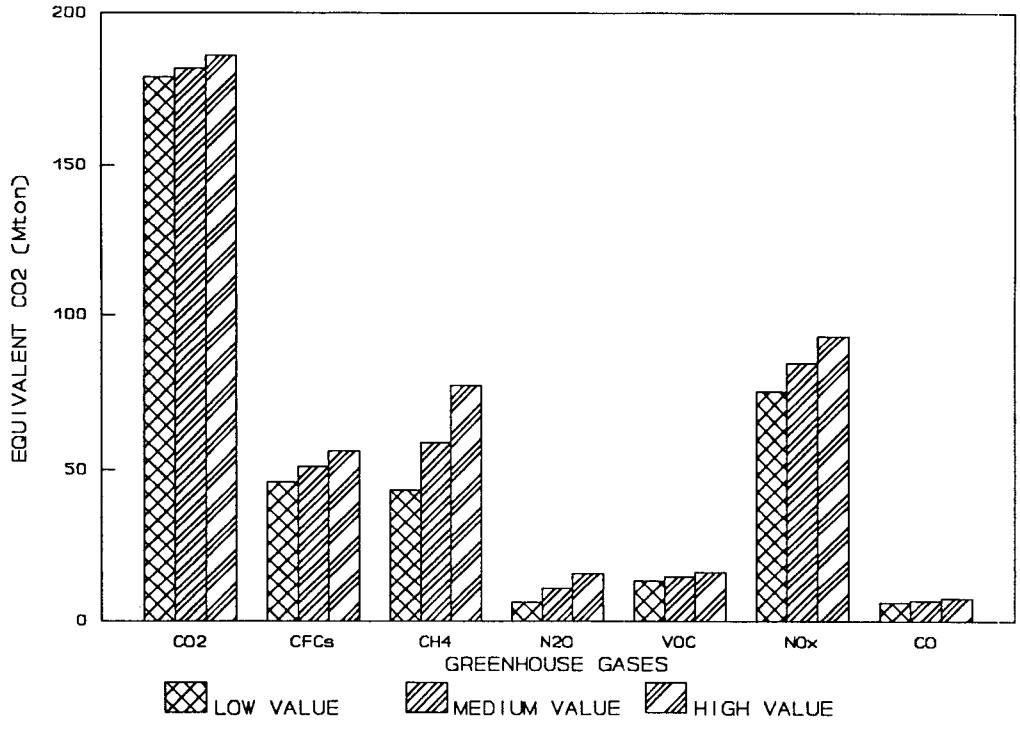


Figure 6.6: Relative importance of greenhouse gases in the Netherlands for a time horizon of 20 years; direct effect plus precursors of ozone and CFCs.



In Tables 6.4 and 6.5 and in Figure 6.7 to 6.9 the contribution per sector is shown in the Netherlands, expressed in equivalent CO_2 emissions. Table 6.4 shows the contribution using an intermediate time horizon of 100 years and 20 years for each of the gases (directly effecting or as precursor of ozone) and in Table 6.5 these data per gas are summarized per group of effects.

The 1989/1990 contribution of the industrial sector is, if an intermediate time horizon and only direct effects are considered (Table 6.5, Direct effect incl. CFCs) about 110 Mton CO_2 equivalent or 43% of a total of about 260 mton CO_2 equivalent emissions in the Netherlands. The energy sector contributes 20%, followed by transportation (11%), residential (9%), agriculture (8%), commercial (5%) and others (2%). The last group includes waste water treatment, landfills, natural emissions, etc. Even if we exclude the contribution of CFCs, then industry is still the highest contributor. For more details on the contribution for each of the gases, see Table 6.4. Especially when the precursors are included the contribution of transportation sector increases markedly to 15%, caused by high NO_x emissions in this sector.

If a time horizon of 20 years is applied, the most striking figure is the relative high contribution of the agricultural and the other sectors (mainly due to landfilling), when compared with the 100 year time horizon. If only the direct effects (including CFCs) are considered, the share of agriculture increases from 8% to 11% and other sectors increase their share from 2% to 4%.

According to IPCC the most important greenhouse gas (expressed in equivalent of CO_2 and for a time horizon of 100 years) is CO_2 (61%) followed by CH_4 (15%), CFCs (12%), N_2O

(4%) and others (8%) (based on Houghton, 1990). The contribution in equivalent oc CO_2 of trace gas emissions in the Netherlands is slightly different: CO_2 (63%), CFCs (17%), CH_4 (7%), N_2O (4%) and others (9%). Both data sets are based on different inventory methods and different sets of emission factors.

Based on energy consumption figures it is possible to make a rough comparison between the global and national CO_2 emission data. For the Netherlands the per capita emission is approximately 12.5 ton CO_2 equivalents per year, whereas the world average is 4.5 ton CO_2 equivalents per year (Van den Born, 1991). The national emission per capita is thus about three times as high as the average emission per world citizen. Compared to the average of the European Community the Dutch emission per capita is about 30% higher and if compared to the average of the OESO countries the Dutch emission per capita is a little lower. A comparison between countries or regions for other greenhouse gases is because of the lack of enough reliable national greenhouse gas budget data.

Table 6.4: Equivalent potential CO_2 emissions per sector and per gas in the Netherlands in 1989/1990 in kton/yr for a time horizons of 100 and 20 years.

Sector	Direct effect						Precursors of O_3			
	CO_2	CH_4	N_2O	CO	VOC	CFCs	CH_4	CO	VOC	NO_x
100 years										
Energy *	50,400	18	340	6	2	0	12	6	8	4,300
Industry	61,400	60	160	280	200	48,800	40	280	790	2,700
Commercial	13,100	40	80	5	16	0	30	5	60	800
Agriculture	7,500	4,700	8,500	0	50	0	3,100	0	190	0
Residential	22,800	100	80	80	20	0	70	80	80	760
Waste	0	3,200	1,100	0	0	0	2,000	0	0	0
Transportation	25,300	100	1,200	700	400	0	60	700	1,600	13,800
Others	1,600	3,300	100	0	300	0	2,200	0	1,200	0
Total (rounded off)	182,000	11,500	11,600	1,100	1,000	48,800	7,500	1,100	3,900	22,400
20 years										
Energy	50,400	60	310	6	2	0	36	30	28	16,200
Industry	61,400	200	150	280	200	51,200	120	1,400	2,800	10,200
Commercial	13,100	140	80	5	16	0	90	26	220	3,000
Agriculture	7,500	14,900	8,000	0	50	0	9,400	0	670	0
Residential	22,800	320	80	80	20	0	200	400	280	2,900
Waste	0	9,900	1,000	0	0	0	6,200	0	0	0
Transportation	25,300	310	1,100	700	400	0	190	3,700	5,700	51,800
Others	1,600	10,400	100	0	300	0	6,500	0	4,100	0
Total (rounded off)	182,000	36,200	10,800	1,100	1,000	51,200	22,700	5,600	13,800	84,100

* excluding mobile sources

Table 6.5: Equivalent potential CO_2-emissions per sector, summarized for gases with direct effect (including and excluding CFCs) and precursors of ozone, in the Netherlands in 1989/1990 (in kton/yr) for time horizons of 100 and 20 years.

Sector	Sum Direct effect excl. CFCs	Perc.	Sum Direct effect incl. CFCs	Perc.	Sum Precursors of O_3	Perc.	Sum Direct + CFCs + Precursors.	Perc.
100 years *								
Energy	50,800	25%	50,800	20%	4,300	12%	55,110	19%
Industry	62,100	30%	110,900	43%	3,800	11%	114,700	39%
Commercial	13,200	6%	13,200	5%	900	3%	14,100	5%
Agriculture	20,800	10%	20,800	8%	3,300	9%	24,100	8%
Residential	23,100	11%	23,100	9%	1,000	3%	24,100	8%
Waste	4,300	2%	4,300	2%	2,000	6%	6,300	2%
Transportation	27,700	13%	27,700	11%	16,200	46%	44,000	15%
Others	5,300	3%	5,300	2%	3,400	10%	8,600	3%
Total (rounded off)	207,000	100%	256,000	100%	35,000	100%	291,000	100%
20 years								
Energy *	50,800	21%	50,800	18%	16,300	13%	67,100	16%
Industry	62,200	27%	113,400	40%	14,500	12%	128,000	31%
Commercial	13,300	6%	13,300	5%	3,300	3%	16,700	4%
Agriculture	30,500	13%	30,500	11%	10,100	8%	40,600	10%
Residential	23,300	10%	23,300	8%	3,800	3%	27,100	7%
Waste	10,900	5%	10,900	4%	6,200	5%	17,100	4%
Transportation	27,800	12%	27,800	10%	61,400	48%	89,300	22%
Others	12,400	5%	12,400	4%	10,600	8%	23,100	6%
Total (rounded off)	231,000	100%	282,000	100%	126,000	100%	409,000	100%

* excluding mobile sources

Figure 6.7: Sectoral contribution to greenhouse gases emissions for a time horizon of 100 year; direct effect and CFCs.

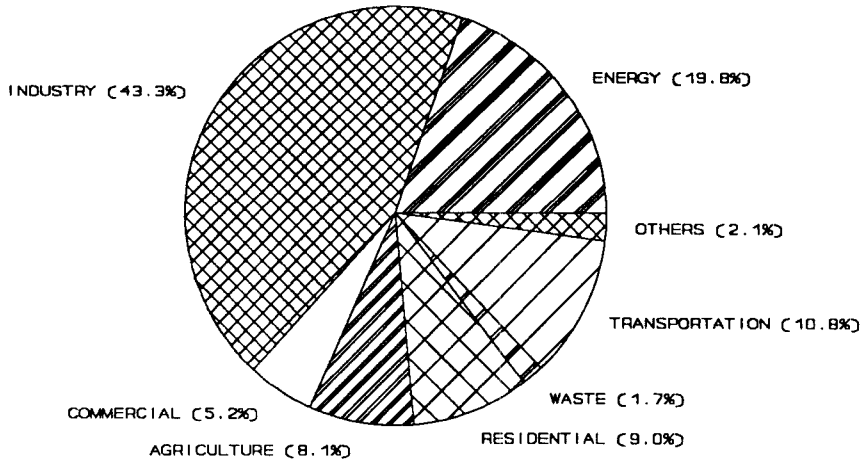


Figure 6.8: Sectoral contribution to greenhouse gases emissions for a time horizon of 100 year; precursors of ozone.

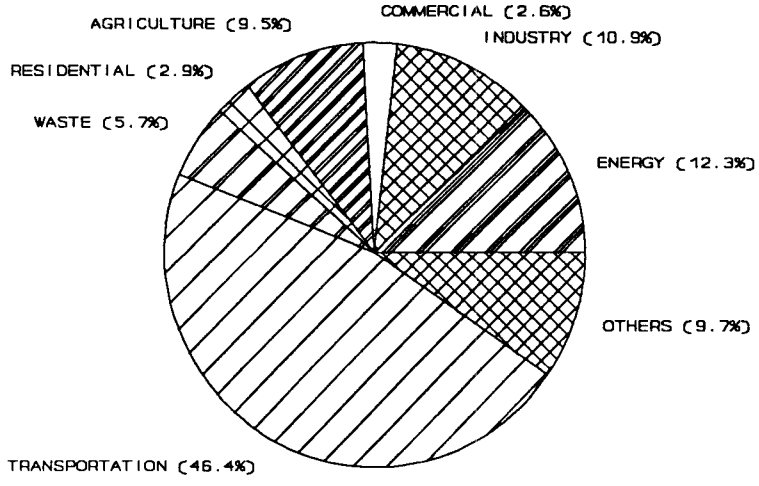
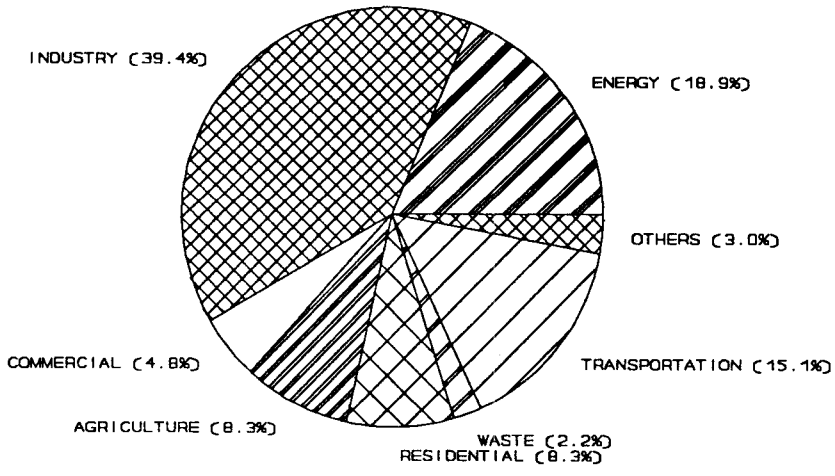


Figure 6.9: Sectoral contribution to greenhouse gases emissions for a time horizon of 100 year; direct effect, CFCs and precursors of ozone.



6.3. PROJECTED FUTURE EQUIVALENT EMISSIONS IN THE NETHERLANDS.

6.3.1. Existing policies

According to Table 6.6 the total CO_2 equivalent emission (time horizon of 100 year) for gases with direct effect including CFCs in the Netherlands will decrease by approximately 18% from 256 Mton CO_2-equivalent to 208 Mton CO_2 equivalent under existing policies (VROM, 1989b; VROM, 1990a). The decrease (compared to present emission) will mainly be caused by the phase-out of CFCs, a substantial decrease of carbon monoxide and a small reduction in carbon dioxide and methane emissions. If the precursors of ozone are considered the decrease will be approximately 45%, mainly caused by decreasing emissions of nitrogen oxides and decrease in VOC, carbon monoxide and methane. If both direct and indirect effects are considered the decrease is about 22%. Figure 6.10 shows the results for a timehorizon of 100 year and Figure 6.11 for a timehorizon of 20 year.

