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COST-EFFECTIVENESS OF NON-CO_2-GREENHOUSE GAS EMISSION REDUCTION MEASURES IMPLEMENTED IN THE PERIOD 1990-2003

-FINAL-

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Summary

Several measures were implemented to reduce the emissions of non-CO_2 greenhouse gases (NCG gases) in the Netherlands over the period 1990-2003. This report analyses the cost-effectiveness of these measures and provides an overview of the factors that influenced the implementation.

Implemented measures reduced non-CO_2-greenhouse gas emissions with approximately 11 million ton of CO_2-eq in 2003.

Measures implemented in the period 1990-2003 resulted in emission reductions of approximately 11 Mton in 2003 compared to the reference situation. This means that without the implementation of these measures emissions of non-CO_2 greenhouse gases in 2003 would have been 51 Mton instead of 40 Mton of CO_2-eq.

Largest reductions were achieved with (see figure S.1):

- The emissions of HFC-23 through the implementation of an after burner with the manufacturer of HCFC-22,
- The emissions of PFC through the modernisation of the production sites with both aluminium producers in the Netherlands,
- The emissions of CH_4 through the implementation of several reduction measures with the oil and gas industry,
- The emissions of CH_4 through the collection, and utilisation of landfill gas at waste dumping sites.

A mix of policies drove implementation of reduction measures.

Large part of the reductions was primarily driven by government policies already in place before specific climate change policies were introduced in the late nineties. These policies were at that time not introduced with the specific aim to reduce the emissions of non-CO_2 greenhouse gases.

The policies include:

- Environmental permit requirements for the producers of HCFC-222 and aluminium to limit emissions of fluoride and other pollutants, resulting in reductions of HFC and PFC emissions.
- Voluntary agreements with the oil, gas and the aluminium industry to improve their energy efficiency, resulting in reductions of CH_4 and PFC emissions.
- Dumping regulations to reduce emissions of methane from landfill site, which were introduced to reduce local safety hazards from the potential build up and explosion of methane as well as odours associated with landfill sites.
- Introduction of good housekeeping measures with the cooling sector to reduce emissions of substances regulated under the Montreal Protocol (CFCs), which also contributed to reductions of HFC emissions.

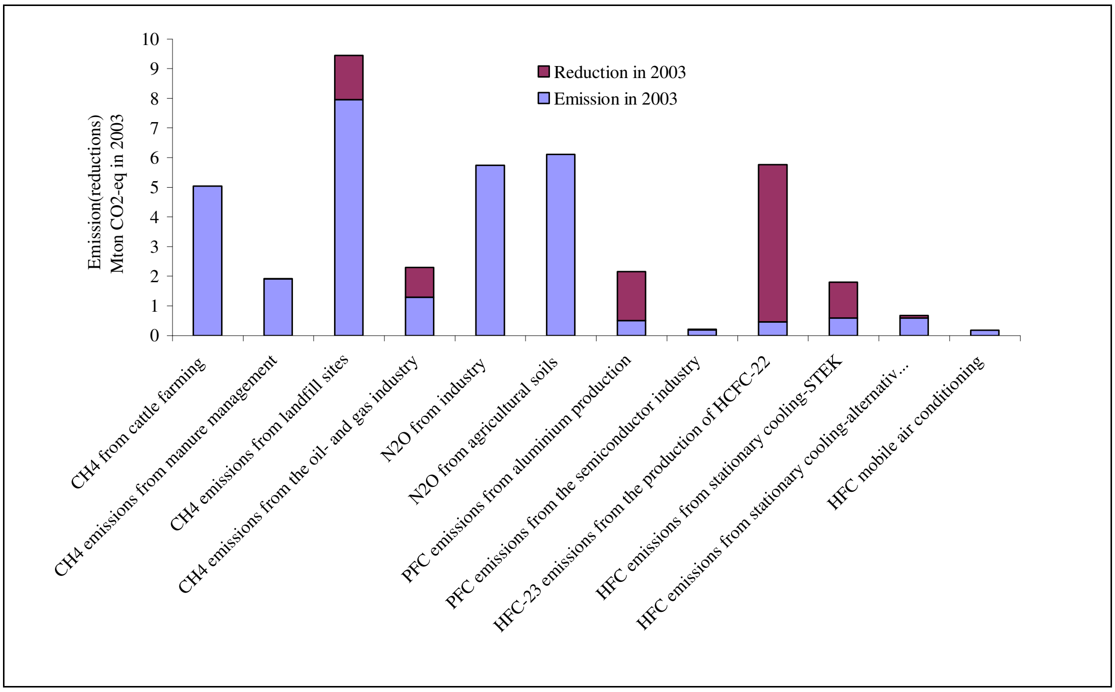

Figure S.1 Emissions and achieved reductions through the implementation of reduction measures at the end of 2003.

With the publication of the Climate Change Action Plan in 1999, which held the policies for The Netherlands to achieve its Kyoto targets, the Reduction Plan on non-CO_2 greenhouse gases started. This plan aims to speed up the implementation of measures to reduce the emissions of non-CO_2 greenhouse gases. For this aim it works amongst others on (i) enforcing the effectiveness of instruments already in place (e.g. with the producer of HCFC-22 and the aluminium industry), (ii) removing barriers for the implementation of reduction measures (e.g. with respect to rules for co-digestion) and (iii) raising awareness and increasing knowledge on reduction measures.

It can be concluded that most reductions (over 80% of total reductions) were mainly driven by policies already in place before the Kyoto target was set, and which were reinforced with the introduction of the Reduction Plan on non-CO_2 greenhouse gases. Roughly 20% of achieved reductions in 2003 can be attributed to this specific Plan.

Over 90% of the reductions were achieved against costs below 5 euro per ton reduced CO_2-eq for the society as whole.
Total investments related to the implemented reduction measures were estimated to be at least 150 million euro. Over 30% of the investments were made by the aluminium industry and another 30% of the investments went to landfill gas projects. For the society as a whole the bulk of implemented reduction measures were achieved against national costs below 5 euro per ton of reduced CO_2-eq.

Government expenditures amount to approximately 40 million euro in the period 1990-2003.
Total government expenditure in the period 1990-2003 is estimated at almost 37-44 million euro. Figure S2 provides an overview of the split-up of the government expenditures for the period 1990-2003 over the different government instruments and over the different sectors.

- Approximately 70% of the budget went to investment support in reduction measures, whereas 30% was used to finance all kind of activities to initiate, stimulate and/or facilitate the implementation of reduction measures (this is the chart pie 'ROB other activities' in Figure S2).
- More than 40% of the government expenditure went to support implementation of reduction measures at landfill sites. Most of these costs were made in the beginning of the '90. This is also the sector with the second largest reductions achieved over the period 1990-2003.
- Almost 17% of the government expenditures were spent to support the market transition to natural cooling agents, which so far led to limited reductions.

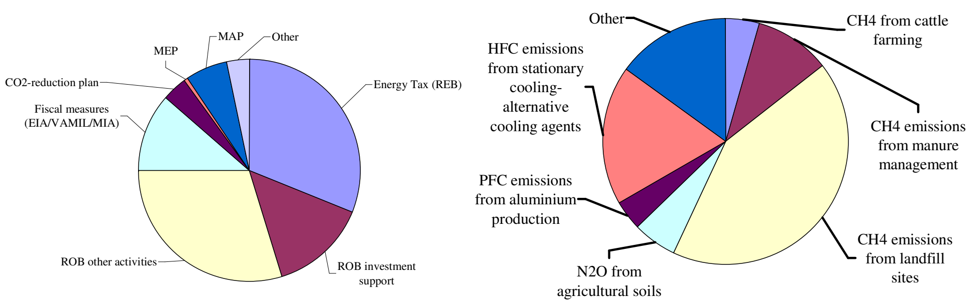

Figure S2 Split of government expenditures over different government programmes (left) and emission sources (right)

Overall cost effectiveness for the government ranges from 0.5 to 1.7 euro per ton of reduced CO_2-eq.

The overall cost-effectiveness for government expenditures ranges from 0.5 to 1.7 euro per ton of CO_2-eq. The lower limit (gross cost-effectiveness) represents the situation in which it is assumed that all reduction measures result from the implementation of policy instruments (i.e. no measure would have been implemented if no policy measure would have been in place). Whereas the upper limit (net cost-effectiveness) represents the situation in which the effects are corrected for 'autonomous' developments (i.e. the effectiveness of policies was taken into account and an estimate was made of the reductions that also would have been realised in the absence of policies).

Both implemented government policies and threat of new policies were most important drivers for the implementation of reduction measures…

Government policies were the most important driver for the implementation of reduction measures in the period 1990-2003 in The Netherlands. With the exception of the aluminium industry, measures to reduce emissions of non-CO_2 greenhouse gases are not profitable and would most likely not have been implemented in the absence of government policies. Examples from other countries show that also the threat of government policies, e.g. in the cooling and foam sector, already drove sectors to implement reduction measures. Government policies will also have to play a crucial role in achieving further reductions in coming years. In this case it is important to keep in mind that government policies often have long lead times before their effect is visible in decreasing emissions on the national level. This is also the reason that the effect of new policies initiated under the reduction plan for non-CO_2 greenhouse gas emissions is up to now only partly visible in reductions on a national level because time has been to short for the policies to fully result in actual implemented reduction measures.

…but lack of clear policies on the other hand was also an important barrier.

On the other hand the lack of clear policies was an important barrier for the implementation of reduction measures. Co-digestion of manure in the Netherlands was e.g. hampered by lack of clear policies on the use of the remains from the co-digestion process (which was recently solved with the publication of the white list) and long lead-time for obtaining permits. In countries with clear policies like Denmark and Germany market implementation is significantly higher.