This decrease in total CO_2 equivalent emission will be due to the measures associated with the National Environmental Policy Plan, the Memorandum on Energy Conservation and the Acidification Abatement Plan.

Table 6.6: Projection of future development under existing policies (kton CO_2-equivalent)

Trace gases	Time horizon 20 years:			Time horizon 100 years:		
	1990	1995	2000	1990	1995	2000
Direct effect (including CFCs and indirect effect via H_2O and CO_2)						
CO_2	182,000	182,000	177,000	182,000	182,000	177,000
CH_4	36,200	35,600	32,000	11,400	11,200	10,100
N_2O	10,800	10,700	10,500	11,600	11,500	11,300
CO	1,100	800	500	1,100	800	500
VOC	1,000	700	500	1,000	700	500
CFC-11	13,000	9	0	10,100	7	0
CFC-12	23,700	21	0	24,300	22	0
CFC-113	4,100	18	0	3,900	17	0
CFC-115	170	0	0	210	0	0
Halon-1211	870	0	0	870	0	0
Halon-1301	870	0	0	870	0	0
HC-10	1300	200	0	1300	200	0
HC-140a	640	450	190	640	450	190
HFC	2,700	3,400	3,400	2,700	3,400	3,400
HCFC	3,800	4,700	4,700	3,800	4,700	4,700
Subtotal (rounded off)	282,000	239,000	229,000	256,000	215,000	208,000
Indirect effect (precursors of O_3)						
CH_4	22,900	22,500	20,200	7,600	7,500	6,700
CO	5,600	4,100	2,700	1,100	800	500
NO_x	84,000	58,900	36,600	22,400	15,700	9,800
VOC	13,700	10,200	6,700	3,900	2,900	1,900
Subtotal (rounded off)	126,000	96,000	66,000	35,000	27,000	19,000
Total (direct+ind., rounded off)	408,000	335,000	295,000	291,000	242,000	227,000

Figure 6.10: Projected future greenhouse gases emission for a time horizon of 100 year under **existing policies**: direct effect, CFCs and precursors of ozone.

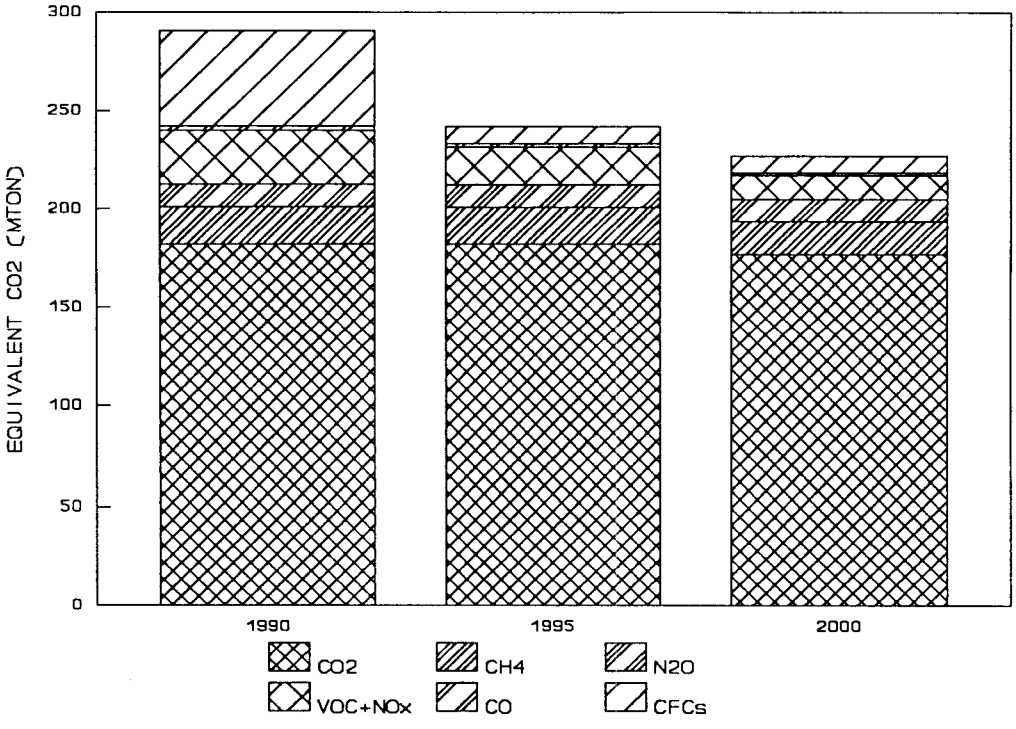
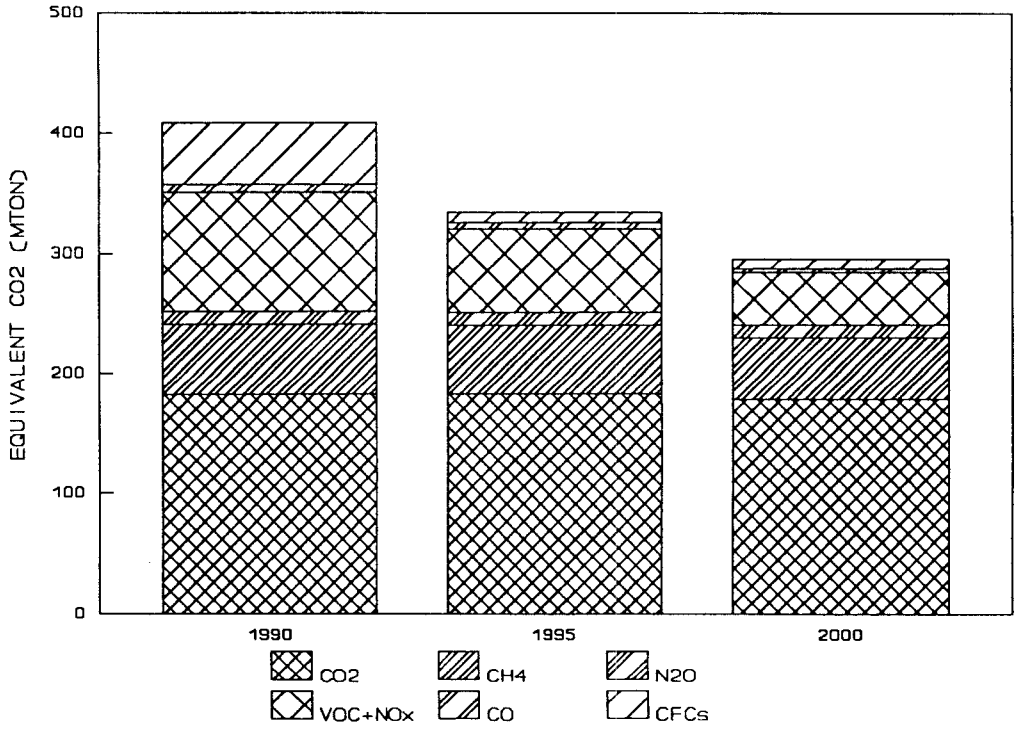


Figure 6.11: Projected future greenhouse gases emission for a time horizon of 20 year under **existing policies**: direct effect, CFCs and precursors of ozone.



Information on the development of the emissions of all greenhouse gases for the first decade after 2000 is not available or cannot be generated. This is due to the fact that the present measures do not reach further than 2000. Only for carbon dioxide, the highest contributor to global warming, estimations of the emissions in 2010 have been used (Maas, 1990). The results for CO_2 emissions scenarios strongly depend on the type of energy used in the energy sector. If in the future the use of natural gas is favoured instead of other energy carriers the targets defined in the existing policies might be reached or even surpassed. If this is not the case and the energy demand increases more than predicted, consumption might result in a growth of CO_2 emissions to a level of about 200 Mton or more in 2010.
One determining parameter for the emission level of carbon dioxide is the kind of fossil energy that will be used in power plants.

6.3.2. Additional policies

Table 6.5 shows that the total CO_2 equivalent emission in the Netherlands of greenhouse gases with direct effect, will decrease by approximately 30-35% under additional response options, from 256 Mton CO_2 equivalent to 175 Mton CO_2 equivalent. The decrease is mainly caused by a decrease in CO_2 through additional energy savings and by the

Table 6.7: Projected future development with additional measures.

Trace gases	Time horizon 20 years:			Time horizon 100 years:		
	1990	1995	2000	1990	1995	2000
Direct effect (including CFCs and indirect effect via H_2O and CO_2)						
CO_2	182,000	170,000	150,000	182,000	170,000	150,000
CH_4	36,200	32,000	22,900	11,400	10,100	7,200
N_2O	10,800	9,800	8,700	11,600	10,500	9,300
CO	1,100	700	400	1,100	700	400
VOC	1,000	700	450	1,000	700	450
CFC-11	13,000	9	0	10,100	7	0
CFC-12	23,700	21	0	24,300	22	0
CFC-113	4,100	18	0	3,900	17	0
CFC-115	170	0	0	210	0	0
Halon-1211	870	0	0	870	0	0
Halon-1301	870	0	0	870	0	0
HC-10	1300	0	0	1300	0	0
HC-140a	640	400	0	640	400	0
HFC	2,700	3,400	3,400	2,700	3,400	3,400
HCFC	3,800	4,700	3,800	3,800	4,700	3,800
Subtotal (rounded off)	282,000	222,000	190,000	256,000	201,000	175,000
Indirect effect (precursors of O_3)						
CH_4	22,900	20,200	14,500	7,600	6,700	4,800
CO	5,600	3,700	2,000	1,100	700	400
NO_x	84,000	55,900	33,200	22,400	14,900	8,900
VOC	13,700	10,000	6,400	3,900	2,900	1,800
Subtotal (rounded off)	126,000	90,000	56,000	35,000	25,000	16,000
Total (direct +ind., rounded off)	408,000	311,000	246,000	291,000	226,000	191,000

prevention of methane emissions, e.g. through use of waste gas and biogas, flaring of non-used gas, new techniques in waste water treatment and earlier renewal of old gas distribution networks. The effect on the emission of precursors of ozone is approximately 50-55%, this higher percentage being caused by a strong additional decrease of emissions of nitrogen oxide.

For the first decade after 2000 a further decrease in emissions is feasible, only if the measurements included in present policies and the indicated additional policies are successfully implemented.

Figure 6.12 shows the results of additional measures for a timehorizon of 100 year and Figure 6.13 for a timehorizon of 20 year.

Figure 6.12: Projected future greenhouse gases emission for a time horizon of 100 year with **additional measures**: direct effect, CFCs and precursors of ozone.

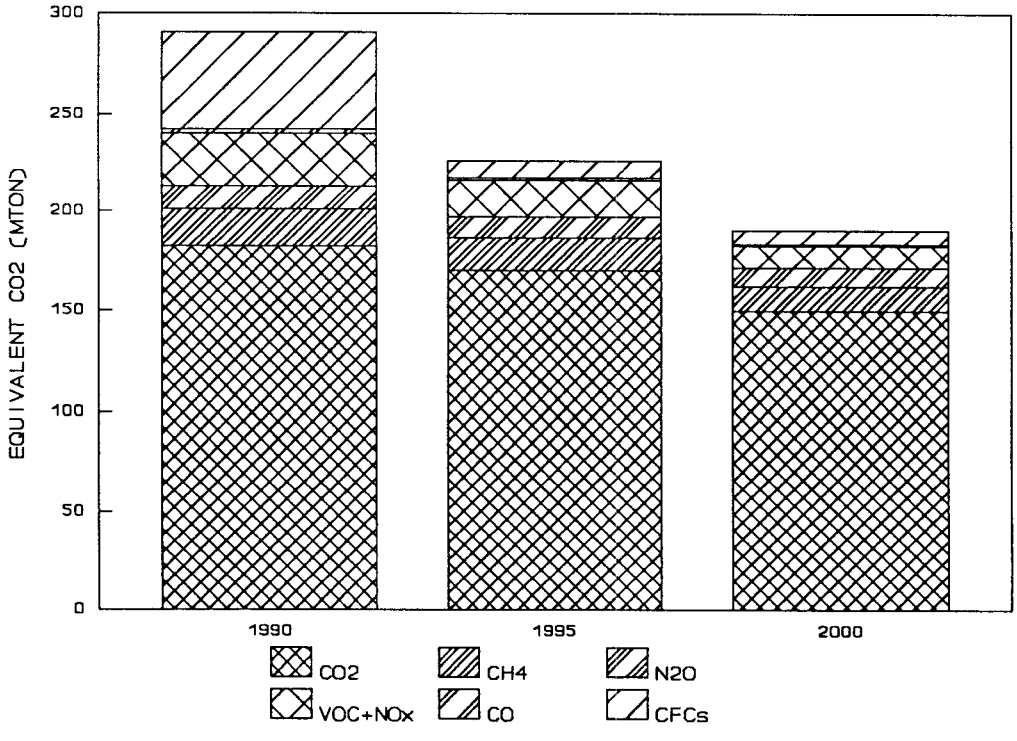
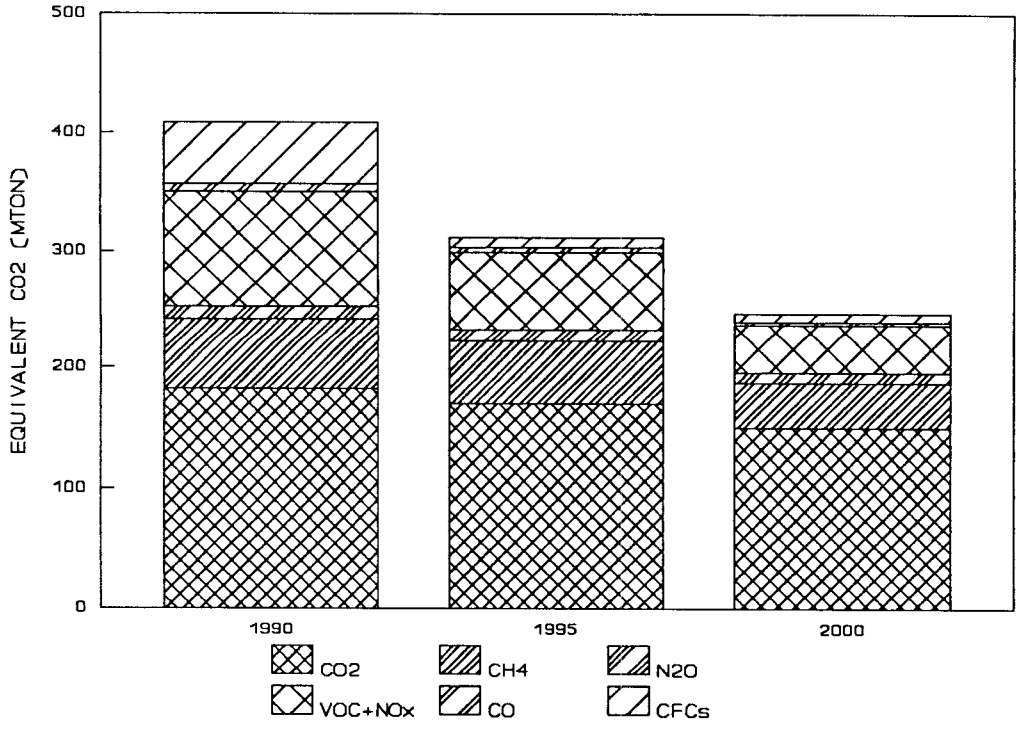


Figure 6.13: Projected future greenhouse gases emission for a time horizon of 100 year with **additional measures**: direct effect, CFCs and precursors of ozone.



7. CONCLUSIONS AND RECOMMENDATIONS

In this report a first complete inventory of the emissions of greenhouse gases in the Netherlands is presented. In Table 6.2 of Chapter 6 an overview of the emissions is given and Table 6.4 shows an overview of the emission per sector.

The most important sources of methane in the Netherlands are cattle, landfills, gas distribution and the production of oil and natural gas. Continuation of current trends and policies are expected to lead to a slight decrease in methane emissions by about 10 percent in 2000. Most important in this respect is the reduction of the emission from landfills (recovery and reduction of dumping of organic waste), cattle and replacement of obsolete gas distribution systems. Basically this development is consistent with the assumptions of the IPCC Accelerated Policies Scenario that is suggested to serve as a provisional target, provided that other countries achieve similar reductions. Stabilization of the global methane concentration could eventually require reductions of global methane emissions of 0 to 30%. The exact number depends partly on emissions of other gases, notably of carbon monoxide.

Additional measures for reduction of methane emissions are integrated measures in the waste sector (recovery of waste gas from landfills, prohibition of dumping of waste containing organic material), diminishing of methane emissions per animal and reduction of cattle population, further promotion of the use of biogas from animal waste and storage measures of animal waste, earlier renewal of the oldest cast iron distribution networks, prohibition of the venting of associated, uneconomic volumes of gas (gas production, drinking water production and waste water treatment plants) and on increase in level of maintenance of especially residential gas devices. These measures would lead to a reduction of about 30% of present levels by 2000.

The uncertainties in the emissions of non-CO_2 greenhouse gases and in the total emissions of CO_2 equivalent are still high. Improvement of estimates and the identification and development of further response strategies will require additional research. Important areas for further research include the emissions from cattle, sheep and goats, animal waste systems and organic soils. Industry may be requested to provide more information about methane losses during exploration and exploitation of natural gas and oil.

The following major sources of nitrous oxide are identified: grasslands (both on organic and mineral soils), agricultural lands, transportation and - surprisingly - coastal and inland waters and waste water treatment plants. The source strength are extremely uncertain and therefore more research is required for a better quantification of the emission level and to evaluate response options. Without specific nitrous oxide policies the Netherlands' emissions in 2000 are likely to stabilize at the 1990 level. This is due to the fact that Dutch policies to reduce the emissions of ammonia and nitrogen oxide for acidification abatement will reduce the availability of nitrogen for nitrous oxide production. This effect is assumed to be counteracted by increasing emissions from cars equipped with catalysts.

The most important way for a further reduction in nitrous oxide emissions is to intensify the policies to reduce the nitrogen input in soils and waters. This could provide opportunities for emission reduction up to 20%. Further research is needed to improve the assessments made in this report, especially experiments to quantify nitrous oxide fluxes in grassland and other agricultural systems, coastal and inland water systems, waste water treatment plants and automobiles with catalytic converters.

The emissions of carbon dioxide are treated in less detail. Government plans to reduce emissions by 3-5% in 2000 are consistent with the IPCC Accelerated Policies Scenarios,

provided that further reductions are achieved thereafter. Stabilization of the global concentration of carbon dioxide at present levels would require at least 60% reduction globally and more in industrialized countries. Options should primarily be found in energy conservation, reduction of demand and efficiency improvements, to be followed by a shift to non-fossil fuels. Because of the small size of the Netherlands CO_2 sequestration by afforestry programmes can only play a minor, albeit psychologically important role. Research to determine the carbon budget for the Netherlands more precisely may provide useful information for further policy actions. Additional measures in the energy sector to achieve another 20% reduction are technically feasible, but the cost-effectiveness of these measures is still subject to discussion.

The major sectors which may contribute substantially to the decrease are transportation, energy (fuel switching, cogeneration), industry, agriculture (greenhouse horticulture) and residential and commercial buildings (insulation).

The Netherlands' programme to phase out CFCs and reduce associated emissions will effectively reduce their contribution to the enhanced greenhouse effects. On the long term it is important that HCFCs and HFCs with a remaining (though smaller) global warming potential should be regarded as useful products only in a (short) transition period. Continuation of further search for low or zero-GWP substitutes in an international context is important.

Carbon monoxide contributes to the enhanced greenhouse effect as precursor of ozone and carbon dioxide, and competes with methane for hydroxyl radicals (•OH) in the troposphere. Main sources are the transportation sector and industry, notably the basic metals producers. Present policies in the transportation sector are likely to reduce emissions by 40% in 2000. Research in this area may focus on the options for further reduction of industrial carbon monoxide emissions.

Emissions of nitrogen oxides and non-methane volatile organic compounds (VOC) in the Netherlands contribute significantly to climate change because of their role as precursor of ozone and the fact that the national emissions are relatively high due to intensive traffic and industrialization. It is found that the present policies to abate acidification and photochemical air pollution are also important from the point of view of climate change. The enhanced greenhouse effect provides another reason to persue or even to intensify these policies. Decreasing nitrogen deposition also limits nitrous oxide emissions from soils and surface waters. Decreasing emissions of non-methane hydrocarbons not only reduce ozone production, but are also assumed (depends on NO_x concentrations) to increase the atmospheric sink of methane. Additional research aiming at better quantification of the present and future role of these gases for the problem of global climate change is recommended.

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APPENDIX 1, page 1

Appendix 1: Global emission scenarios of the IPCC Response Strategies Working Group (IPCC, 1990c)

2030 High Emissions/Businsess-as-usual — CO_2 EMISSIONS BY REGION — (1000 Tg C/yr)

REGION	1985	1990	1995	2000	2005	2010	2015	2020	2025	2050	2075	2100
United States	1.37	1.45	1.50	1.58	1.66	1.67	1.72	1.70	1.88	2.03	2.34	2.94
Canada	0.11	0.11	0.12	0.12	0.13	0.13	0.14	0.14	0.15	0.18	0.19	0.21
Western Europe	0.74	0.78	0.81	0.86	0.92	0.94	0.98	1.04	1.12	1.28	1.36	1.49
Japan	0.24	0.25	0.26	0.27	0.28	0.29	0.29	0.30	0.31	0.39	0.48	0.63
Other OECD Asia	0.08	0.09	0.09	0.10	0.11	0.11	0.12	0.12	0.13	0.15	0.16	0.19
USSR & E. Eur.	1.43	1.56	1.64	1.77	1.92	2.07	2.17	2.28	2.51	3.15	4.16	4.95
C-Planned Asia	0.57	0.66	0.76	0.88	1.02	1.17	1.32	1.49	1.69	2.80	3.62	4.62
Middle East	0.15	0.16	0.18	0.20	0.23	0.27	0.34	0.42	0.53	0.73	0.83	0.91
North Africa	0.17	0.20	0.22	0.24	0.26	0.28	0.30	0.33	0.37	0.52	0.56	0.63
South Africa	0.14	0.16	0.18	0.21	0.24	0.26	0.30	0.34	0.35	0.39	0.47	0.59
Argentina	0.02	0.03	0.03	0.03	0.04	0.04	0.05	0.06	0.07	0.13	0.16	0.18
Brazil	0.18	0.21	0.23	0.26	0.29	0.31	0.34	0.38	0.41	0.47	0.40	0.37
O-Latin America	0.29	0.33	0.36	0.41	0.45	0.50	0.55	0.63	0.72	1.01	1.05	1.09
India	0.14	0.16	0.19	0.23	0.28	0.33	0.39	0.45	0.51	0.86	1.35	1.82
Other Asia	0.33	0.38	0.43	0.48	0.54	0.59	0.65	0.71	0.77	1.11	1.39	1.79
Oceans	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

2030 High Emissions/Business-as-usual — CH_4 EMISSIONS BY REGION — (Tg CH_4/yr)

REGION	1985	1990	1995	2000	2005	2010	2015	2020	2025	2050	2075	2100
United States	57.72	58.15	56.92	59.93	60.73	61.28	61.30	63.44	64.35	67.76	80.88	105.00
Canada	14.73	14.48	14.76	15.09	15.39	15.66	15.95	16.25	16.56	16.52	15.97	16.24
Western Europe	35.31	35.60	37.27	38.79	40.28	41.50	42.82	44.33	46.62	52.89	53.26	54.77
Japan	7.47	7.76	8.05	8.31	8.52	8.67	8.85	9.06	9.32	11.93	12.79	13.55
Other OECD Asia	15.09	15.70	16.28	16.90	17.50	17.90	18.40	18.78	19.37	21.81	25.36	30.95
USSR & E. Eur.	74.55	79.93	84.67	89.68	93.58	96.44	100.93	105.14	111.44	128.45	160.48	178.63
C-Planned Asia	74.15	75.01	77.88	81.24	84.89	88.80	92.96	97.79	103.61	137.08	149.79	156.75
Middle East	9.59	10.50	11.53	12.69	14.00	15.72	18.25	21.46	25.49	38.18	30.92	34.24
North Africa	43.63	45.08	46.83	48.76	50.58	52.27	54.10	56.09	58.05	65.71	69.37	76.86
South Africa	22.25	22.86	23.82	25.01	26.24	27.36	28.90	30.16	31.93	39.22	43.61	52.36
Argentina	8.16	8.52	9.00	9.55	10.03	10.47	10.97	11.50	11.94	13.28	13.50	13.40
Brazil	27.43	28.15	28.90	29.67	30.73	31.50	32.36	33.24	34.17	35.34	32.85	31.71
O-Latin America	28.94	31.10	33.55	36.21	38.82	41.30	43.91	46.48	48.96	56.71	54.22	52.73
India	47.50	49.46	52.76	57.65	61.81	65.40	69.30	73.20	77.77	106.05	123.12	127.00
Other Asia	58.93	62.33	65.55	69.27	73.96	76.77	80.07	82.77	86.20	93.15	102.89	103.71
Oceans	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00

2030 High Emissions/Business-as-Usual — N_2O EMISSIONS BY REGION — (Tg N/yr)

REGION	1985	1990	1995	2000	2005	2010	2015	2020	2025	2050	2075	2100
United States	1.08	1.73	1.67	1.22	1.25	1.25	1.26	1.29	1.32	1.29	1.24	1.18
Canada	0.52	0.55	0.60	0.63	0.63	0.65	0.66	0.69	0.70	0.65	0.63	0.61
Western Europe	0.61	0.67	0.73	0.78	0.80	0.82	0.85	0.88	0.92	0.97	0.93	0.88
Japan	0.09	0.09	0.10	0.10	0.11	0.11	0.11	0.11	0.12	0.13	0.15	0.16
Other OECD Asia	0.45	0.46	0.47	0.48	0.48	0.49	0.49	0.50	0.50	0.52	0.52	0.52
USSR & E. Eur.	1.82	1.89	1.97	2.06	2.11	2.16	2.18	2.22	2.26	2.40	2.45	2.42
C-Planned Asia	1.17	1.26	1.35	1.41	1.47	1.53	1.58	1.63	1.68	1.87	1.91	1.98
Middle East	0.33	0.34	0.35	0.36	0.37	0.38	0.40	0.42	0.45	0.50	0.52	0.54
North Africa	1.20	1.24	1.28	1.32	1.34	1.37	1.40	1.44	1.47	1.54	1.45	1.41
South Africa	0.56	0.58	0.59	0.61	0.62	0.64	0.65	0.67	0.68	0.73	0.73	0.75
Argentina	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.15	0.15	0.16	0.16	0.20
Brazil	0.68	0.71	0.73	0.75	0.77	0.79	0.82	0.64	0.87	0.91	0.81	0.78
O-Latin America	0.75	0.79	0.82	0.86	0.89	0.93	0.96	1.01	1.05	1.16	1.21	1.37
India	0.36	0.41	0.49	0.54	0.56	0.59	0.61	0.65	0.68	0.74	0.90	1.04
Other Asia	0.75	0.83	0.91	0.98	1.06	1.15	1.25	1.40	1.55	1.70	1.69	1.74
Oceans	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00