Dutch government could speed up reductions of HFC in the cooling and foam sector.

The Dutch government could speed up the implementation of alternative refrigerants (like CO_2 and ammonia) and alternative blowing agents. The use of alternatives is now a proven technology and examples in others countries show that setting clear targets and policies speeds up the implementation of these options. Because of lack of good monitoring data in the Netherlands and abroad this can however not be quantified.

The concept of cost-effectiveness is a useful tool for the macro government level but has its limitations for application on the meso/micro company level.

- The concept of cost-effectiveness is a useful tool in the hands of the government to evaluate ex-ante and ex-post the efficiency and effectiveness of her own policies and make comparisons across sectors and gases in order to set priorities in her climate change policies.
- The concept of cost-effectiveness is however far more difficult to apply in discussions between the government and individual companies because companies often use of much broader definition of involved costs and benefits which can lead to a completely different picture on the cost-effectiveness of reduction measures. Measures that seem cost-effective from an end-users point of view are not implemented automatically because they have to be weighed against other investments (which may be more profitable for the company) or may be hampered by other barriers. This means that discussion on the company level will have to focus on the complete implementation context and not just on the 'bare' cost-effectiveness.

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Table of contents

1 Introduction

1.1 Background

Several measures were implemented to reduce the emissions of non-CO_2 greenhouse gases (NCG gases) in the period 1990-2003. Amongst others the Dutch government introduced the Reduction Programme non-CO_2 greenhouse gases (ROB) by the end of 1999, which aims to promote and facilitate the implementation of non-CO_2 greenhouse gas emission reduction measures (SenterNovem, 2004a)[1]. The Dutch government therefore wants an updated overview on the effects, total costs and cost-effectiveness of implemented non-CO_2-greenhouse emission reduction measures. Also more insight was needed into factors that influenced and in the future will influence the implementation, costs and cost-effectiveness of these measures. Focus of the research was on the implementation context of measures in The Netherlands. This context is illustrated and completed with relevant cases from other countries.

1.2 Objectives

The project has two main objectives:

1. To provide an overview of developments in total costs, avoided emissions and cost-effectiveness of measures taken in the Netherlands to reduce emissions of non-CO_2 greenhouse gases.
2. To provide an overview on the "lessons learnt" with respect to the cost-effectiveness of implemented non-CO_2 greenhouse gas emission reduction measures.

1.3 Research questions

Three clusters of research questions are distinguished:

1. Developments in the cost-effectiveness of implemented non-CO_2 greenhouse gas emission reduction measures in the Netherlands.
    a. What are the total costs, the avoided emissions and the cost-effectiveness of implemented non-CO_2-greenhouse gas emission reduction measures in the Netherlands?
    b. What are the differences between the cost-effectiveness, total costs and total reductions of these measures as forecasted in the Option document

[1] SenterNovem (2004a) www.robklimaat.nl 30 August 04

(ECN/RIVM, 1998)[2] and the cost-effectiveness, total costs and total reductions of measures that have actually been implemented in the last couple of years?

    c. Which developments can be observed in the cost-effectiveness of implemented emission reduction measures over time, and which factors are mainly responsible for changes in the cost-effectiveness?

2. Comparison of the Dutch situation with foreign efforts to reduce the emissions of non-CO_2-greenhouse gases.
    a. Which data on the cost-effectiveness of implemented non-CO_2-greenhouse gas emission reduction measures are available from other countries, and which information on factors influencing the cost-effectiveness?
    b. In which way do efforts in these other countries relate to the Dutch situation? Is it possible to provide a ranking in terms of costs and measures?
    c. Can significant differences in the implementation degree of non-CO_2-greenhouse emission reduction measures between countries or regions be explained by differences in the cost-effectiveness? Which factors next to cost-effectiveness play a dominant role?
3. Indicators to ‘measure’ efforts in the field of non-CO_2 greenhouse gases.
    a. Which other indicators, next to costs and reductions, can ‘measure’ the efforts in the field of non-CO_2 greenhouse gases?
    b. Which significant differences between countries, emission reduction measures and/or sectors are revealed through these indicators?
    c. Which conclusions can be drawn from the observed differences in efforts in the field of non-CO_2 greenhouse gases and do the observed differences lead to concrete recommendations to improve the cost-effectiveness of emission reduction measures and speed-up the implementation?

1.4 Structure of the report

Chapter 2 starts with defining the research boundaries for the project and furthermore sets the theoretical framework for the implementation context of non-CO_2 greenhouse gas reduction measures. Chapter 3, 4 and 5 deal with the implementation context of CH_4, N_2O and F-gases respectively. Chapter 6 provides an overall picture on effect, cost and cost-effectiveness and holds the conclusions and an overview of lessons learnt that may help to speed up the implementation of reduction measures in the Netherlands and abroad.

The annex includes a detailed overview of all the information that was gathered for the analysis of the implementation context. This annex also holds the reference to

[2] ECN/RIVM (1998). Options to reduce the emissions of greenhouse gases (Optiedocument voor emissiereductie van broeikasgassen). ECN/RIVM, October 1999.

all used information sources and assumptions made for the calculations. A summary of the information in this annex is included in Chapter 3, 4 and 5. This means that no reference to used sources is made in these chapters.

2 Project boundaries, theoretical framework and practical approach

2.1 Introduction

This chaper starts with clearly setting the boundaries for the projects. Implying that an overview of sources and countries that are included in the analysis is provided. Futhermore a general framework is provided to analyse the different factors influencing the implementaion of reduction measures. Finally this chapter provides an overview of the used definitions for effects and costs.

2.2 Selection of emission sources and emission reduction measures

The aim of the project is to map out

1. The current implementation and realised cost effectiveness of non-CO_2 emission reduction measures, and
2. The efforts in the field of non-CO_2 greenhouse gases.

We focussed on the following two types of emission sources and associated reduction measures:

- Emission sources for which relatively large reductions were achieved in the last couple of years in the Netherlands, through the implementation of technical measures.
- Emissions sources that got much attention from stakeholders (Dutch government, industry, consumers etc) as they put in relatively great efforts to establish concrete policies and actions to stimulate the implementation of emission reduction measures.

These selection criteria resulted in the following list of emissions sources for which implemented reduction measures will be evaluated:

- CH_4 emissions from manure management
- CH_4 emissions from landfill sites
- CH_4 emissions from the oil- and gas industry
- PFC emissions from aluminium production
- PFC emissions from the semiconductor industry
- SF_6 emissions from the electricity sector
- HFC-23 emissions from the production of HCFC22
- HFC emissions from the production and use of foams
- HFC emissions from stationary cooling

Next to this we also assessed the developments in the emissions of N_2O, CH_4 and HFC resulting from policies aimed at reducing the volume of the livestock or the amount of waste.

2.3 Selection of countries

In the international comparison Dutch 'efforts' in the field of non-CO_2-greenhouse policies will be compared to 'efforts' in other countries. The majority of countries have not yet developed specific non-CO_2-greenhouse gas policies and 'efforts' of most stakeholders are limited. This does not imply that emissions of non-CO_2-greenhouse gases did not decrease. Reductions realised so far however do mostly not result from specific non-CO_2-greenhouse gas policies but from other policies (like manure policies and waste policies). Within this project developments in other countries will be used to illustrate how reduction of non-CO_2 greenhouse gas emissions could probably develop in the Netherlands. For these illustrations we focussed on active EU-countries.

2.4 Implementation context of non-CO_2-GHG emission reduction measures

The market implementation of measures to reduce the emissions of non-CO_2 greenhouse gases is influenced by a large number of factors. We have categorised these measures into three clusters:

1. Government policies / regulations
2. Structural characteristics of the sector
3. Feasibility of the measure on the (company) level

These factors and their mutual relationship are outlined in Figure 1. The figure shows that in theory there are a large number of cause-impact relationships between the different clusters and the market implementation of reduction measures (defined in cluster 4). Within this section we first described the cause-impact relationships and next translated the framework to concrete indicators and factors explaining (potential) market implementation with the specific emission sources considered in this project. To achieve this aim each group of factors affecting the (potential) market implementation included in Figure 1 was unravelled to different indicators and factors explaining the market implementation of reduction measures with specific emission sources (or the absence of market implementation).

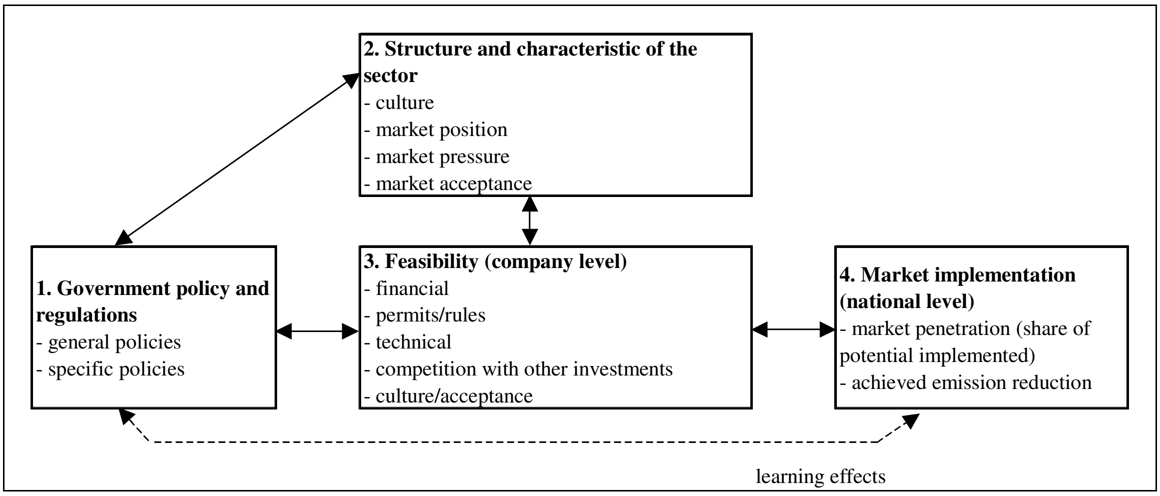

Figure 1 Outline of the implementing framework of non-CO_2-GHG emission reduction measures

<u>*Cluster 1 Government policies and regulations*</u>

The feasibility on a company level is affected by generic and specific government policies and regulations; financially (e.g. though government support), permit wise (e.g. through government regulations regarding permits in order to be able to operate an installation or does the implementations of non-CO_2 greenhouse gases conflict with local permits), technically (e.g. through grants for R&D or technical setting standard, which stimulated research into technologies), cultural acceptance (e.g. by financing demonstration projects and information centres/campaigns). Government policies and regulations on the other hand can affect the structure of specific markets, like regulations regarding liberalisation of energy markets and agricultural policies. The regulations may result in changes in the room to invest in reduction measures and/or the power to innovate.