2030 High emissions/Business-as-usual — NO_x EMISSIONS BY REGION — (Tg N/yr)

REGION	1985	1990	1995	2000	2005	2010	2015	2020	2025	2050	2075	2100
United States	7.35	7.39	7.30	7.33	7.48	7.20	7.13	7.15	7.28	7.28	7.36	7.87
Canada	1.43	1.45	1.46	1.47	1.50	1.49	1.49	1.51	1.55	1.61	1.60	1.66
Western Europe	4.08	4.16	4.21	4.35	4.54	4.47	4.53	4.67	4.95	5.41	5.46	5.86
Japan	1.30	1.31	1.32	1.35	1.40	1.36	1.36	1.37	1.41	1.64	1.81	2.12
Other OECD Asia	1.26	1.27	1.28	1.29	1.31	1.32	1.33	1.34	1.35	1.43	1.45	1.52
USSR & E. Eur.	8.72	9.26	9.55	10.06	10.55	10.89	11.14	11.46	12.23	13.54	14.81	15.83
C-Planned Asia	3.93	4.33	4.73	5.27	5.78	6.35	6.93	7.59	6.30	11.94	15.16	17.50
Middle East	1.12	1.18	1.24	1.33	1.42	1.54	1.75	2.03	2.40	3.07	3.51	4.09
North Africa	2.93	3.04	3.14	3.27	3.35	3.42	3.55	3.71	3.91	4.45	4.57	4.92
South Africa	1.60	1.68	1.77	1.89	1.99	2.08	2.21	2.34	2.47	3.07	3.60	4.18
Argentina	0.39	0.40	0.41	0.43	0.45	0.47	0.49	0.52	0.56	0.73	0.07	0.99
Brazil	1.73	1.62	1.91	2.01	2.10	2.19	2.30	2.43	2.58	3.06	3.09	3.24
O-Latin America	2.30	2.44	2.60	2.80	2.98	3.13	3.34	3.59	3.94	5.14	5.70	6.43
India	1.14	1.25	1.37	1.54	1.71	1.87	2.07	2.30	2.55	3.97	5.75	7.43
Other Asia	2.22	2.40	2.50	2.80	2.98	3.15	3.35	3.58	3.85	5.35	6.76	8.90
Oceans	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LIGHTNING	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00

2030 High Emissions/Business-as-Usual — CO EMISSIONS BY REGION — (Tg C/Yr)

REGION	1985	1990	1995	2000	2005	2010	2015	2020	2025	2050	2075	2100
United States	60.13	55.16	47.99	39.05	39.75	36.15	35.12	35.12	36.28	37.40	36.80	39.94
Canada	11.10	11.20	11.08	10.93	11.17	10.91	10.93	11.12	11.56	11.88	11.00	11.24
Western Europe	44.00	43.70	42.06	40.23	41.41	38.93	38.57	39.32	41.94	44.41	43.82	48.48
Japan	13.77	13.73	13.24	12.69	13.09	12.22	12.07	12.21	12.86	14.36	15.04	17.68
Other OECD Asia	10.01	10.41	10.63	10.82	11.12	11.19	11.40	11.68	12.05	12.32	10.29	9.62
USSR & E. Eur.	54.79	62.63	68.31	76.04	81.81	85.21	89.53	95.69	109.18	124.21	129.47	146.66
C-Planned Asia	51.80	55.57	59.07	62.98	65.88	68.81	72.42	76.72	81.92	100.38	106.13	137.36
Middle East	9.02	9.47	10.16	11.12	11.82	12.50	14.32	17.03	21.03	29.09	34.71	46.29
North Africa	49.45	53.70	57.61	61.96	65.05	67.81	72.07	76.99	82.65	90.85	77.54	75.29
South Africa	22.36	24.10	25.79	27.53	28.81	29.97	31.62	33.50	35.58	38.42	32.07	30.09
Argentina	3.44	3.61	3.88	4.25	4.47	4.63	4.93	5.35	5.96	7.76	9.01	10.98
Brazil	44.83	49.46	53.23	57.06	60.05	62.72	65.86	69.44	73.42	77.36	57.17	49.31
O-Latin America	54.55	60.02	65.19	71.01	75.20	78.68	83.46	89.30	96.62	110.65	98.03	101.50
India	21.60	22.67	23.76	25.01	25.88	26.59	27.57	28.72	30.12	35.96	39.65	48.30
Other Asia	69.38	76.14	81.89	87.90	92.45	96.25	101.09	106.65	113.00	129.88	119.39	138.20
Oceans	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00

2060 Low Emissions — CO_2 EMISSIONS BY REGION — (1000 Tg C/yr)

REGION	1985	1990	1995	2000	2005	2010	2015	2020	2025	2050	2075	2100
United States	1.35	1.38	1.33	1.34	1.34	1.24	1.21	1.20	1.17	1.07	1.04	1.12
Canada	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.09	0.10
Western Europe	0.74	0.76	0.73	0.74	0.75	0.72	0.72	0.74	0.74	0.68	0.63	0.66
Japan	0.24	0.24	0.24	0.24	0.24	0.23	0.24	0.24	0.23	0.23	0.23	0.26
Other OECD Asia	0.06	0.06	0.07	0.06	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.08
USSR & E. Eur.	1.42	1.53	1.49	1.52	1.57	1.50	1.61	1.64	1.66	1.75	1.93	2.35
C-Planned Asia	0.57	0.62	0.62	0.67	0.75	0.83	0.91	1.00	1.10	1.55	2.05	2.51
Middle East	0.15	0.16	0.17	0.19	0.21	0.24	0.28	0.33	0.39	0.47	0.48	0.50
North Africa	0.17	0.12	0.08	0.06	0.04	0.03	0.03	0.04	0.06	0.17	0.28	0.36
South Africa	0.14	0.12	0.10	0.10	0.10	0.10	0.11	0.12	0.13	0.09	0.06	0.10
Argentina	0.02	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.05	0.09	0.11	0.12
Brazil	0.18	0.12	0.05	0.01	0.00	0.02	-.03	-.02	-.00	0.00	0.02	0.00
O-Latin America	0.29	0.23	0.18	0.15	0.14	0.14	0.14	0.17	0.20	0.36	0.47	0.49
India	0.13	0.15	0.15	0.17	0.19	0.21	0.23	0.26	0.29	0.43	0.62	0.80
Other Asia	0.33	0.26	0.19	0.15	0.14	0.14	0.14	0.17	0.20	0.44	0.68	0.87
Oceans	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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2060 Low Emissions — CH_4 EMISSIONS BY REGION — (Tg CH_4/Yr)

REGION	1985	1990	1995	2000	2005	2010	2015	2020	2025	2050	2075	2100
United States	57.72	56.22	54.74	53.85	52.59	51.12	49.62	50.16	48.83	44.29	40.29	39.05
Canada	14.73	14.16	14.46	14.67	14.63	14.90	15.15	15.37	15.40	14.64	13.78	13.02
Western Europe	35.31	31.98	35.32	35.82	36.28	36.24	36.83	37.56	38.32	39.41	36.13	33.07
Japan	7.47	7.44	7.45	7.40	7.36	7.25	7.23	7.26	7.26	9.17	9.33	9.26
Other OECD Asia	15.09	15.37	15.59	15.92	16.25	16.33	16.64	16.81	16.99	18.11	19.10	19.99
USSR & E. Eur.	74.55	79.56	82.59	86.27	88.15	88.92	91.23	92.83	94.45	90.16	88.85	99.55
C-Planned Asia	74.15	73.61	75.41	77.75	80.29	82.95	85.83	89.05	92.68	105.90	111.00	114.04
Middle East	9.59	10.39	11.42	12.49	13.54	14.94	17.14	20.06	23.60	33.76	31.47	28.33
North Africa	43.63	43.20	44.36	45.71	46.90	47.97	49.33	50.75	52.27	57.42	59.06	58.31
South Africa	22.25	22.05	22.53	23.30	24.13	24.78	25.82	26.54	27.58	32.04	36.18	37.58
Argentina	8.16	8.58	9.00	9.55	10.00	10.43	10.96	11.44	11.90	13.01	13.04	12.64
Brazil	27.43	25.79	25.74	25.97	26.26	26.28	26.49	26.67	26.91	26.31	26.17	25.62
O-Latin America	28.94	28.74	30.45	32.38	34.20	35.96	36.04	39.76	41.60	46.86	45.94	44.01
India	47.50	49.21	52.14	56.75	60.58	64.06	68.06	71.99	76.29	99.39	105.01	104.67
Other Asia	58.93	59.13	61.23	64.01	67.79	69.69	72.16	73.90	76.36	78.35	82.01	81.44
Oceans	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00

2060 Low Emissions — N_2O EMISSIONS BY REGION — (Tg N/Yr)

REGION	1985	1990	1995	2000	2005	2010	2015	2020	2025	2050	2075	2100
United States	1.07	1.67	1.59	1.17	1.15	1.11	1.08	1.08	1.07	0.98	0.91	0.84
Canada	0.52	0.54	0.59	0.62	0.64	0.68	0.68	0.67	0.67	0.62	0.60	0.58
Western Europe	0.61	0.66	0.71	0.75	0.88	1.12	1.05	0.79	0.80	0.79	0.73	0.68
Japan	0.09	0.09	0.09	0.10	0.14	0.21	0.18	0.09	0.09	0.09	0.09	0.09
Other OECD Asia	0.45	0.45	0.45	0.46	0.46	0.48	0.47	0.46	0.46	0.47	0.47	0.48
USSR & E. Eur.	1.81	1.89	1.93	2.01	2.02	2.04	2.05	2.08	2.09	2.14	2.13	2.10
C-Planned Asia	1.17	1.19	1.25	1.29	1.32	1.35	1.37	1.39	1.40	1.44	1.43	1.42
Middle East	0.33	0.34	0.35	0.35	0.36	0.38	0.39	0.41	0.43	0.45	0.45	0.45
North Africa	1.21	1.16	1.17	1.17	1.18	1.19	1.20	1.21	1.23	1.29	1.30	1.32
South Africa	0.56	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.55	0.56	0.57
Argentina	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.15	0.16	0.17	0.19
Brazil	0.68	0.58	0.58	0.57	0.56	0.55	0.54	0.53	0.53	0.53	0.56	0.59
O-Latin America	0.75	0.68	0.67	0.67	0.68	0.68	0.70	0.71	0.72	0.80	0.96	1.17
India	0.36	0.40	0.47	0.51	0.52	0.55	0.56	0.56	0.60	0.57	0.65	0.71
Other Asia	0.75	0.68	0.70	0.73	0.77	0.82	0.88	0.98	1.09	1.16	1.32	1.42
Oceans	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00

2060 Low emissions — NO_x EMISSIONS BY REGION — (Tg N/yr)

REGION	1985	1990	1995	2000	2005	2010	2015	2020	2025	2050	2075	2100
United States	7.28	7.06	6.68	6.53	6.08	5.16	4.59	4.21	3.94	3.11	2.89	3.04
Canada	1.43	1.42	1.40	1.41	1.38	1.31	1.27	1.24	1.23	1.18	1.16	1.17
Western Europe	4.03	3.97	3.64	3.85	3.64	3.11	2.70	2.56	2.46	2.10	1.92	2.00
Japan	1.29	1.26	1.21	1.21	1.13	0.94	0.82	0.73	0.68	0.59	0.57	0.65
Other OECD Asia	1.25	1.23	1.21	1.21	1.17	1.13	1.09	1.06	1.04	1.01	1.00	1.02
USSR & E. Eur.	8.63	8.97	8.80	6.95	8.45	7.88	7.57	7.36	7.31	5.74	5.69	6.23
C-Planned Asia	3.92	4.20	4.34	4.69	4.91	5.20	5.42	5.69	5.99	4.55	4.79	5.24
Middle East	1.12	1.16	1.19	1.25	1.29	1.34	1.45	1.59	1.79	1.65	1.46	1.51
North Africa	2.94	2.61	2.83	2.88	2.85	2.82	2.83	2.86	2.92	2.90	3.02	3.16
South Africa	1.59	1.57	1.57	1.61	1.61	1.61	1.63	1.65	1.66	1.46	1.47	1.53
Argentina	0.39	0.39	0.40	0.41	0.41	0.42	0.42	0.43	0.45	0.49	0.53	0.56
Brazil	1.73	1.55	1.53	1.53	1.50	1.48	1.46	1.46	1.46	1.42	1.40	1.42
O-Latin America	2.30	2.14	2.15	2.23	2.21	2.18	2.19	2.23	2.32	2.37	2.46	2.63
India	1.13	1.21	1.24	1.33	1.39	1.43	1.49	1.57	1.65	1.43	1.57	1.76
Other Asia	2.22	2.03	2.05	2.12	2.12	2.11	2.13	2.16	2.21	2.20	2.48	2.93
Oceans	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LIGHTNING	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00

2060 Low Emissions — CO EMSSIONS BY REGION — (Tg C/yr)

REGION	1985	1990	1995	2000	2005	2010	2015	2020	2025	2050	2075	2100
United States	60.12	52.89	44.74	36.44	36.14	28.09	23.79	20.45	20.95	18.67	17.64	16.13
Canada	11.10	10.29	9.88	9.54	9.40	8.30	7.47	6.64	6.65	6.40	6.25	6.28
Western Europe	43.98	41.30	38.99	37.11	36.69	29.11	23.59	18.08	18.77	17.46	16.40	16.38
Japan	13.77	13.03	12.32	11.76	11.59	8.93	7.06	5.18	5.35	5.06	4.92	5.15
Other OECD Asia	10.01	8.77	8.43	8.15	7.94	7.30	6.79	6.28	6.13	5.92	5.83	5.78
USSR & E. Eur.	54.76	53.62	53.97	56.53	55.32	49.83	47.64	46.03	49.11	32.44	32.30	34.03
C-Planned Asia	51.79	45.54	45.08	45.32	44.63	43.85	43.45	43.22	43.77	41.77	42.00	42.19
Middle East	9.02	8.69	8.75	9.09	9.01	8.72	9.06	9.71	11.26	8.06	8.07	8.66
North Africa	49.46	39.98	38.56	37.92	36.27	34.26	33.00	31.88	31.67	26.20	25.53	24.87
South Africa	22.36	18.32	17.72	17.40	16.75	15.99	15.46	15.00	14.80	13.20	12.79	12.35
Argentina	3.44	3.32	3.34	3.46	3.41	3.26	3.22	3.22	3.44	2.66	2.69	2.79
Brazil	44.83	32.81	30.60	28.98	26.97	24.73	22.77	20.89	19.47	16.00	15.31	14.46
O-Latin America	54.55	42.03	39.94	39.01	36.75	33.63	31.19	29.62	29.45	21.41	20.91	20.71
India	21.59	20.64	20.82	21.24	21.27	21.11	21.17	21.30	21.75	21.21	20.98	20.52
Other Asia	69.38	53.10	50.35	48.63	45.99	42.74	40.19	37.80	36.48	31.23	31.18	31.58
Oceans	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00