<u>*Cluster 2 Characteristics of the sector*</u>

Specific characteristics of a sector affect the feasibility and as a result the market implementation of a reduction measures as well. Limited progress might be expected for a non-CO_2-gas in a sector consisting of a large number of small conservative companies, with no room for investments or power to innovate. On the other hand, a much higher reduction of non-CO_2-gas emissions will be achieved for a small number of large international companies with good international contacts, room for investments, own funding for research and development and especially if they experience pressure from non-governmental organisations to limit their emissions.

<u>*Cluster 3 Feasibility on the company level*</u>

If an emission reduction measure is feasible on a company level market implementation on a national level will increase. Feasibility on the company level is determined by a number of factors such as

- Financial feasibility (does the investment meet internal criteria for this kind of investments),
- Permits/rules (e.g. is the investment necessary in order to obtain a permit and what is the time span to obtain required permits
- Technical (e.g. is the measure a proven technology, how does it affect the primary production process),
- Local constraints (e.g. room and safety).
- Competition with other investments (e.g. what are the constraints with respect to the investment budget companies must prioritise their expenses),
- Culture (e.g. is a sector innovative and at the forefront of technological developments or conservative and a late adapter of new technologies) and acceptance.

Government policies and regulations might be updated as a consequence of better feasibility on the company level. Next to this an improvement of the feasibility can lead to a further development of the technology market. As a result suppliers of the technique will increase and improve their supply. As a result the rate of return will improve and affect the feasibility of the measure positively.

Cluster 4: Market implementation
Government policies and regulations might be updated as a consequence of higher market penetration. Through higher market penetration the knowledge on the technique will be more easily available and more companies within the sector will implement the measure (learning effects) and the government might decide to adapt the type of policies it implemented.

Translation to indicators
The described general framework for the implementation context was translated to concrete indicators and factors explaining (potential) market implementation with the specific emission sources considered in this project. Table 1 provides an overview of the indicators and factors that were analysed for each of the emission sources. These factors were also investigated for the comparison of the situation in the Netherlands with other countries. The table distinguished between indictors and explaining factors that applies to all considered emissions sources and indicators and factors applying to specific sources.

Table 1 Overview of indicators and factors explaining market implementation of reduction measures for different emission sources

Emission source • (Reduction measure)	1. Government policies and regulations	2. Structure and characteristics of the sector	3. Feasibility	4. Market Implementation
All sources • All measures	• Specific policies in the field of non-CO_2-greenhouse gases[3] • Type of financial support and level of support • Environmental policies already in place before climate policies were implemented.	• Size and number of firms • International competition • Profitability of the sector (relating to room for investments) • Innovative character and environmental image of the sector	• Level of investment • Cost-effectiveness of the technique • Possibility to monitor and verify emission reductions.	• Implementation degree • Achieved emission reductions
CH_4 emissions from manure management: • Anaerobic co-digestion of manure	• Regulations regarding use of remains from co-digestion (fertiliser and sanitation regulations) • Procedure and requirements to obtain an environmental permit • Requirements for obtaining a building permit	• Availability of land to spread manure • Structure of the market for substrates to co-digest	• Image of the technique with the farming sector.	
CH_4 emissions from landfill sites: • Collection and utilisation of landfill gas	• Dumping regulations • Waste policies: separate waste collection.	• Ownership structure of dumping site		

[3] Are there e.g. separate targets and specific budgets for policies in the field of non-CO_2- greenhouse gases.

Emission source • (Reduction measure)	1. Government policies and regulations	2. Structure and characteristics of the sector	3. Feasibility	4. Market Implementation
CH_4 emissions from the oil- and gas industry:	• Environmental covenant • Safety regulations			
PFC emissions from aluminium production:	• Environmental covenant			
PFC emissions from the semiconductor industry		• International agreements within the sector to limit emissions.		
SF_6 emissions from the electricity sector	• Policies aimed at opening of energy markets (liberalisation)			
HFC-23 emissions from the production of HCFC-22	• Environmental permits			
HFC emissions from the production and use of foams	• Ban on the use of HCFC • Safety regulation with respect to use of blowing agents.	• Structure and supply of the market for HFCs.	• Requirements for foams in different applications	
HFC emissions from stationary cooling	• Safety regulation with respect to use of alternative cooling agents (like e.g. ammonia). • Regulation with respect to leakage of cooling agents from equipment	• Structure and supply of the market for HFCs.		

2.5 Reference situation

When mapping out the effects, costs and cost-effectiveness of emission reduction measures and government policies the choice of the reference situation is a crucial step. Within this project the reference situation was defined as the situation that would have occurred in the absence of policies aimed at reducing the emissions of non-CO_2-greenhouse gases since 1990 (for CH_4 and N_2O) or 1995 (for F-gases).

The two questions that had to be answered when determining the reference situation are:

1. Which technology would have been implemented in the absence of policies aimed at reducing the emissions of non-CO_2 greenhouse gases? Dutch guidelines for monitoring and evaluation state that the reference technology is 'the best available technique on the market' in case no environmental policies would have been in place (VROM, 2004)[4]. For each reduction measure we clearly described the assumptions made with respect to the applied reference technology.
2. Which part of the sector would have implemented the reference technology also if no policies aimed at reducing the emissions of non-CO_2 greenhouse gases would have been introduced? Not all reductions may be the result of implemented policy instruments, because part of the reductions may also have occurred in the absence of policies (e.g. because they are cost-effective). In principle this means that the effectiveness of policies has to be determined.

2.6 Calculations of achieved reductions

It goes beyond the scope of this study to make a detailed analysis of the effectiveness of policies aimed at reducing emissions of non-CO_2 greenhouse gases. We therefore applied a pragmatic two-step approach to determine the achieved emission reductions.

- In the first step we determined the 'gross' emission reduction potential. The 'gross' emission reductions are determined by subtracting emissions of the reference technology from the actual emissions. Emissions for the reference technology are calculated by taking the actual production levels in the years 1990 to 2003 (e.g. produced amount of aluminium or amount of waste dumped) and multiply this with the emission factor of the reference technology (e.g. PFC emissions per tonne of produced aluminium).
- In the second step we made a rough estimate of the 'net' emission reductions, by determining which part of the 'gross' emissions would also have been implemented in the absence of policies aimed at reducing non-CO_2 greenhouse gases. The 'net' emission reductions are the gross emission reductions minus

[4] VROM (2004) Assistance for monitoring and evaluation of climate policies (Handreiking voor monitoring en evaluatie van klimaatbeleid). Ministry of VROM, Den Haag, March, 2004.

autonomous emission reductions, which are reductions that also would have been realised in the absence of policies aimed at reducing the emissions of non-CO_2-greenhouse gases since 1990.

Throughout the whole report two numbers are presented:

- Annual gross and net reductions achieved in 2003 compared to the reference situation.
- Cumulated gross and net reductions over the period 1990-2003 (for N_2O and CH_4) or the period 1995-2003 (F-gases).

Figure 2 provides an outline on how the annual reductions and cumulative reductions are determined.

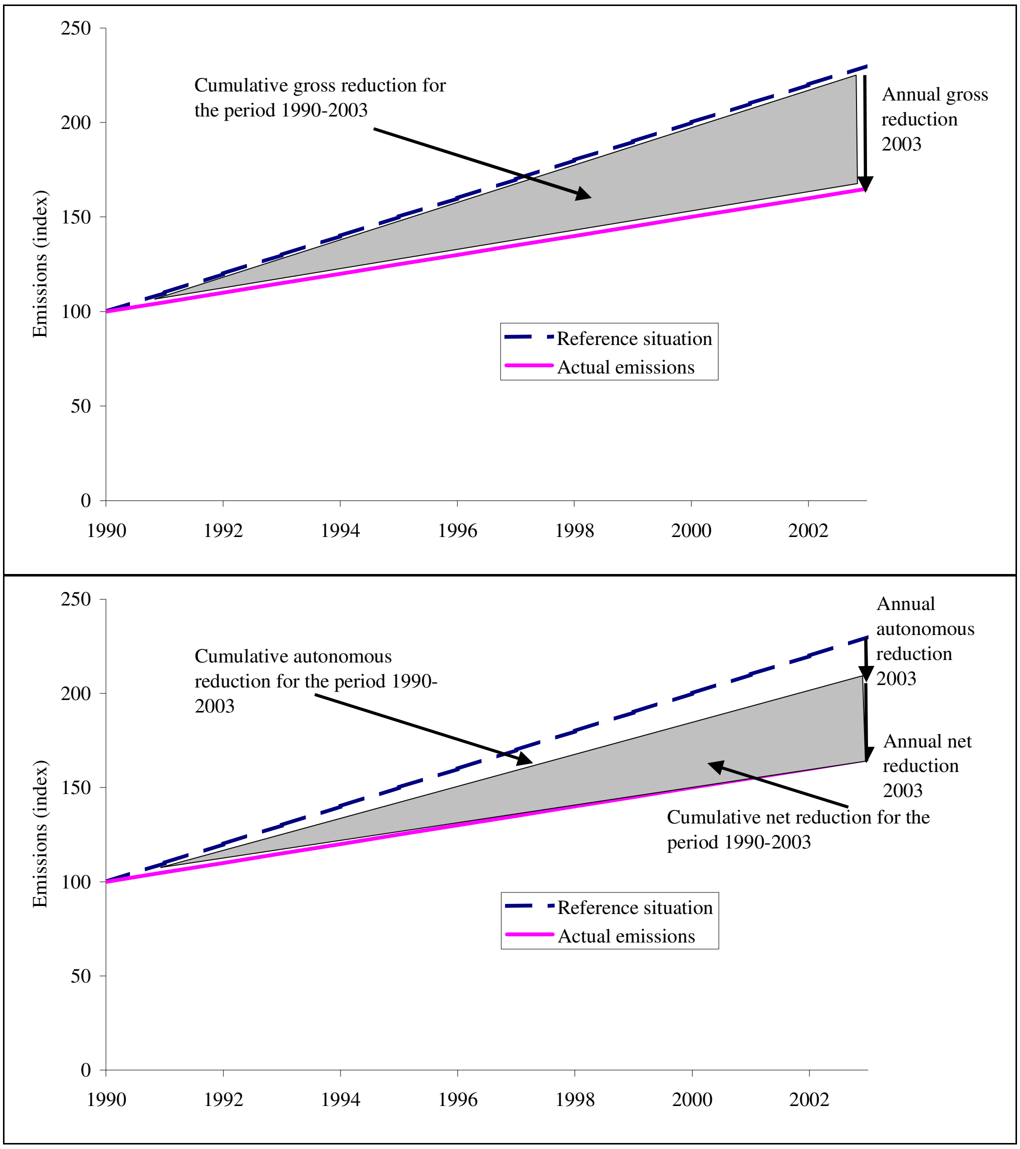

Figure 2 Outline of how annual reductions and the cumulative gross reductions are determined

2.7 Definitions of costs

A further aim of the study is to map out the costs related to the achieved reductions. This means that the additional costs have to be determined compared to the reference situation.

Within the framework of environment policy evaluation in the Netherlands three types of additional costs are distinguished (Vrom, 1998)[5].

- *End-user costs*. These costs provide an indication of the costs as the user that has implemented the reduction measures experiences them. In (Vrom, 1998) these costs are defined as all additional costs that have to be made by the end-user compared to the reference situation in case no environmental policies would have been in place. Additional costs include additional investments, staff-costs, overhead costs, energy costs (which are negative in case of savings) and transfers (e.g. paid taxes but also granted subsidies and fiscal profits).
- *National costs*. These are the costs as they are experienced by the society as a whole. In (Vrom, 1998) these costs are defined as all additional costs that have to be made by the society as a whole compared to the reference situation in case no environmental policies would have been in place. These include the same costs as mentioned for the end-user however excluding transfers, because the transfers for the society as a whole are a zero-sum-game.
- *Government expenditure*. These are all expenditures that have been made by the government, which can be related to the implementation of the reduction measures. Government expenditure includes budgets for subsidies and fiscal measures, grants for research and development, costs for monitoring and the administrative machinery.

Limitation to the definition of costs

The costs as defined in Vrom (1998) and used in official policy evaluations only take into account the direct 'out of pocket' costs. All kinds of indirect costs, which are in most cases more difficult to monetarise, such as costs for collecting information on the reduction measure and time-losses, are not taken into account. We have tried to capture these types of indirect costs in our analysis of implementation context in which we analysis a whole range of factors affecting the implementation degree.

2.8 Calculation of cost-effectiveness

In order to be able to make a comparison between the cost-effectiveness forecasted in the Option document (ECN/RIVM, 1998)[2] and the cost-effectiveness of meas-

[5] VROM (1998). Costs and benefits of environmental policies – Definitions and calculations methods (Kosten en baten van milieubeleid – Definities en berekeningemethoden). Publicatiereeks Milieustrategie1998/6, Ministry of Vrom, Den Haag, 1998.

ures implemented in the period 1990-2003 the same method was applied. Within this project we determined two types of costs-effectiveness:

(i) *National costs-effectiveness* (€/ton CO_2-eq). The national cost-effectiveness provides insight in the costs and benefits of implemented emission reduction measures for the society as a whole. The national cost method is mainly used to make reduction measures comparable. This cost-effectiveness is calculated by:
  a. Taking the gross additional investments of a reduction measure (additional compared to the reference situation) and depreciating these investments over 10 years (for installations and appliances) and 25 years (for measures connected to buildings) using an interest rate of 4%.
  b. (If applicable) reducing the capital costs found under point (i)a with the gross annual costs savings on energy or (raw) materials. Cost savings on energy are calculated using national shadow prices for energy. In these national shadow prices costs for one sector (e.g. taxes for private companies) cancel out the benefits for another sector (e.g. tax proceeds of government authorities).
  c. Taking the sum found under (i)b and divide by the gross reductions of non-CO_2 greenhouse gases due to the implementation of the emission reduction measures (the reductions compared to a reference situation).

(ii) *Gross cost-effectiveness for the government* (€/ton CO_2-eq). The cost-effectiveness for the government provides insight on the efficiency of the implemented government policies. Efficiency of policies refers to ratio between the costs for the government and the emission reduction achieved through the implementation of the instrument. The cost-effectiveness for the government is calculated by:
  a. Taking the total government expenditure and depreciate it over 10 years (for installations and appliances) and 25 years (for measures connected to buildings) using an interest rate of 4%. By depreciating the cost for the government the fact is taken into account that the government is profiting several years from her once-only spending.
  b. Taking the number found under (ii)a and divide by gross reductions of non-CO_2 greenhouse gases.

(iii) *Net cost-effectiveness for the government* (€/ton CO_2-eq). Next to the gross cost-effectiveness for the government, in chapter 6 we also made an estimate of the net cost-effectiveness for the government by making an estimate of which part of the gross reductions can be attributed to autonomous developments. The net cost-effectiveness is calculated by taking the number found under (ii)a and divide by net reductions of non-CO_2 greenhouse gases.

3 Analysis of the implementation context of CH_4 emissions

3.1 Introduction

This chapter provides an analysis of the developments in the emissions of CH_4 in the Netherlands and factors influencing the implementation of reduction measures. Detailed information on the implementation context per reduction measure is included in *Annex I*. This annex also holds an overview of the used assumptions and information sources. The following information is included in this chapter:

1. The trends in emission per source including an overview of factors influencing the emission level per source.
2. Achieved reductions, costs and cost-effectiveness of the reduction measure and an overview of the most important factors responsible for high or low market implementation.
3. Comparison of the implementation context in the Netherlands with the situation in other countries.
4. A comparison with the Option document (if applicable).

Figure 3 provides an overview of the development in emissions of CH_4 in the Netherlands in the period 1990-2003. The figure shows that CH_4 emissions have decreased by almost 30% over the period 1990-2003.

3.2 CH_4 emissions from enteric fermentation

Farm animals produce methane as a result of their incomplete digestion process. CH_4 emissions from enteric fermentation by farm animals have decreased by 25% over the period 1990-2003. These reductions result from a decrease in the amount of cattle, which diminished with 24% over the period 1990-2003 (CBS, 2004a)[6] (see Figure 4). Decrease of the cattle stock is mainly influenced by European policies being:

- Reform of the Common Agricultural Policies (CAP). Reform of the CAP resulted in e.g. milk quotas and less protection against competition from international markets (However the autonomous increase of the milk production per animal in combination with the decrease in the number of animals due to the introduction of the milk quotas resulted in an almost unchanged milk production)

[6] CBS (2004a) CBS Statline. Download October 5, 2004.

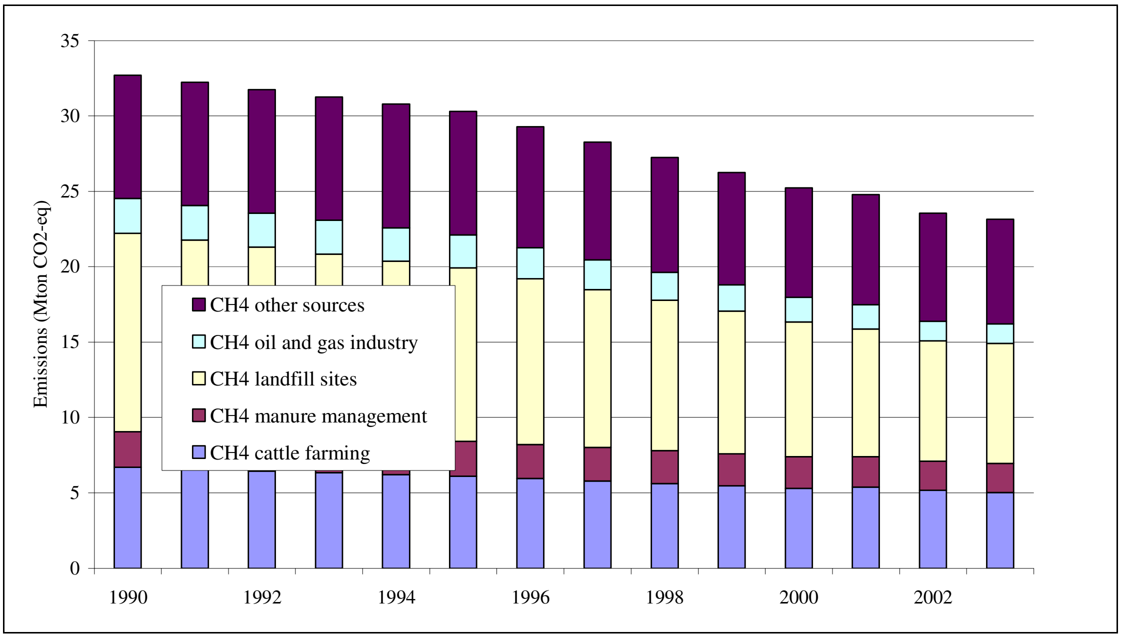

Figure 3 Development of emissions of methane in the period 1990-2003 for the selected sources (RIVM, 2004a)[7]