2090 Control Policies — CO_2 EMSSIONS BY REGION — (1000 Tg C/yr)

REGION	1985	1990	1995	2000	2005	2010	2015	2020	2025	2050	2075	2100
United States	1.35	1.38	1.33	1.35	1.35	1.25	1.22	1.21	1.17	1.04	0.63	0.43
Canada	0.11	0.10	0.10	0.10	0.10	0.09	0.09	0.10	0.10	0.10	0.07	0.05
Western Europe	0.74	0.76	0.73	0.74	0.75	0.72	0.72	0.74	0.73	0.66	0.41	0.29
Japan	0.24	0.24	0.24	0.24	0.24	0.23	0.23	0.23	0.23	0.22	0.15	0.12
Other OECD Asia	0.08	0.08	0.07	0.06	0.07	0.06	0.06	0.06	0.06	0.06	0.04	0.02
USSR & E. Eur.	1.42	1.54	1.50	1.54	1.59	1.61	1.63	1.66	1.67	1.69	1.12	0.78
C-Planned Asia	0.57	0.62	0.62	0.68	0.75	0.83	0.90	0.99	1.06	1.50	1.26	0.95
Middle East	0.15	0.16	0.17	0.19	0.21	0.24	0.28	0.33	0.39	0.46	0.37	0.30
North Africa	0.17	0.12	0.08	0.05	0.04	0.03	0.02	0.04	0.08	0.24	0.34	0.42
South Africa	0.14	0.12	0.11	0.10	0.11	0.10	0.11	0.13	0.09	-.04	-.24	-.47
Argentina	0.02	0.02	0.03	0.03	0.03	0.03	0.04	0.04	0.05	0.10	0.11	0.11
Brazil	0.18	0.12	0.05	0.01	-.00	-.02	-.03	-.02	-.03	-.08	-.20	-.35
O-Latin America	0.29	0.23	0.27	0.15	0.14	0.14	0.14	0.16	0.19	0.33	0.25	0.14
India	0.13	0.15	0.15	0.17	0.19	0.21	0.24	0.27	0.28	0.36	0.28	0.14
Other Asia	0.33	0.26	0.16	0.15	0.14	0.13	0.13	0.17	0.21	0.45	0.54	0.59
Oceans	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

2090 Control Policies — CH_4 EMSSIONS BY REGION — (Tg CH_4/yr)

REGION	1985	1990	1995	2000	2005	2010	2015	2020	2025	2050	2075	2100
United States	57.72	56.83	53.86	52.48	50.82	48.93	47.05	47.12	45.14	38.57	29.41	23.41
Canada	14.73	14.09	14.25	14.33	14.38	14.36	14.50	14.65	14.68	13.85	12.39	11.40
Western Europe	35.31	31.53	34.30	34.25	34.17	33.64	33.70	33.95	34.22	32.59	25.21	19.71
Japan	7.47	7.35	7.27	7.12	6.99	6.70	6.64	6.55	6.42	7.20	6.44	5.60
Other OECD Asia	15.09	15.28	15.41	15.66	15.89	15.85	16.02	16.07	16.07	16.29	15.31	14.27
USSR & E. Eur.	74.55	78.85	80.95	83.66	84.52	84.66	86.32	87.62	89.39	85.71	68.49	56.93
C-Planned Asia	74.15	72.65	73.50	74.92	76.38	77.89	79.64	81.83	83.96	90.65	80.31	68.28
Middle East	9.59	10.30	11.23	12.23	13.21	14.44	16.41	18.91	21.63	27.75	26.00	24.11
North Africa	43.63	43.01	43.89	44.94	45.04	46.54	47.47	48.43	49.17	50.80	50.52	50.06
South Africa	22.25	21.96	22.34	23.01	23.68	24.15	24.97	25.47	26.17	28.72	28.98	20.70
Argentina	8.16	6.40	6.75	9.15	9.45	9.67	10.00	10.33	10.57	10.99	10.36	9.63
Brazil	27.43	25.61	25.38	25.42	25.41	25.34	25.34	25.35	25.40	24.18	23.30	22.27
O-Latin America	28.94	28.47	29.75	31.27	32.64	33.74	35.15	36.43	37.58	40.46	37.55	34.71
India	47.50	48.33	50.29	53.74	56.33	58.50	60.97	63.30	65.82	76.86	73.00	65.74
Other Asia	58.93	58.18	59.22	60.77	63.15	63.04	64.97	65.44	66.47	61.93	59.70	55.13
Oceans	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00

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2090 Control Policies — N_2O EMISSIONS BY REGION — (Tg N/yr)

REGION	1985	1990	1995	2000	2005	2010	2015	2020	2025	2050	2075	2100
United States	1.07	1.66	1.57	1.14	1.11	1.06	1.03	1.01	1.00	0.88	0.76	0.68
Canada	0.52	0.54	0.58	0.61	0.62	0.66	0.66	0.63	0.64	0.58	0.55	0.53
Western Europe	0.61	0.65	0.69	0.72	0.05	1.07	0.99	0.73	0.73	0.68	0.57	0.50
Japan	0.09	0.09	0.09	0.10	0.13	0.21	0.18	0.09	0.09	0.08	0.07	0.07
Other OECD Asia	0.45	0.45	0.45	0.46	0.46	0.47	0.47	0.46	0.46	0.46	0.46	0.45
USSR & E. Eur.	1.01	1.00	1.91	1.97	1.97	1.98	1.98	1.99	1.98	1.97	1.01	1.70
C-Planned Asia	1.17	1.19	1.23	1.26	1.28	1.29	1.30	1.30	1.31	1.29	1.18	1.08
Middle East	0.33	0.34	0.35	0.35	0.36	0.37	0.38	0.40	0.41	0.43	0.40	0.39
North Africa	1.21	1.15	1.16	1.17	1.17	1.17	1.16	1.19	1.19	1.22	1.21	1.20
South Africa	0.56	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.53	0.53	0.52	0.51
Argentina	0.14	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.16	0.16	0.17
Brazil	0.68	0.58	0.58	0.57	0.56	0.55	0.54	0.53	0.52	0.52	0.53	0.53
O-Latin America	0.75	0.68	0.67	0.67	0.67	0.68	0.68	0.69	0.68	0.74	0.81	0.89
India	0.36	0.40	0.46	0.49	0.50	0.51	0.52	0.54	0.54	0.49	0.49	0.48
Other Asia	0.75	0.67	0.63	0.72	0.74	0.78	0.82	0.90	0.97	0.99	1.00	0.98
Oceans	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00

2090 Control Policies — NO_x EMISSIONS BY REGION — (Tg N/yr)

REGION	1985	1990	1995	2000	2005	2010	2015	2020	2025	2050	2075	2100
United States	7.28	7.06	6.69	6.55	6.10	5.18	4.61	4.23	3.99	3.19	2.66	2.62
Canada	1.43	1.41	1.40	1.40	1.37	1.30	1.26	1.23	1.23	1.19	1.14	1.16
Western Europe	4.03	3.97	3.82	3.83	3.62	3.09	2.77	2.55	2.49	2.15	1.76	1.79
Japan	1.29	1.26	1.21	1.21	1.13	0.93	0.81	0.72	0.68	0.61	0.52	0.55
Other OECD Asia	1.25	1.23	1.21	1.21	1.17	1.13	1.09	1.06	1.04	1.02	0.99	0.99
USSR & E. Eur.	8.63	8.97	8.85	9.02	8.52	7.95	7.64	7.42	7.38	5.88	5.27	5.23
C-Planned Asia	3.92	4.19	4.35	4.70	4.92	5.20	5.41	5.67	5.95	4.50	4.09	3.87
Middle East	1.12	1.16	1.19	1.25	1.28	1.34	1.44	1.58	1.78	1.65	1.34	1.30
North Africa	2.94	2.81	2.83	2.87	2.84	2.80	2.82	2.84	2.96	3.03	3.06	3.13
South Africa	1.58	1.57	1.58	1.63	1.63	1.62	1.64	1.66	1.67	1.47	1.38	1.39
Argentina	0.39	0.39	0.40	0.41	0.41	0.41	0.42	0.43	0.47	0.53	0.55	0.57
Brazil	1.73	1.55	1.52	1.53	1.50	1.47	1.46	1.45	1.46	1.43	1.35	1.33
O-Latin America	2.30	2.13	2.14	2.21	2.19	2.18	2.19	2.23	2.37	2.50	2.44	2.50
India	1.13	1.21	1.24	1.34	1.40	1.42	1.49	1.57	1.65	1.44	1.37	1.35
Other Asia	2.22	2.03	2.04	2.11	2.10	2.15	2.16	2.19	2.27	2.27	2.36	2.59
Oceans	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LIGHTNING	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00

2090 Control Policies — CO EMSSIONS BY REGION — (Tg C/yr)

REGION	1985	1990	1995	2000	2005	2010	2015	2020	2025	2050	2075	2100
United States	60.12	52.66	44.72	36.41	36.11	28.06	23.76	20.42	20.95	18.77	17.02	17.11
Canada	11.10	10.29	9.88	9.53	9.40	8.29	7.46	6.64	6.65	6.41	6.19	6.16
Western Europe	43.98	41.29	38.97	37.08	36.67	29.08	23.56	18.06	18.76	17.53	15.86	15.47
Japan	13.77	13.03	12.32	11.76	11.58	8.92	7.06	5.10	5.36	5.11	4.75	4.86
Other OECD Asia	10.01	6.77	8.43	8.15	7.94	7.29	6.79	6.28	6.13	5.93	5.80	5.72
USSR & E. Eur.	54.76	53.61	53.95	56.49	55.27	49.78	47.58	45.96	49.10	32.52	31.26	32.06
C-Planned Asia	51.79	45.53	45.08	45.31	44.62	43.84	43.45	43.22	43.78	41.02	40.69	39.64
Middle East	9.02	8.69	8.75	9.09	9.01	8.72	9.05	9.70	11.25	8.08	7.84	8.25
North Africa	49.46	39.98	38.56	37.92	36.26	34.25	32.99	31.86	31.69	26.31	25.38	24.54
South Africa	22.36	18.32	17.72	17.40	16.75	15.99	15.48	15.00	14.80	13.11	12.63	12.03
Argentina	3.44	3.32	3.34	3.46	3.41	3.25	3.22	3.22	3.45	2.69	2.67	2.72
Brazil	44.83	32.81	30.60	28.79	26.97	24.73	22.77	20.88	19.48	16.02	15.20	14.25
O-Latin America	54.55	42.03	39.93	39.00	36.73	33.62	31.47	29.60	29.48	21.56	20.64	20.09
India	21.59	20.64	20.82	21.24	21.27	21.10	21.17	21.29	21.74	21.22	20.66	19.85
Other Asia	69.38	53.10	50.35	48.62	45.98	42.73	40.17	37.78	36.49	31.32	30.72	30.46
Oceans	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00

Accelerated Polices/ Well below doubling[1] CO_2 EMISSIONS BY REGION (1000 Tg C/yr)

REGION	1985	1990	1995	2000	2005	2010	2015	2020	2025	2050	2075	2100
United States	1.28	1.26	1.22	1.20	1.16	1.06	0.99	0.94	0.91	0.53	0.44	0.41
Canada	0.12	0.12	0.12	0.11	0.11	0.10	0.10	0.10	0.11	0.09	0.08	0.08
Western Europe	0.85	0.85	0.82	0.81	0.78	0.73	0.70	0.66	0.64	0.40	0.35	0.33
Japan	0.26	0.26	0.25	0.25	0.24	0.23	0.21	0.20	0.20	0.13	0.12	0.13
Other OECD Asia	0.09	0.08	0.07	0.07	0.06	0.06	0.05	0.05	0.04	0.01	0.00	0.00
USSR & E. Eur.	1.33	1.44	1.44	1.47	1.43	1.36	1.28	1.19	1.12	0.67	0.59	0.55
C-Planned Asia	0.65	0.69	0.73	0.81	0.89	0.97	1.05	1.12	1.20	0.88	0.86	0.79
Middle East	0.11	0.12	0.13	0.15	0.16	0.18	0.20	0.22	0.26	0.30	0.30	0.28
North Africa	0.18	0.13	0.09	0.06	0.05	0.04	0.06	0.16	0.32	0.62	0.67	0.65
South Africa	0.13	0.11	0.10	0.10	0.10	0.10	0.08	-.03	-.27	-.88	-.89	-.92
Argentina	0.02	0.02	0.03	0.03	0.03	0.04	0.05	0.06	0.11	0.17	0.17	0.15
Brazil	0.18	0.12	0.05	0.02	-.00	-.02	-.05	-.12	-.26	-.62	-.61	-.64
O-Latin America	0.29	0.23	0.18	0.15	0.15	0.16	0.17	0.19	0.19	0.11	0.13	0.07
India	0.14	0.15	0.17	0.19	0.21	0.24	0.25	0.22	0.13	-.11	-.06	-.03
Other Asia	0.35	0.27	0.21	0.18	0.18	0.19	0.21	0.28	0.38	0.62	0.79	0.85
Oceans	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Accelerated Polices/Well below doubling CH_4 EMISSIONS BY REGION (Tg CH_4/yr)