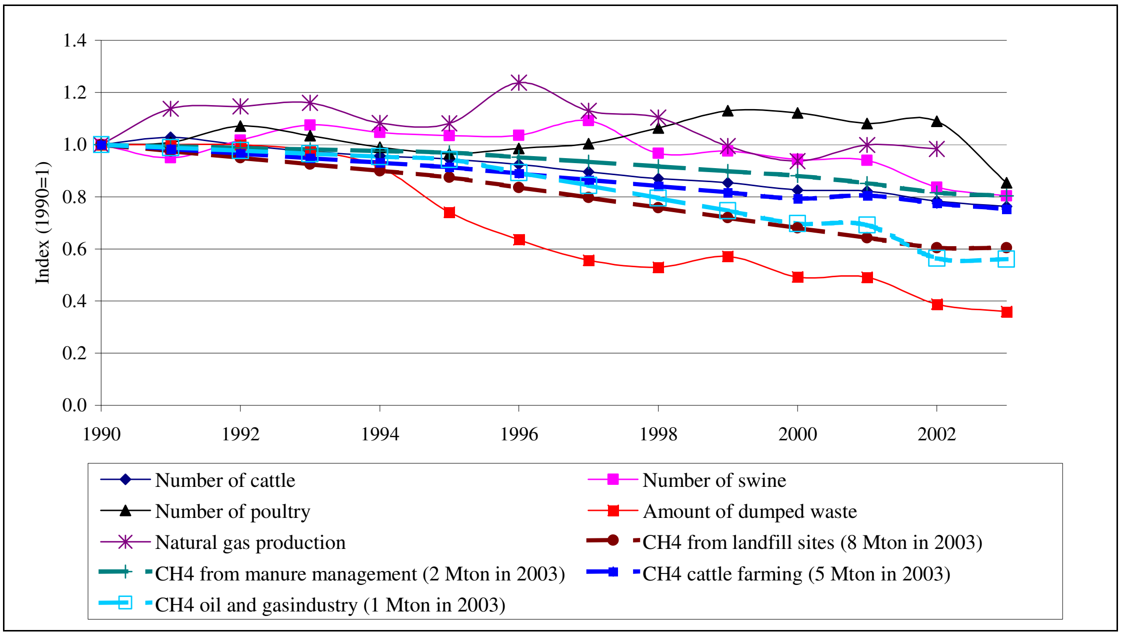

Figure 4 Development of methane emissions and different physical indicators for selected sources. Sources: emissions (RIVM, 2004a)[7] number of animals (CBS, 2004a)[6], waste (AOO/VVAV, 2004)[12], natural gas production (EZ, 2004)[13]

[7] RIVM (2004a). Data received from Emission Registration (ER), Kees Peek. Data 03 September 2004

- The Nitrogen Directive (91/676/EC) (EC, 1991)[8]. This Directive is aimed at gradual decline in excess nitrogen flushing to the ground water. Amongst others this resulted on the national level in (stricter) regulations with respect to application and storage of manure, and a decrease in the number of animals.

It must be noted that the inventory of CH_4 emission is surrounded by a lot of uncertainties, because a whole range of factors influences the emissions of enteric fermentation.

No reduction measures have been implemented to reduce the emissions of CH_4 per animal. In the last couple of years efforts in the Netherlands were mainly focussed on getting a better understanding of the actual volume of emissions from cattle farming and the reductions that can be achieved with specific measures like changes in diet. Efforts are still in the research phase, which is funded by the government (the ROB programme). The total government budget related to the research projects in the agricultural sector (CH_4 and N_2O) was approximately 3.4 million euro (SenterNovem, 2005a)[9].

3.3 CH_4 emissions from manure management

The way manure is handled and stored in stables determines the amount of produced and emitted CH_4. CH_4 emissions from manure management have decreased by almost 20% in the period 1990-2003. Decrease of emissions is closely linked to the decrease in the animal stock resulting in a decrease in the amount of produced manure. Figure 4 shows that the cattle stock dropped by 24%, the number of pigs with 20% and the amount of poultry with 15% (CBS, 2004a)[6]. The policy instruments that are already mentioned in section 3.2 mainly influenced the decrease in animal stock. Again it must be noted that the inventory of CH_4 emission is surrounded by a lot of uncertainties and does not yet take the effect of all implemented measures into account. E.g. the effect of capping of the manure storage site and the effect of shortening the storage period of manure is not yet taking into account in the national emission inventories.

So far the drop in emissions was primarily affected by a decrease in the number of animals. Implementation of anaerobic co-digestion of manure to reduce emissions started in the last couple of years but this is not yet visible in a drop of specific emissions (emissions per ton of produced manure) on the national scale. By using a bottom-up approach (calculation the emission reduction on a project by project basis) the achieved cumulative emission reductions amounted to approximately 0.02 Mton CO_2-eq in the period 1990-2003. These reductions resulted from the implementation of approximately 10 projects. Total investments in this period accumu-

[8] EC (1991) Directive 91/676/EC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources.
[9] SenterNovem (2005a). Information received by e-mail from Mr E. ter Avest from SenterNovem date januari 4, 2005.

lated to 4-4.5 million euro. National cost-effectiveness lies in the range of 60-80 euro/ton CO_2-eq.

In the Option document it was still assumed that almost no co-digestion would take place in the Netherlands, because of the strict sanitation rules in the Netherlands. It was assumed that instead only manure would be digested leading to a much lower methane production per ton of manure and significantly less profitable projects. It was furthermore assumed that the biogas would be used in a boiler instead of a co-generation plant.

Main government expenditure for anaerobic co-digestions included financial support for investments through the ROB, CO_2 reduction plan, EIA, VAMIL, MIA, EINP and MEP. Expenditure within the ROB programme is mainly aimed at reducing CH_4 emissions by shortening the storage period of manure, whereas the other instruments primarily approach this measures as an option to increase renewable energy production. Furthermore, the government supported several studies aimed at investigating the feasibility, barriers etc. The total estimated government expenditure in the period 1990-2003 amounts to 4 million euro[10], resulting in a cost-effectiveness ranging from 140-180 euro/ton CO_2-eq[11].

Market implementation in the Netherlands was until recently mainly hampered by strict policies and regulation with respect to use of the remains from co-digestion and long lead times to obtain environmental and building permits. With the publication of the 'positive list' of substances that may be co-digested an important barrier for further implementation is removed. Furthermore, with a pay back time of 6-10 years, investments do not always meet internal investments criteria.

Two countries with a much higher market implementation of anaerobic co-digestion of manure are Denmark and Germany. The implementation degree is 7% in Denmark and 18% in Germany respectively compared to 0.3% in the Netherlands. The countries are characterised by transparent rules with respect to the use of the remains from the co-digestion process. Next to this the investments are more profitable because of high government contribution (in Germany the Eneubare Energie Gesetz and in Denmark through relatively high investments subsidies) and e.g. additional benefits from the sale of heat and received compensation for the intake of waste in Denmark.

[10] This means that we attributed the government expenditure primarly meant to increase renewable product to the reduction of greenhouse gases.
[11] It must that for our calculations we also took into account government expenditures for projects that have not led to emissions reductions, such as feasibility studies and measurements and projects that are not yet in operation.

3.4 CH_4 emissions from landfill sites

In landfills anaerobic bacteria decompose the degradable organic fraction of solid waste. Main product of this decomposition, apart from water, is landfill gas composing of methane and carbon dioxide. CH_4 emissions from landfill sites dropped by almost 40% over the period 1990-2003. It can be noted that the amount of methane from landfill sites dropped at a slower pace (-40%) than the annual amount of land filled waste (-65%). This is caused by the fact that the amount of produced methane varies over time (increase in the first two years and a decrease in the next 20 years), as a result of which reductions of methane lag behind on the reductions of the amount of waste.

The decrease in emissions results from a combination of factors:

- The amount of waste that is disposed in landfills decreased by almost 65% over the period 1990-2003 (AOO/VVAV, 2004)[12]. The decrease results from environmental policies in the Netherlands aimed at minimising the disposal of waste in landfills (among others by increasing the tariffs for dumping) and to increase recycling and the incineration of waste.
- The composition of the dumped waste changed, resulting in a lower C-content and lower CH_4 emissions. The lower C-content results from environmental policies aimed at recycling and separate waste collection.
- The amount of CH_4 recovered from landfill sites increased, resulting from dumping regulations under which it is compulsory to implement reduction measures. The measures include covering the landfill site with an imperative layer and collect the methane. The collected methane is then either flared, used for energy production in a CHP unit or be upgraded to replace natural gas.

In the period 1990-2003 almost forty landfill sites were covered with an imperative layer and methane collection and utilisation equipment was installed. Total reductions at the end of 2003 are 1.5 Mton of CO_2-eq and in the period 1990-2003 the reductions accumulated to 17 Mton. Total investments relating to these reduction measures amounted to 35-55 million euro. These mainly include investments to cover the landfill site and install equipment to collect the gas for flaring or use the landfill gas for energy production. The national cost-effectiveness of the implemented measures lies in the range of 2-5 euro/ton CO_2-eq.

In the Option document the reduction measures implemented in the period 1990-2003 were already included in the baseline scenario. An additional potential was assumed for three types of measures to increase methane production and collection, which at the end of 2003 were however still in the demonstration phase. All additional measures include options to increase methane production at current landfill sites. These options are all still in the pilot phase and it is not clear if they will be

[12] AOO/VVAV (2004) Waste process in the Netherlands, data 2003 (Afvalverwerking in Nederland, gegevens 2003) AOO 2004-11, VA04001IR.R, July 2004

implemented on a large scale. Furthermore, room for investments in the waste sector is decreasing because the amount of dumped waste is dropping.

Government expenditures range from investments subsidies to studies and demonstration projects. Investments in measures to utilise the landfill gas for energy production were financially support by the government through the MAP, REB, MEP and the ROB. These amount to approximately 13-19 million euro in the period 1990-2003. Furthermore the government financially supported the foundation and maintenance of a landfill gas information centre, which according to the sector is one of the key success factors for the successful uptake of measures to reduce methane emissions. Within the framework of the ROB several demonstration projects were financially supported aimed at investigating the opportunities to further increase methane production. Cost-effectiveness for the government over the period 1990-2003 lies in the range of 1-2 euro per ton CO_2-eq.

Due to government regulation in most (Western) Northern European countries landfill gas is collected and utilised. Like the Netherlands the markets in Denmark, Sweden and Germany are (almost) saturated. Due to high pay back tariffs for electricity from landfill gas in Denmark there are many landfill gas collection and utilisation projects at relative small sites in this country.

3.5 CH_4 emissions from the oil- and gas-industry

In the production process of oil and natural gas the raw hydrocarbon feedstocks undergo several treatments. In these processing steps part of the methane is emitted to atmosphere. CH_4 emissions from the oil- and gas-industry dropped by 44% in the period 1990-2003 (RIVM, 2004)[7]. The emissions mainly derive from the production of natural gas. The production volume of natural gas hardly changed in the period 1990-2003 and furthermore a shift took place from production onshore to offshore (EZ, 2004)[13]. The specific emissions (CH_4 emissions per m^3 of natural gas produced) have decreased due to the implementation of reduction measures.

Reduction measures included a whole range of measures the most important being:

- Reduction of purge gas streams.
- Recovery and utilisation of process emissions as a fuel gas.
- Minimising of strip gas in glycol dehydration.

Total reductions achieved at the end of 2002 compared to the baseline is 1 Mton of CO_2-eq, total reductions achieved in the whole period 1990-2003 accumulate to 6.8 Mton. No figures are available on the total investments related to these reductions. We can however probably conclude that most reductions measures were (very)

[13] EZ (2004). Oil and gas in the Netherlands. Annual report 2003 and outlook 2004-2013. Ministry of Economic Affairs, The Hague, The Netherlands.

cost-effective, because voluntary reduction targets were exceeded. We therefore assumed that the total national costs are negative.

In the Option document it was assumed that large reductions would be achieved autonomously, because new drilling stations are put into operation and old ones are demolished (at the time of writing the Option document this was however not yet included in the reference scenario).

Reduction measures had to be implemented in order to comply with Dutch Emission Regulations for the oil and gas industry and to meet the targets set in the environmental covenant between the oil- and gas-industry and the Dutch government. Actions taken within the framework of the Reduction Plan on non-CO_2 greenhouse gases resulted in taking up measures specially aimed at reducing the emission of CH4 in the environmental agreement with the industry sector. The government did not support investments or studies on reduction measures in this sector. The government did however make costs to negotiate environmental agreements with this sector and monitor the agreement. Total costs for the government are estimated at 0.5 million euro (SenterNovem, 2005)[14].

Voluntary Approach policies forced companies to have a thorough look into reduction measures and led to investments in reduction measures at a much higher pace.

Compared to other countries the Netherlands achieved substantial reductions. Another important gas producer in Europe is the United Kingdom. Emissions in the United Kingdom have dropped, but not as substantially as in the Netherlands. Reductions measured were mainly aimed at minimising flaring, which were implemented because the government put a ceiling on the amount of gas each facility can flare each year.

3.6 CH_4 emissions from other sources

CH_4 emissions from other sources dropped by 15% over the period 1990-2003, this is mainly due to a reduction of the emissions associated with gas distribution by 17%. These reductions are mainly achieved as a result of the gradual replacement of old cast iron pipes by modern materials, which are part of regular replacement investments.

Within the Reduction Plan on non-CO_2 greenhouse gases (ROB) CH_4 emissions from gas engines were also examined. Research was aimed at getting a better understanding of the actual volume of CH_4 emissions from gas engines. However no reduction measures were implemented. Total costs for this research was 0.05 million euro.

[14] SenterNovem (2005). Oral information Mr ter Avest date 14 March 2005.

3.7 Overall picture CH_4 emissions

Table 2 provides an overall picture of realised cumulative reductions, costs and cost-effectiveness of measures to reduce emissions of CH_4 in the Netherlands in the period 1990-2003. Total reductions at the end of 2003 accumulated to ~2.5 Mton CO2-eq. The table shows that these were achieved by measures implemented with landfill sites and the oil and gas industry.

Measures within the waste sector mainly follow from government regulations regarding collection and utilisation of landfill gas that came into force in the beginning of the '90s. The government substantially supported these investments with tax exemption from the energy tax and grants within the Environmental Action Plan of the energy distribution companies. Measures with the oil- and gas industry were triggered by environmental and energy efficiency covenants as a result of which the sector investigated reduction options, which on average turned out to be very cost-effective.

Emission reductions in the agricultural sector are still lagging behind. Reduction options are still in the research phase (enteric fermentation by cattle) or are hampered by strict regulation with respect to use of the remains from co-digestion, long lead times to obtain environmental and building permits (anaerobic co-digestion of manure) and low profitability of investments. The government financially supported investments and research, but very limited reductions have been achieved up to now.

Table 2 Overall picture of realised (cumulative) gross reductions and costs to reduce emissions of CH_4 in the Netherlands in the period 1990-2003

Emission source	Reduction measure	Gross emission reductions in 2003	Cumulative gross emission reductions 1990-2003	Cumulative investments	Cumulative government expenditure	Gross cost-effect. for the government	National cost-effect.
		Mton CO_2-eq		Million euro		€/ton CO_2-eq	
CH_4 from cattle farming	N.A.	0	0	0	1.7[15]	N.A.	N.A.
CH_4 emissions from manure management	Anaerobic (co)-digestion of manure	0.01	0.02-0.03	4.5-5.0	3.8-4.1	140-180[16]	60-80
CH_4 emissions from landfill sites	Collection and utilisation landfill gas	1.5	17	35-55	13-19	1-2	2.-5
CH_4 emissions oil- and gas industry	Several measures	1.0	6.8[17]	Unknown	0.5	0	< 0
CH_4 from gas engines	N.A.	0	0	0	0.05	N.A.	N.A.
TOTAL		~2.5	~24	39-60 + pm	19-25		

Table 3 provides a comparison between the realised costs and effects and the exception in the Option document and the Climate Change Action Plan (CCAP). The table shows that main part of the reductions was stimulated by policies already in place before the CCAP was published (~ 2.5 Mton in 2003). Reduction measures that attracted specific attention since the publication of the CCAP (partly the co-digestion of manure and the more advanced techniques to increase landfill gas production) no substantial effects on the level of emissions are available yet.

[15] Total assignment budget of the government for research into reduction options for the agricultural sector was 3.4 million euro (SenterNovem, 2005a). It was assumed that 50% went to CH_4 and 50% went to N_2O options.
[16] It must that for our calculations we also took into account government expenditures for projects that have not led to emissions reductions, such as feasibility studies and measurements and projects, which are not yet in operation.
[17] These are the reductions in the period 1990-2002

Table 3 Comparison between realised costs and effects and expectation in the Option document.

Emission source • **Reduction measure**	**Comparison between realised and expected reductions and costs in the Option document and the climate change action plan (CCAP)**
CH_4 from cattle farming	Reduction measures for cattle were not included in the Option document and the CCAP.
CH_4 emissions from manure management • Anaerobic (co)-digestion of manure	Anaerobic co-digestion of manure and use of biogas in a CHP was not included in the Option document. It the Option document it was assumed that manure would not be co-digested and that the biogas only would be used in a boiler for heat production. Therefore the realised and expected costs and effects cannot be compared.
CH_4 emissions from landfill sites • Collection and utilisation landfill gas	The Option document only held options to further increase landfill gas production on top of the 'standard' techniques to collect and utilise landfill gas, which were already in place before the CCAP was published. The more advanced options were so far only implemented on a pilot scale, which makes it impossible to compare the effects and costs with the expectation in the Option document.
CH_4 emissions oil- and gas industry • Several measures	The Option document did not hold large reduction volumes for the oil- and gas industry as it was assumed that next to the measures implemented under policies already in place before the CCAP was published not much additional reduction potential would be available.
CH_4 from gas engines	This was not included in the Option document.

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4 Analysis of the implementation context of N_2O emissions

4.1 Introduction

This chapter provides an overview of the developments in emissions of N_2O in the Netherlands. As no reduction measures were implemented in the period 1990- 2002 we did not analyse the implementation context in detail as we did for the other sources, and we made no comparison with other countries.

Figure 5 provides an overview of the emissions of N_2O in the Netherlands in the period 1990-2003. The figure shows that N_2O emissions have decreased by 10% over the period 1990-2003.