REGION	1985	1990	1995	2000	2005	2010	2015	2020	2025	2050	2075	2100
United States	57.29	55.27	53.72	51.84	49.66	47.21	44.63	43.03	39.60	27.62	25.74	24.47
Canada	14.81	14.99	15.25	15.25	15.11	14.92	14.77	14.36	13.80	11.73	11.84	11.80
Western Europe	35.62	33.95	36.76	36.37	35.65	34.60	33.81	32.35	31.36	26.29	23.92	21.87
Japan	7.55	7.45	7.31	7.14	6.99	6.77	6.61	6.48	6.32	6.96	5.67	4.79
Other OECD Asia	15.16	15.61	15.76	15.88	15.95	15.78	15.76	15.49	15.27	14.38	13.62	13.14
USSR & E. Eur.	76.70	74.97	76.25	77.96	79.71	81.64	81.52	79.86	76.87	69.67	64.82	61.08
C-Planned Asia	74.23	74.97	76.25	77.96	79.71	81.64	83.45	85.38	87.11	82.42	77.12	71.43
Middle East	9.32	10.19	10.88	11.74	12.71	13.85	15.19	16.60	17.93	18.22	19.15	21.61
North Africa	43.38	43.09	43.94	44.95	45.09	45.64	47.38	47.82	47.97	47.60	48.55	48.49
South Africa	22.26	21.97	22.42	23.12	23.79	24.28	25.10	25.48	26.06	26.45	27.89	27.82
Argentina	8.16	8.48	8.81	9.18	9.47	9.69	9.95	10.12	10.17	10.06	9.91	9.65
Brazil	27.17	25.42	25.39	25.43	25.42	25.35	25.35	25.32	25.30	23.59	23.29	22.65
O-Latin America	26.80	28.65	30.01	31.40	32.73	33.84	35.02	35.66	36.05	36.05	35.76	35.22
India	46.81	48.40	50.69	54.20	56.84	59.09	61.52	63.80	66.26	75.74	70.25	61.18
Other Asia	58.39	58.02	59.46	61.31	63.81	65.54	65.65	65.91	66.37	61.06	57.56	51.68
Oceans	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00

Accelerated Polices /Well below doubling N_2O EMISSIONS BY REGION (Tg N/yr)

REGION	1985	1990	1995	2000	2005	2010	2015	2020	2025	2050	2075	2100
United States	1.06	1.61	1.49	1.09	1.07	1.02	0.98	0.97	0.96	0.82	0.77	0.75
Canada	0.52	0.55	0.59	0.61	0.63	0.67	0.67	0.63	0.64	0.58	0.56	0.55
Western Europe	0.63	0.68	0.71	0.73	0.85	1.12	1.04	0.71	0.72	0.66	0.61	0.58
Japan	0.09	0.10	0.09	0.09	0.13	0.21	0.18	0.08	0.08	0.07	0.07	0.07
Other OECD Asia	0.46	0.45	0.45	0.45	0.46	0.47	0.47	0.45	0.45	0.45	0.44	0.44
USSR & E. Eur.	1.77	1.84	1.90	1.96	1.94	1.93	1.91	1.90	1.89	1.83	1.77	1.74
C-Planned Asia	1.21	1.23	1.26	1.30	1.31	1.32	1.32	1.33	1.33	1.24	1.18	1.14
Middle East	0.32	0.33	0.34	0.34	0.35	0.36	0.36	0.37	0.38	0.39	0.39	0.39
North Africa	1.21	1.15	1.16	1.17	1.17	1.18	1.18	1.20	1.21	1.23	1.24	1.23
South Africa	0.56	0.54	0.54	0.54	0.54	0.54	0.54	0.53	0.53	0.52	0.53	0.52
Argentina	0.14	0.14	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.16	0.16	0.16
Brazil	0.67	0.59	0.58	0.57	0.56	0.55	0.54	0.53	0.52	0.52	0.51	0.51
O-Latin America	0.74	0.67	0.67	0.67	0.67	0.68	0.68	0.69	0.70	0.73	0.73	0.72
India	0.37	0.41	0.46	0.50	0.50	0.52	0.52	0.53	0.54	0.48	0.48	0.47
Other Asia	0.76	0.69	0.70	0.72	0.75	0.79	0.84	0.92	1.00	1.00	1.01	0.98
Oceans	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00

[1] Updated version, 1985 and 1990 data of IPCC-D scenario slightly differ from other IPCC scenarios.

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Accelerated Policies/Well below doubling — NO_x EMISSIONS BY REGION — (Tg N/yr)

REGION	1985	1990	1995	2000	2005	2010	2015	2020	2025	2050	2075	2100
United States	7.11	5.65	6.25	5.96	5.58	4.80	4.33	4.05	4.11	3.29	3.05	3.04
Canada	1.51	1.47	1.44	1.43	1.40	1.33	1.29	1.27	1.29	1.25	1.24	1.26
Western Europe	4.65	4.37	4.14	4.03	3.86	3.27	2.91	2.65	2.77	2.37	2.30	2.38
Japan	1.41	1.33	1.26	1.21	1.16	0.96	0.83	0.73	0.77	0.72	0.69	0.72
Other OECD Asia	1.30	1.27	1.24	1.23	1.20	1.14	1.09	1.05	1.06	1.04	1.03	1.03
USSR & E. Eur.	8.32	8.62	8.64	8.79	8.36	7.80	7.40	7.15	7.22	5.70	5.33	5.43
C-Planned Asia	4.53	4.75	5.12	5.58	5.90	6.18	6.47	6.83	7.43	4.48	4.28	4.25
Middle East	0.96	0.98	1.02	1.07	1.10	1.13	1.18	1.25	1.36	1.30	1.24	1.29
North Africa	2.96	2.82	2.82	2.86	2.85	2.84	2.29	3.14	3.44	3.69	3.60	3.55
South Africa	1.60	1.56	1.60	1.65	1.66	1.66	1.69	1.70	1.73	1.38	1.35	1.35
Argentina	0.39	0.39	0.39	0.40	0.41	0.41	0.44	0.51	0.61	0.76	0.78	0.78
Brazil	1.72	1.53	1.51	1.51	1.50	1.48	1.47	1.48	1.50	1.40	1.39	1.36
O-Latin America	2.28	2.08	2.06	2.14	2.16	2.17	2.26	2.50	2.86	3.16	3.20	3.20
India	1.20	1.25	1.34	1.45	1.53	1.59	1.68	1.77	1.88	1.43	1.45	1.54
Other Asia	2.26	2.07	2.11	2.19	2.23	2.25	2.33	2.54	2.81	2.80	2.96	3.26
Oceans	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LIGHTNING	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00

Accelerated Policies/Well below doubling — CO EMISSIONS BY REGION — (Tg C/yr)

REGION	1985	1990	1995	2000	2005	2010	2015	2020	2025	2050	2075	2100
United States	60.14	50.24	41.25	32.93	32.90	27.44	24.27	21.56	22.76	19.51	18.64	18.76
Canada	11.78	10.65	10.05	9.59	9.52	8.59	7.80	6.89	6.96	6.57	6.48	6.48
Western Europe	49.03	43.98	40.29	37.52	37.63	31.31	26.04	19.89	20.98	18.69	18.12	18.01
Japan	14.40	12.84	11.69	10.80	10.83	8.95	7.37	5.53	5.86	5.41	5.38	5.52
Other OECD Asia	10.13	8.75	8.33	8.00	7.82	7.31	6.85	6.35	6.23	5.98	5.92	5.85
USSR & E. Eur.	50.86	47.37	47.43	49.78	50.18	47.16	43.32	43.74	46.44	31.11	31.15	32.01
C-Planned Asia	53.10	46.33	45.80	45.95	45.64	45.19	45.05	45.11	46.06	41.95	42.29	41.29
Middle East	7.71	7.30	7.27	7.42	7.52	7.44	7.63	7.90	8.55	6.95	7.34	7.69
North Africa	49.75	39.75	38.04	37.11	35.85	34.21	33.19	32.34	32.32	26.78	26.33	25.19
South Africa	22.45	16.24	17.55	17.15	16.63	15.99	15.55	15.14	14.96	13.12	12.92	12.29
Argentina	3.41	3.18	3.15	3.21	3.25	3.19	3.21	3.29	3.56	2.79	2.80	2.79
Brazil	44.76	32.52	30.19	20.44	26.62	24.59	22.73	20.94	19.54	16.00	15.37	14.33
O-Latin America	54.30	40.97	38.45	37.08	35.48	33.12	31.37	29.92	29.93	21.76	21.25	20.35
India	21.85	20.65	20.73	21.04	21.22	21.22	21.39	21.60	22.10	21.40	21.63	20.90
Other Asia	70.13	53.14	50.07	48.06	45.86	43.06	40.76	38.65	37.55	31.97	32.42	32.32
Oceans	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00	17.00

Appendix 2: Methane emissions from the energy sector in the Netherlands in 1988.

Type of conversion/ fuel used	Energy (PJ/yr)	Emission factor (g/GJ)	Emission (ton/yr)	Emission (kton/yr)
- COKE MANUFACTURING				0
coal (input)	115	n.a.	p.m.	
coke oven (consumption)	13	1	10	
- REFINERIES				0.5
refining process	2174 *	0.17	370	
gas	27	1	30	
oil products	38	3	110	
- POWER PLANTS				2.0
gas	269	6	1600	
coal	208	2 **	400	
oil	6	1	10	
- DISTRICT HEATING				0
gas	0	6	0	
- MUNICIPAL WASTE				0
waste combustion	0	n.a.	p.m.	
TOTAL				2.5

* Energy content of crude oil processed.
** Including the average emission from coal storage (1 g/GJ).

source: CBS, 1990a (energy consumption), Piccot et al., 1990 (emission factors, adapted to LHV cf. IEA/OECD, 1991).

APPENDIX 3

Appendix 3: Methane emissions from end-use in the Netherlands in 1988.

Category of end-use/ fuel used	Non-el.energy (PJ/yr)	Emission factor (average) (g/GJ)	Q.R.*	Emission (ton/yr)	Emission (kton/yr)
- INDUSTRY					5.2
gas	316	4	Nielen	1,260	
gas non-energy use	94	41	Nielen	3,850	
oil products	13	3	A	40	
coal	30	1	B	30	
cokes	36	n.a.	D	0	
wood	1	15	E	20	
- COMMERCIAL					3.6
agriculture/gas	110	30	Nielen	3,300	
building	9	2	n.a.	270	
trade	50		n.a.		
transports & communic.	11		n.a.		
services	11		n.a.		
other/government	75		n.a.		
- RESIDENTIAL					8.4
gas-combustion	269	30	Nielen	8,000	
gas-cooking losses	-	-	Nielen	400	
coal/oil	8	1	n.a.	10	
others (wood/biomass)	?	n.a.	n.a.	p.m.	
- TRANSPORTATION					8.1
road-gasoline	151	39	D	5,900	
road-diesel	130	6	D	800	
road-lpg	38	26	Steenlage	1,100	
rail-diesel	1	14	D	20	
ships - oil/diesel	20	21	D	400	
aircraft - jet fuel	6-55 **	2	E	15-130	
TOTAL					25.3

* Quality rating: A-E = high to low confidence (Piccot et al., 1990)
** Highest figure includes international bunkers

source: CBS, 1990a (energy consumption): RCN, 1988 (wood combustion); Piccot et al., 1990 (all emission factors except residential, industrial and agricultural gas combustion, adapted to LHV cf. IEA/OECD, 1991); Nielen, 1991 (industrial, agricultural and residential gas consumption)

Appendix 4: Methane emissions from ruminants, pseudo ruminants, other animals and humans in the Netherlands in 1989 (a comparison of three different references; Crutzen, IKC and IVVO)

Type	Popu-lation x 1000	Crutzen [1] CH_4/ unit kg/yr	Crutzen [1] CH_4 kton/yr low	Crutzen [1] CH_4 kton/yr high	IKC [2] GVE/ animal	IKC [2] CH_4 kton/yr if 350 l/d	IKC [2] CH_4 kton/yr if 550 l/d	IVVO [3] CH_4 unit kg/yr	IVVO [3] CH4 kton/yr
RUMINANTS (CBS, 1989b)									
Cattle <1yr	772	51	33	45	0.3	21	33	53	41
Cattle >1yr	830	65	46	62	0.5	38	59	53	44
Dairy cattle/cow in calf	1,913	94	153	207	1.0	175	274	128	245
Steer/bull >1yr	536	65	30	40	0.7	34	54	55	29
Fattening/grazing cattle	83	47	3	4	0.5	4	6	64	5
Fattening calves	597	0							
TOTAL RUMINANTS			270	360		270	430		360
SHEEP/GOATS (CBS, 1989b)									
Sheep	665	8	4.5	6.1	0.1	6.1	9.5	n.a.	n.a.
Goats	42	5	0.2	0.2	0.1	0.4	0.6	n.a.	n.a.
TOTAL SHEEP/GOATS			4.7	6.4		6.5	10.1		n.a.
PIGS (CBS, 1989c)									
Piglets per farrowing Other piglets/pigs <50 kg Pigs 20-50 kg Porkers >50kg Breeding pigs >50kg	13,964	1.5	18	24		n.a.	n.a.		n.a.
TOTAL PIGS			18	24		n.a.	n.a.		n.a.
HORSES/DONKEYS (CBS, 1989b)									
Horses	67	18	1.0	1.4	n.a.	n.a.		n.a.	
OTHER ANIMALS									
Wild animals in nature reserve area/zoo's		p.m	p.m.	n.a.	n.a.		n.a.		
HUMANS (CBS, 1990b)									
Humans		14,891	0.05	0.6	0.9	n.a.	n.a.		n.a.