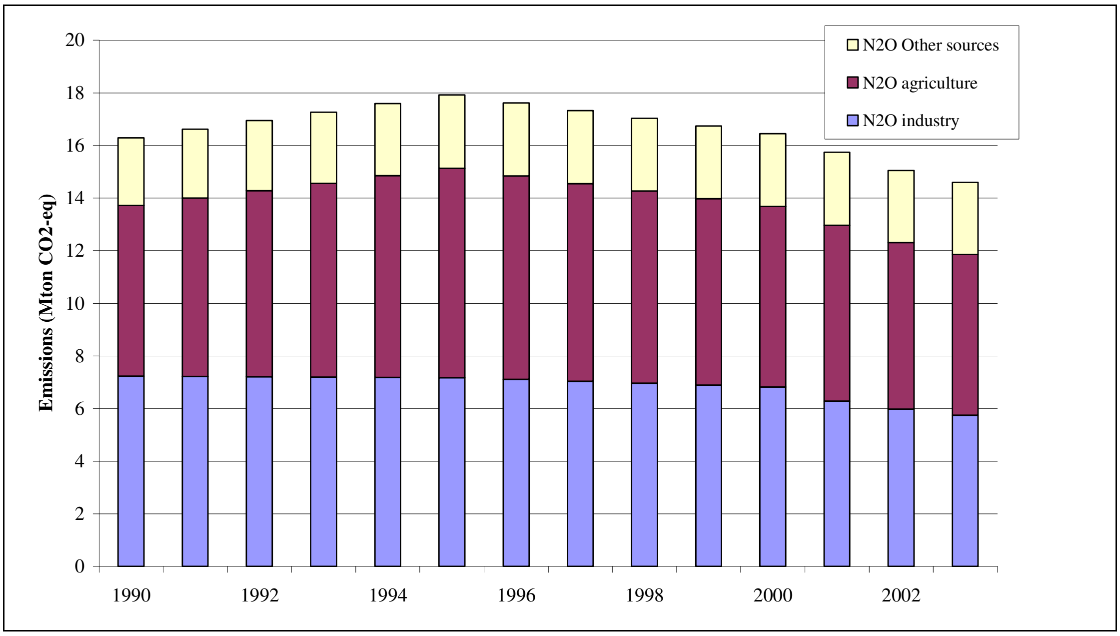

Figure 5 Development of emissions of N_2O in the period 1990-2003 for the selected sources (RIVM, 2004a)[7]

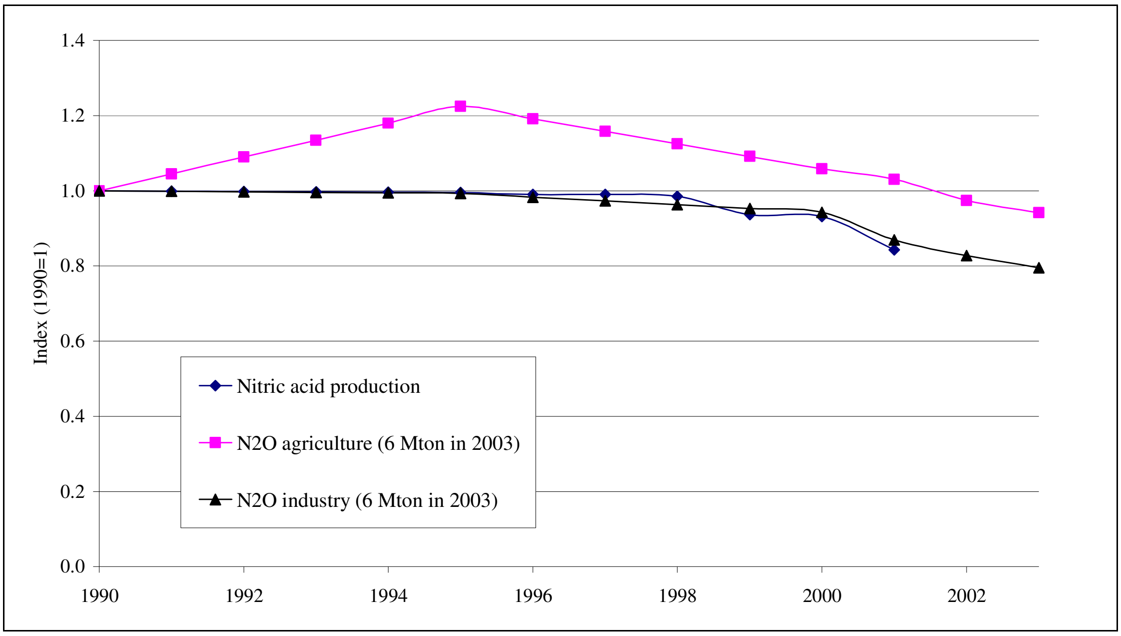

Figure 6 Development of N_2O emissions and one physical indicator for the selected sources. Sources: emissions (RIVM, 2004a)[7] nitric acid production (EEA, 2004)[18]

4.2 N_2O emissions from industry

N_2O emissions from industry mainly derive from the production of nitric acid (approximately 85%) and to a lesser extent from the production of caprolactam (approximately 15%). N_2O emissions from the chemical industry have dropped by 20% in the period 1990-2003. Reductions result from changes in production volume and are not due to the implementation of reduction measures (EEA, 2004)[18](see Figure 6). Possible reduction measures to reduce N_2O from nitric acid production (the application of a catalyst to remove N_2O from the tail gases) are still in the research phase and not yet implemented on a commercial production scale.

Within the framework of the ROB several projects were carried out to examine several technical options to reduce N_2O emissions from nitric acid production. These range from theoretical studies to testing options on the pilot scale. Total investments in these projects amounted to 2.7 million euro. The projects received financial support within the framework of the ROB for a total sum of 1.4 million euro.

[18] EEA (2004). EEA (2004). Annual European Community greenhouse gas inventory 1990-2002 and inventory report 2004, Technical Report 2/2004, European Environment Agency, Copenhagen.

Furthermore a project was executed aimed at investigating reduction options with the production of Caprolactam production. This has not yet resulted in the implementation of reduction options on a full scale.

4.3 N_2O emissions from agriculture

Direct emissions of N_2O from agriculture derive from the application of artificial fertiliser and animal manure. Emissions of N_2O from agriculture hardly changed in the period 1990-2003, which is the end-result of two main developments:

- On the one hand N_2O emissions increased due to changes in the application method of animal manure (from surface spreading to incorporation of manure into the soil leading to higher emissions per amount of manure applied on the land). These changes in application methods result from policies aimed at reducing the emissions of ammonia, which had to be introduced in order to comply with the National Emission Ceilings (NECs) Directive (2001/81/EC) (EC, 2001)[19]. This directive sets upper limits for the emissions of SO_2, NO_x, VOCs and ammonia on the Member State level but leaves it to a large extent to the Member States to decide which measures to take in order to comply. National policies to reach reduction of NH_3 included introducing regulation for application of manure (assuring that less ammonia is emitted).
- On the other hand the number of animals decreased resulting in a lower production of manure. The policy instruments that are already mentioned in section 3.2 mainly contributed to the decrease in animal stock.

Due to these contrary developments emissions of N_2O cannot be directly related to physical developments (like the number of animals or the amount of manure). In the first half of the nineties the first development was dominant resulting in an increase in N2O emissions, in the second half of the nineties the second development was dominant resulting in a decrease in N_2O emissions to approximately 1990 levels.

Efforts in the field of N_2O emissions from soil in the Netherlands focussed on a better understanding of the actual volume of emissions from soils and the reductions that can be achieved with specific measures like alternative use of fertiliser. Efforts are still in the research phase, and were supported by funding from the government (the ROB programme). Within the framework of the ROB a large number of projects were executed. The total government expenditure related to these projects was ~ 2.3 million euro.

[19] EC (2001) Directive 2001/81/EC of the European parliament and of the council of 23 October 2001 on national emission ceilings for certain atmospheric pollutants.

4.4 N_2O from other sources

At the time the Option document and the Dutch Climate Policy Implementation Plan (VROM, 1999)[20] was written it was still assumed that N_2O emissions from the transport sector would be an important source. Within the framework of the ROB a measuring programme was executed to measure N_2O emissions from cars. Results of this measurement programme show that emissions are much lower than anticipated earlier and no actions needed to be taken.

4.5 Overall picture N_2O emissions

N_2O emissions have decreased by 10% over the period 1990-2003. These reductions result from structural changes in the agricultural sector (changes in the application of manure and a decrease in the number of animals) and reductions in production volumes in the chemical industry.

So far no reduction measures have been implemented with sources of N_2O emissions. Efforts were aimed at getting a better understanding of emissions and feasibility of reduction measures in the agricultural sector and the industrial sector. Total governments costs amount to ~3.7 million euro.

[20] VROM (1999). Climate Policy Implementation Plan (CPIP) Part I. Ministry of Vrom, The Hague.

5 Analysis of the implementation context of emissions of HFC, PFC and SF_6

5.1 Introduction

This chapter provides an analysis of the developments in emissions of F-gases in the Netherlands and the implementation context of reduction measures. Detailed information on the implementation context per reduction measure is included in *Annex I*. The following information is included in this chapter:

1. The trends in emissions per source including an overview of factors influencing the emission level per source.
2. Achieved reductions and costs (effectiveness) of the reduction measure, including an overview of the most important factors responsible for high of low market implementation.
3. Comparison of the Dutch implementation context for reduction measures with the situation in other countries.
4. A comparison with the Option document (if applicable).

Figure 7 provides an overview of the emissions of F-gases in the Netherlands in the period 1990-2003. For the Kyoto target the base year for the F-gases is 1995 and the figure shows that in the period 1995-2003 the emissions have decreased by 70%.