Sources:
[1] Crutzen et al., 1986
[2] Goossensen and Meeuwissen, 1990
[3] Van der Honing and Van Vuuren, 1991

APPENDIX 5

Appendix 5: Summary of spreadsheet for calculating the present and projected emissions of methane from landfills in the Netherlands.

A: Basic data and parameter settings

Target year of emission	:	2000
Basic data landfilling :		
- Before 1945	:	negligible
- 1945-1970	:	interpolation landfilling data '45-70
- 1970-1986	:	interpolation landfilling data '70-86
- 1986-1990	:	extrapolation landfilling data before 1986
Projected future landfilling (from 1990 on) :		
- Option 1	:	Phase out in 2000
Parameters of landfilling and methane release to atmosphere :		
- Code option	:	1 (Phase out)
- Perc. of growth after 1990	:	0 %
- CH_4 Emission duration	:	50 year
- CH_4 % of waste gas produced in landfill	:	50 procent
- Perc of prod. CH_4 oxidized before emitted to atmosphere	:	20 procent

B: Calculation of methane emissions to the atmosphere in 2000 from waste landfilled before 2000.

Description	Unit	Results per years (some examples only)					
Year of emission (see above)	year	2000	2000	2000	2000	2000	2000
Year of landfilling	year	1945	1970	1990	1999	2025	2049
Total waste landfilled	x 1000 ton	0	5874	14006	1401	0	0
Fraction (P_O)	kg/ton	180	180	170	170	170	170
Waste gas production in 2000	x 1000 m3	0	10328	48264	6703	0	0
Perc. CH_4 in waste gas	%	0.5	0.5	0.5	0.5	0.5	0.5
weight one m_3 of CH_4	kg	0.714	0.714	0.714	0.714	0.714	0.714
oxidation percentage	%	10	10	10	10	10	10
Production of CH_4 in 2000	kiloton CH_4	0.00	3.69	17.23	2.39	0.00	0.00
Oxidation 2000	kiloton CH_4	0.00	0.74	3.45	0.48	0.00	0.00
Emission in year of choice	kiloton CH_4	0.00	2.95	13.78	1.91	0.00	0.00

* Formula for calculation of accumulated waste gas production is described in text: see Section 3.3.6

C: Development of past, present and projected emissions of methane under phasing out policy
(For parameters used see A: basic data)

Year	Waste prod. kton av./yr	Production kton CH_4/yr	Oxidation kton CH_4/yr	Emission kton CH_4/yr
1945	0	0	0	0
1960	3500	39	8	31
1970	5874	100	20	80
1980	10640	198	40	158
1990	14005	335	67	268
2000	0	341	69	272
2010	0	237	52	184
2020	0	164	46	119
2030	0	114	48	66
2040	0	79	59	20
2050	0	55	55	0

Appendix 6: Tentative scenario for the development of the energy consumption in the Netherlands.

Sector	1989 (PJ) subtotal		2000 (PJ) subtotal		Increase/ decrease 1990-2000
POWER PLANTS *		325		280	-14%
inputs:	547		510		
producing:	-222		-230		
INDUSTRY		1,147		1,310	+14%
energy	738		810		
feedstock	409		500		
COMMERCIAL		425		390	-8%
RESIDENTIAL		460		400	-13%
gas	385		?		
electr.	75		?		
TRANSPORTATION		370		400	+8%
TOTAL		2,727		2,780	+2%

* Primary energy minus electricity produced

source: EZ, (1990b) MEC, Annex 1, table 4.

APPENDIX 7

Appendix 7: Estimated emissions of nitrous oxide from fossil sources in the Netherlands in 1988.

Source/ fuel type	Energy used (PJ)	Emission factor (g N_2O-N/GJ)		Emission (ton N_2O-N/yr)
- ENERGY SECTOR				240-1,180
. gas	269	0-1		0-300
. coal	208	1-4		200-800
. oil	6	1-2		10- 20
. refining process,coke production	168	n.a.		p.m.
- INDUSTRY				90-640
. gas, incl. CO-gas	316	0-1		0-400
. oil	77	1-2		80-140
. coal	30	1-4		30-120
. cokes	70	n.a.		p.m.
. feedstock (gas/oil)	400	n.a.		p.m.
- COMMERCIAL				40-330
. gas	255	0-1		0-250
. oil	37	1-2		40- 80
- RESIDENTIAL				10-320
. gas	332	0-1	*	0-300
. oil	9	1-2	*	10- 20
. others (wood/biomass)	?	n.a.		p.m.
- TRANSPORTATION				1,370-4,060
. gasoline	151	(1-12)	**	200-1,740
. diesel	153	(6-14)	**	980-2,130
. LPG	38	(5)	**	190
. others (aircraft) ***	6-55	n.a.		p.m.
TOTAL				1,730-6,490

* Application of emission factors for large combustors.
** Average emission factors per fuel type calculated for comparative purposes only (see also Table 4.2).
*** Highest figure including international bunkers

source: CBS, 1990a (energy consumption); De Soete, 1990 (emission factors, except for LPG), Knapp, 1990 (CNG; for LPG the same value is used)

Appendix 8: Estimated nitrous oxide emissions from mobil sources in the Netherlands in 1988

Category	Fuel	Energy used (PJ)	Emission factor (g N_2O-N/GJ)	Emission (ton N/y)
ROAD				1,210-3,740
- car *	gasoline	144	1-11	150-1,600
	diesel	33	3-10	100-330
	LPG	37	n.a./5(=CNG)	190
- bus	diesel	7	2-4	10-30
- motorbike	gasoline	3	1-11	0-30
Subtotal road-passenger transport:				450-2,180
- truck	gasoline	7	8-15	50-100
	diesel	90	8-15	700-1,400
- special vehicles	gasoline	0.4	1-15	0-10
	diesel	3	3-15	10-50
Subtotal road-freight transport :				760-1,560
RAIL				10-20
- train	diesel	1.3	8-15	10-20
WATER				150-300
- ships	oil/diesel	19	n.a.(=diesel)	150-300
AIR			(8-15)	n.a.
- aircraft-airliners	jet fuel	6-55	n.a.	n.a.
- aircraft-small aircrafts	aviation gasoline	3	n.a.	n.a.
TOTAL :				1,300-4,100

* Without catalyst
** Higher figure includes international bunkers

source: CBS, 1990a (energy consumption); De Soete,1990 (emission factors, except LPG), Knapp, 1990 (LPG, assumed to be equal to CNG)

Appendix 9: Nitrous oxide emissions for agricultural land (areas in ha, emissions in ton N2O-N). Effective N-input is total N in organic and mineral fertilizer minus NH3 volatilization

Province	Grassland			Tuber/root crops			Cereals+other crops (legumes,maize)			Fodder maize			Legumes		Fallow		Horticulture glass		Horticulture open		Total Agriculture
	Area	Eff. N-input kg N/ha	N_2O	Area	Eff. N-input kg N/ha	N_2O	Area	Eff. N-input kg N/ha	N_2O em.	Area	Eff. N-input kg N/ha	N_2O	Area	N_2O	Area	N_2O	Area	N_2O	Area	N_2O	N_2O
Groningen	59,468	511	314	45,485	254	134	55,936	191	150	2,800	500	11	3,814	11	480	1	152	0	1,407	5	626
Friesland	200,902	532	1094	13,786	262	41	8,298	176	22	3,533	500	14	876	3	602	1	91	0	1,432	5	1,179
Drenthe	75,858	521	407	53,185	250	155	17,528	213	48	13,439	500	53	4,930	15	140	0	221	1	1,121	4	684
Overijssel	156,676	527	847	9,439	282	29	2,991	177	8	38,363	500	152	1,488	4	162	0	99	0	638	2	1,043
Flevoland	12,646	607	76	38,092	225	107	31,370	179	82	2,070	500	8	4,310	13	361	1	0	0	8,626	29	316
Gelderland	184,272	517	982	9,561	284	29	9,872	162	25	41,065	500	163	1,710	5	830	2	845	3	9,317	30	1,239
Utrecht	64,320	470	320	305	282	1	355	163	1	3,407	500	14	47	0	213	0	316	1	2,522	8	345
N.Holland	77,698	382	336	20,067	263	60	18,234	173	47	794	500	3	1,995	6	1,018	2	1,776	6	18,312	61	520
Z.Holland	84,259	453	409	20,808	261	62	23,002	198	62	1,316	500	5	2,919	9	604	1	8,703	31	13,329	47	626
Zeeland	13,233	425	61	35,018	245	102	55,154	191	148	2,650	500	11	10,549	32	252	0	56	0	7,150	25	378
N.Brabant	127,991	575	738	26,458	300	83	25,151	193	67	72,826	500	289	3,443	10	708	1	663	2	18,091	63	1,254
Limburg	41,499	556	233	19,201	289	59	15,307	128	37	20,428	500	81	2,445	7	353	1	797	2	12,009	35	456
Total	1,098,822		5,818	291,405		861	263,198		698	202,691		803	38,526	116	5,723	11	13,719	47	93,954	314	8,668
Fraction of agr. N_2O emission			67%			10%			8%			9%		1%		0%		1%		3%	100%
Low estimate		300	3,647		200	703		150	593		150	457		98		9		35		240	5,781
High estimate		600	7,523		375	1,154		200	821		1,500	1,484		139		13		58		400	11,591
Contribution of grasslands on mineral soils (828822 ha) only:			2,751																		4,885
			5,674																		9,743
Contribution of grasslands on organic soils (270000 ha) based on flux equation (see below)			896																		
			1,848																		

1) grassland : $N_2O = 1.454114 + 0.007496N$;
2) arable land : $N_2O = 1.878536 + 0.00417N$;
3) legumes : $N_2O = 3$ (2-4);
4) fallow : $N_2O = 1.878536 + 0.00417N$;
5) for horticulture 2x N-fertilizer doses for cereals applied with identical flux equations

Appendix 9: Nitrous oxide emissions for non-agricultural land (emissions in ton N_2O-N, areas in ha)

Province	Natural dry	N_2O em.	Natural wet	N_2O em.	Other land	N_2O em.	Coniferous forest	N_2O em.	Deciduous forest	N_2O em.	Total nonagric. area	Nonagric. N_2O emission	Water >6m	N_2O emission
Groningen	436	0.2	4,523	2.3	536	0.3	532	0.3	2,202	1.1	8,229	4.1	26,700	240
Friesland	15,790	7.9	9,937	5.0	656	0.3	3,912	2.0	5,416	2.7	35,711	17.9	43,800	394
Drenthe	6,457	3.2	4,776	2.4	127	0.1	18,172	9.1	10,416	5.2	39,948	20.0	2,500	23
Overijssel	3,087	1.5	9,293	4.6	152	0.1	22,413	11.2	16,752	8.4	51,697	25.8	11,500	104
Flevoland	846	0.4	4,020	2.0	354	0.2	953	0.5	8,826	4.4	14,999	7.5	6,876	62
Gelderland	21,277	10.6	3,245	1.6	491	0.2	66,030	33.0	28,164	14.1	119,207	59.6	22,800	205
Utrecht	1,030	0.5	1,845	0.9	112	0.1	12,309	6.2	7,182	3.6	22,478	11.2	7,100	64
N. Holland	14,229	7.1	5,125	2.6	587	0.3	3,973	2.0	7,192	3.6	31,106	15.6	29,100	262
Z. Holland	8,370	4.2	7,913	4.0	1,039	0.5	315	0.2	5,455	2.7	23,092	11.5	45,800	412
Zeeland	3,765	1.9	4,889	2.4	1,458	0.7	485	0.2	2,771	1.4	13,368	6.7	123,100	1,108
N. Brabant	6,228	3.1	8,020	4.0	925	0.5	51,583	25.8	21,611	10.8	88,367	44.2	15,100	136
Limburg	2,340	1.2	2,265	1.1	383	0.2	17,783	8.9	14,202	7.1	36,973	18.5	3,900	35
Total	83,855	41.9	65,851	32.9	6,820	3.4	198,460	99.2	130,189	65.1	485,175	242.6	338,276	3,044
Low estimate		21		16		2		50		33		121		2,030
High estimate		63		49		5		149		98		364		4,059

a) natural terrain, dry : N_2O = 0.5 (0.25-0.75);
b) natural terrain, wet : N_2O = 0.5 (0.25-0.75);
c) other types : N_2O = 0.5 (0.25-0.75);
d) needleleaved forest : N_2O = 0.5 (0.25-0.75);
e) deciduous forest : N_2O = 0.5 (0.25-0.75);
f) open water > 6m : N_2O = 9 (6-12)

Appendix 10: Input of nitrogen through fertilizer and nitrogen deposition per province for grassland, root and tuber crops, cereals and other crops (in kg N ha^{-1})

		Grassland						Roots and tuber crops						Cereals and other crops					
Province	Deposition	a	b	c	d	Total minus	Total NH_3 loss	a	b	c	d	Total minus	Total NH_3 loss	a	b	c	d	Total minus	Total NH_3 loss
Groningen	35	288	1	187	36	547	476	155	1	72	2	265	219	155	1	0	0	191	156
Friesland	38	278	1	241	11	569	494	139	0	88	13	278	224	138	0	0	0	176	138
Drenthe	38	274	1	224	22	559	483	173	2	41	3	257	212	173	2	0	0	213	175
Overijssel	44	261	1	197	72	575	483	126	12	109	8	299	238	122	11	0	0	177	133
Flevoland	35	428	0	168	0	631	572	142	0	36	23	236	190	144	0	0	0	179	144
Gelderland	47	241	2	173	109	572	470	107	8	95	56	313	237	102	4	11	0	164	115
Utrecht	43	197	2	221	53	516	427	102	13	85	71	314	239	87	1	37	0	168	120
N. Holland	36	195	0	164	14	409	346	138	1	101	1	277	227	135	2	0	0	173	137
Z. Holland	40	193	1	225	36	495	413	152	1	76	3	272	221	156	2	0	0	198	158
Zeeland	36	287	0	119	0	442	389	155	0	29	40	260	209	155	0	0	0	191	155
N. Brabant	59	295	1	190	79	624	516	106	3	143	12	323	241	96	3	22	22	202	134
Limburg	48	282	0	162	121	613	508	91	1	135	46	321	241	79	1	0	0	128	80

a = mineral fertilizer;
b = sewage sludge;
c = cattle manure;
d = manure from intensive pig breeding and poultry

Sources:
N-input from fertilizers : CBS, 1986
N-deposition : Asman and Maas, 1987

Appendix 11: Historical trends and projected emissions of CO_2 of the Netherlands (in Mton/yr).

Source	Historic trend [1] 1988	share	85-88 growth	Level 89/90	Projections: 1994 94/95 auton.	NEPP	2000 auton.	2000 NEPP	2010 target
ENERGY SECTOR	50	28%	+19%			- 1.5 [2]		- 12.5 [2]	
- power plant	35	20%	+14%						
- refineries/coke	14	8%	+35%						
INDUSTRY	60	34%	+2%			\ - 1.5 [2]		\ 1.5/-2.5 [2]	
- direct	38	21%				|		|	
- potential [5]	23	13%				|		|	
COMMERCIAL	20	11%	+14%			|> - 10		|> -17/-20	
- greenhouse hort.	7	4%	+46%			|		|	
- others	13	7%	+2%			|		|	
RESIDENTIAL	22	12%	-4%			/		/	
TRANSPORTATION	25	14%	+8%	25.5	29	-2.5 [3]	29.5	-6.5/-7.5	20.7
WASTE COMBUSTION [6]	2	-%	+88%			-1.6 [4]		-3.5/-4.5	
TOTAL EMISSION (excl. waste combustion)	177	100%	+10%	182	195	182	220	173/177 (NEPP)	
ENERGY (PJ) (excl. transportation, waste and bunkers)				2,775	2,940			3,200	

[1] Adjusted tot standard heating degree days (about 3,200 PJ in the Netherlands)
[2] Fuel switching from coal to natural gas
[3] By means of efficiency improvements (technology, driving behaviour, loadfactor) volume policy (o.a. cycling) and change of modal split (stimulation of rail and water transport)
[4] Contributions from:

- prevention of synthetic materials (plastics, wrapping, tires)	0.35
- natural materials : recycl. of paper and card board	0.50
fermentation of manure and organic matter	0.35
- recycling of energy-intensive materials: glass	0.10
ferro & aluminium	0.30
TOTAL (kton)	1.6

[5] Including exports (about 75%)
[6] CO_2 emission by waste combustion (for energetic application) is already included in potential emissions of industrial sector.

source: Boonekamp et al., 1989; VROM, 1989b (NEP); VROM, 1990a (NEPP); EZ, 1990b (MEC)

Appendix 12: Halocarbons, GWP and ODP, potential and real emissions.

Substance	Chemical formula	GWP CO2 equiv.**	ODP *	M	Emission characteristics: Life-time (yr)	during production (%)	conversion (%)	within <1yr (%)	after >1yr (%)	Potential emissions (ton/yr): Pot. emiss. 1986	Pot. emiss. 1990	Pot. emiss. 1995	Pot. emiss. 1998	Pot. emiss 2000	Pot. emiss 2005
REGULATED HALOCARBONS															
CFC-11	CCl_3F	3500	1.00	Y	60	2	0	78	20	5990	2885	2	0	0	0
CFC-12	CCl_2F_2	7300	1.00	Y	130	3.3	0	80	17	5830	3335	3	0	0	0
CFC-13	CF_3Cl		1.00	A	400										
CFC-14		-			100000										
CFC-111	$CFCl_2CCl_3$		1.00	A											
CFC-112	$CFCl_2CFCl_2$		1.00	A											
CFC-113	$CClF_2CCl_2F$	4200	0.80	Y	90		15	85		1190	920	40	0	0	0
CFC-114	$CClF_2CClF_2$	6900	1.00	Y	200										
CFC-115	$CClF_2CF_3$	6900	0.60	Y	400					40	30	0	0	0	0
CFC-116				Y	1000										
	TOTAL CFCs									13050	7170	45	0	0	0
Halon-1211	CF_2BrCl		3.00	Y	25					225	150	0	0	0	0
Halon-1301	$CBrF_3$	5800	10.00	Y	110					220	150	0	0	0	0
Halon-2402	$C2F_4Br_2$		6.00	Y	28										
	TOTAL HALONS									445	300	0	0	0	0
HC-10	CCl_4	1300	1.00	A	50					1,000	1,000	150	0	0	0
HC-140a	$C2H_3Cl_3$	100	0.11	A	6.3					6,400	6,400	4,400	?	1,920	0
	TOTAL OTHERS									7,400	7,400	4,595	?	1,920	0
ALTERNATIVE HALOCARBONS															
HFC-125	CHF_2CF_3	2500			28.1										
HFC-134a	CF_3CH_2F	1200	0.00		15.5										
HFC-141b					7.8										
HFC-142b					19.1					*** 0	1,600	2,000	?	?	?
HFC-143a		2900	0.00		41										
HFC-152a	CHF_2CH_3	140	0.00		1.7										
HCFC-22	$CHClF_2$	1500	0.05		15										
HCFC-123	CF_3CHCl_2	85	0.02		1.6										
HCFC-124	$CHClFCF_3$	430	0.02		6.6					*** 0	4,800	5,900	?	?	?
HCFC-141b	CCl_2FCH_3	440	0.10		7.8										
HCFC-142b	$CClF_2CH_3$	1600	0.06		19.1										
	TOTAL HFCs/HCFCs									0	6,400	7,900	?	?	?

* Inclusion in Montreal Protocol: Y=yes, A=added in 1990.
** Global Warming Potentials (with time horizon of 100 yr)
*** Consumption in 1986 assumed to be negligable

Sources: VROM, 1990b (ODP); IPCC, 1990a (GWP), Den Elzen et al., 1990 (life times)

APPENDIX 13

Appendix 13: Phase out schedule of halocarbon consumption in the Netherlands

Applications form end-use category	Halo-carbon	Emiss. delay (year)	Stored quant. (kton)	Consumption 1986 (ton)	Consumption 1990 (ton)	1992 (ton)	1994 (ton)	1995 (ton)	1998 * (ton)	2000 (ton)
AEROSOLS/STERILIZATION			-	< 4,700	<2,600	951	6	6	0	0
- dispenser										
. technical, medical	11,12	<1		0	700	50	5	5	0	0
. other purpose	11,12	<1		< 4,600	<1,800	900	0	0	0	0
- sterilization gas	12	<1		100	100	1	1	1	0	0
COOLING			5-6	800	600	150	60	0	0	0
- refrigerators **	12	12								
. hemeticly closed	11,12,115	4		640	480	120	50	0	0	0
. non-hermeticly cl.	11	4		160	120	30	10	0	0	0
- air-conditioners										
FOAMS			50	6,360	5,100	3,050	300	0	0	0
- open cell (soft foam)		<1		930	n.a.	400	150	0	0	0
- closed cell (PUR) for:										
. insulation		10		2,710	n.a.	2,450	150	0	0	0
. other purposes		10		1,720	n.a.	200	0	0	0	0
- other foams		<1		1,000	n.a.	0	0	0	0	0
SOLVENTS			-	1,400	1,080	480	200	50	0	0
- electronics	113	<1		500	350	150	50	0	0	0
- degreasing	113	<1		500	350	150	50	30	0	0
- dry cleaning	113	<1		100	80	80	50	20	0	0
- other purposes	113	<1		300	300	100	50	0	0	0
SUBTOTAL CFCs				13,260	9,380	4,631	566	56	0	0
FIRE EXTINGUISHERS ***			(10)	3	445	300	100	10	0	0
- type #1	1201			225	150	10	0	0	0	0
- type #2	1301			220	150	90	10	0	0	0
SUBTOTAL HALONS				445	300	100	10	0	0	0
TOTAL HALOCARBONS			58-59	13,705	9,680	4,731	576	56	0	0
Carbon tetrachloride	10				1,000	500		150	0	0
Methylchloroform	140a				6,400	6,400		4,400	****	1,920

* Targets for 1998 and further according to proposal of the CEC for modification of EC regulation 3322/88
** Division derived from Table of 5.6
*** Currently about 10% of the consumption rate is released annually
**** Phase out in 2005

Source: VROM, 1990b; VROM, 1989b; Sprong, 1991

Appendix 14: Emissions of carbon monoxide in the Netherlands in 1988.

Source	Sector	Total emission (kton/yr) subsector	(kton/yr) sector
COMBUSTION * :	ENERGY SECTOR		4.4
	- refineries	2.8	
	- power plants	1.6	
	INDUSTRY		153.1
	- chemical industry	7.1	
	- basic metal industry	138.0	
	- wood industry	p.m.	
	- others	8.0	
	COMMERCIAL		3.4
	- commercial	3.4	
	RESIDENTIAL		79.0
	- total households (fossil fuels)	29.0	
	- fuelwood in wood stoves and masonry fires	50.0	
	TRANSPORTATION		745.0
	- passenger cars	581.0	
	- road-freight and other pass.	142.0	
	- rail, water, air ***	22.0	
	SUBTOTAL COMBUSTION	985	985
PROCESS EMISSIONS ** :	ENERGY SECTOR		1.6
	- refineries ****		
	- power plants	1.6	
	INDUSTRY		126.0
	- chemical industry	18.0	
	- basic metal industry	81.0	
	- others	27.0	
	COMMERCIAL		1.7
	- total commercial	1.7	
	SUBTOTAL PROCESS EMISSIONS	129	129
	TOTAL COMB. AND PROC. EMISSIONS	1114	1114

* Data of 1988
** Data of 1986
*** Excluding bunkers
**** Including oil and gas production

Source: CBS, 1990d; CBS, 1990e; Okken, 1982 (fuelwood)

APPENDIX 15

Appendix 15: Sectoral VOC and NO_x emissions in the Netherlands in 1988

Source /sector	VOC emissions (kton/yr) subsector	VOC emissions (kton/yr) sector	NO_x emissions (kton/yr) subsector	NO_x emissions (kton/yr) sector
NATURAL EMISSIONS		15		n.a.
TRANSPORTATION (surface)		202		345
passenger cars, gasoline	113		128	
passenger cars, diesel	7		15	
passenger cars, LPG	15		23	
mopeds, motor bikes	14		|	
other road transport	49		|-> 134	
other transport (excl. bunkers)	4		45	
PROCESS EMISSIONS (excl. agriculture)		225		24
industry	94		24	
others	15			
miscellaneous *	116			
STATIONARY COMBUSTION SOURCES		24		191
refineries	1		20	
power plants	0		88	
industry	5		44	
commercials	8		20	
residentials	10		19	
AGRICULTURE		24		n.a.
TOTAL **		490		560

* Solvent evaporation from paints etc.; the figure of 116 kton is derived from the total anthropogenic process emissions figure of 225 kton for 1985
** Excluding international water and air transport

sources: VROM, 1989c (natural, miscellaneous and agriculture 1985 figures);CBS, 1990c (process emissions from industry and others);CBS, 1990d

Appendix 16: Sectoral process emissions of VOC in the Netherlands according to "KWS 2000" (in kton /yr)

Sector/ emission source	Historic emission: 1981	1985	1988 ***	Projected emissions for 2000: Auto-nomous	Certain reduct.	Condit. reduct.	Uncert. reduct.
- ENERGY SECTOR	33.7	32.7	32	29	23	8	8
Petroleum industry	21.1	21.1	20	18	13	6	6
Storage, transfer and handling	12.6	11.6	11	11	10	2	2
- INDUSTRY	142.4	125.0	124	120	101	74	61
Chemical ind.	38.0	28.0	27	25	16	16	12
Metal ind.	33.5	33.5	34	34	28	15	15
Painting ind.	37.7	32.0	32	32	28	17	16
Printing ind.	13.1	12.3	12	12	10	10	4
Food ind.	6.6	6.2	6	6	6	6	4
Rubber, PVC, synth.	4.3	4.3	4	5	4	3	3
Textile ind.	1.5	1.0	1	1	1	0	0
Leather ind.	1.0	1.0	1	1	n.a.	n.a.	n.a.
Other ind.	6.7	6.7	7	6	7	6	6
- COMMERCIAL	23.1	25.2	25	25	25	19	15
Car-repair enterprises	8.3	11.0	12	14	14	9	5
Wood preservers	7.6	7.6	8	8	n.a.	n.a.	8
Rustproofing/Undercoating	2.0	2.0	2	2	n.a.	n.a.	1
Furniture and carpentry	2.0	1.4	2	2	n.a.	n.a.	n.a.
Dry cleaning	3.0	3.0	1	1	n.a.	n.a.	n.a.
Deconservation of cars	0.2	0.2	0	0	n.a.	n.a.	n.a.
- RESIDENTIAL (households)	30.7	31.7	32	30	30	23	16
- TRANSPORTATION	10.0	10.0	10	10	10	6	2
Gasoline service station	10.0	10.0	10	10	10	6	2
- AGRICULTURE **	24	24	24	20	20*	20*	20*
Manure fermentation	10	10	10	7	n.a.	n.a.	n.a.
Pesticides/herbicides	14	14	14	13	n.a.	n.a.	n.a.
TOTAL:	264	249	247	233	208	149	121

* Provisional first order estimate.
** Not included in the KWS 2000 policy measures.
*** Figures for 1988 are interpolations of 1985 and 2000.
Remark Acc. to Annual Report 1990 of KWS 2000: the total process emissions in 1990 are 214 kton and in 1988 (interpolation 1985 and 1990) are 220 kton.

source: VROM, 1989a; VROM, 1989c; CBS,1990e; CBS,1990d