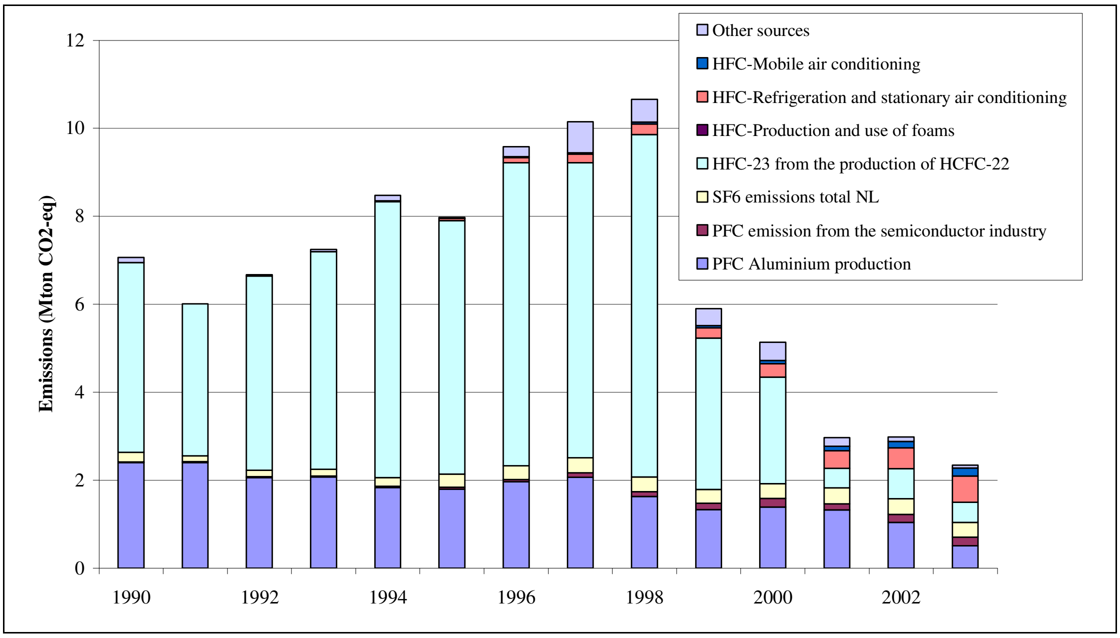

Figure 7 Development of emissions of F-gases in the period 1990-2003 for the selected sources (RIVM, 2004a)[7]

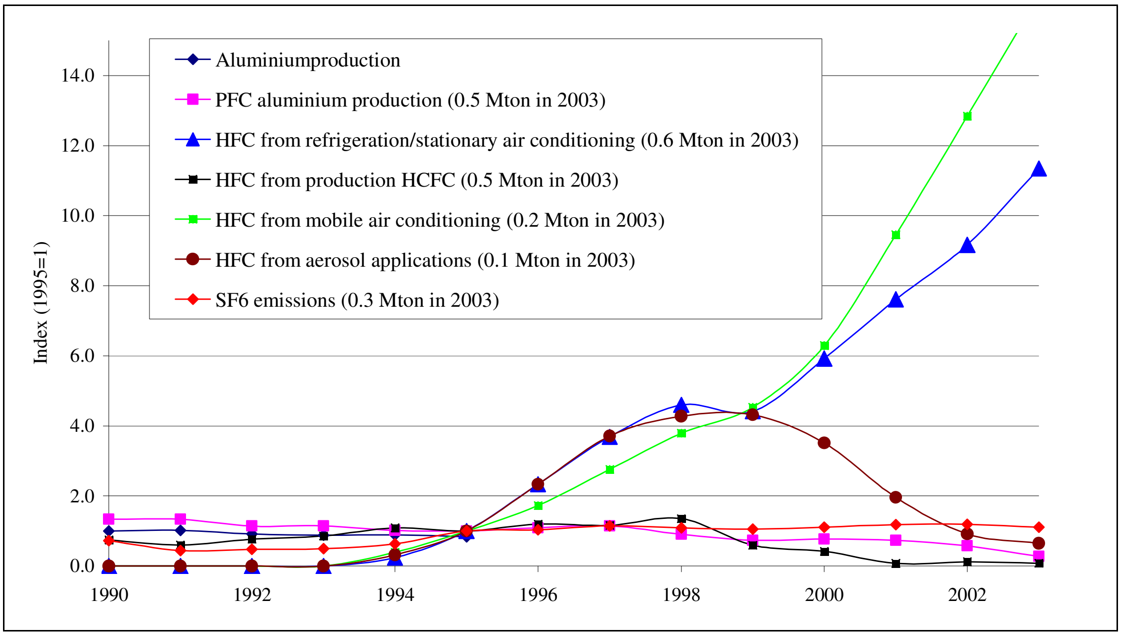

Figure 8 Development of F-gas emissions and different physical indicators for selected sources. Sources: emissions (RIVM, 2004a)[7] aluminium production (CBS, 2004a)[6]

5.2 PFC emissions from aluminium production

Emissions of PFCs from primary aluminium production occur during intermittent periods of the electrolytic process when the cryolithe melt becomes depleted of alumina. Under these circumstances PFCs are formed (a mixture of CF_4, C_2F_6 and C_3F_8). PFC emissions from the aluminium industry have decreased by almost 80% over the period 1990-2003 (see Figure 8). This drop in emissions results from the modernisation of the two aluminium-smelters in the Netherlands, in which they changed from Side-Worked Prebake to Pointfeeder Prebake. Next to economic circumstances the modernisation process was triggered by environmental policies like the European IPPC Directive and the environmental covenants. These policies resulted in regulations on the allowed amount of emissions in the environmental permit of the aluminium producers.

Most important effect of the modernisation process is an increase of production capacity with approximately 20%. For the two Dutch plants this also resulted in decrease in the emissions of PFCs by 1.6-1.7 Mton CO_2-eq per year and a decrease in the use of electricity (resulting in annual reductions of CO_2-emissions with 0.01-0.02 Mton CO_2-eq). Total achieved cumulative emission reductions amount to approximately 3 Mton CO_2-eq in the period 1995-2003 Mton.

Total investment costs to switch from Side-Worked Prebake to Pointfeeder Prebake were estimate at approximately 46 million euro, where total investment for the modernisation process accumulated to 186 million euro. From the national perspective, switching from Side-Worked Prebake to Pointfeeder Prebake results in a cost-effectiveness of approximately 1 euro per tonne of reduced CO_2. From the company perspective the investments in the total modernisation process are probably cost-effective because production capacity is expanded.

The government financially contributed to the investments of one of the producers with a total sum of 1.5 million euro.

Emissions of PFC have decreased drastically in the last decade in the Netherlands. The same trend is observed in other European countries. In the period 1990-2003 a large number of aluminium smelters closed in Europe, and at the remaining production facilities modernisation was carried out resulting in a large decrease of PFC emissions. There is no strong dedicated PFC regulation in EU countries. There are a number of voluntary agreements around (e.g. France, Germany and Norway) and a number of other countries regulate emissions under the Integrated Pollution and Prevention Control.

5.3 PFC emissions from the semiconductor industry

In the production process of Integrated Circuits (IC) silicon discs go through a large number of production stages in which alternately layers are being applied and parts of the layers are being etched off again. PFCs are used in production stages where plasma-techniques are applied: the dry etching stage and the chemical vapour deposition (CVD) stage. In the CVD stage PFCs are used to clean the process room.

The search for reduction measures in this sector is primarily triggered by climate changes policies. The Members of the World Semiconductor Council (WSC) came to a voluntary agreement on emission reductions of PFCs (WSC, 2004)[21] aimed at achieving absolute reductions of 10% in 2010 compared to 1995 levels. Furthermore the Dutch semiconductor industry expects that it will be faced with emission limits for PFC in her environmental permit in future years.

PFC emissions from the semiconductor industry have increased by a factor 4 in the period 1995-2003. In the Netherlands one producer of semiconductors is responsible for these emissions. The Dutch producers started testing reduction measures on a pilot scale, which will result in a reduction of 0.084 Mton at the end of 2004. Full-scale implementation of these measures is planned for future years.

The Option document did not hold detailed figures on costs for the semiconductor industry. In the Option document it was assumed that the semiconductor industry

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[21] WSC (2004). http://www.semiconductorcouncil.org/news/pfc.html (downloaded 1 October, 2004)

sector would grow with 15% per year, whereas Philips currently expect to achieve an annual growth in the output of IC of 10%.

Within the framework of the ROB the governments financially supports the search for feasible reduction measure. Government expenditure so far amounted to 0.3 million euro. This results in a cost-effectiveness for the government of 11 euro/ton CO_2-eq.

5.4 SF_6 emissions for gas insulated switch-gear

SF_6 is used in gas-insulated switchgears (GIS) and similar equipment used by utilities in their high voltage distribution networks. SF_6 is (1) emitted during the manufacturing, erection and testing of GIS and through (2) leakage, repair and maintenance in the user phase. In the Netherlands manufacturing of GIS was stopped in 2002. This means that only emissions form leakage, repair and maintenance are relevant. SF_6 is viewed as practically essential by electric utilities in most mid- and high-voltage applications, i.e. that cost-effective reduction measures are mainly aimed at reducing the leakage rates of SF_6 during production, use and decommissioning. Emissions of SF_6 hardly changed in the period 1990-2003.

Almost no information is available on implemented reduction measures. Within the framework of the CO_2-reduction plan one user of GIS applied for financial support to replace 30-year-old GIS with new GIS with a much lower leakage rate. This resulted in reductions of 2,5 ton CO_2-eq per year. It must be noted that the project involves the replacement of GIS that had reached the end of its technical lifetime (30 years). This means that (part of) these reductions would also have been reached in the absence of environmental policies. No data are available on the number of GIS that were replaced with new equipment in the period 1990-2003 as a result of climate policies. This implies that we cannot give an estimate for the achieved reductions for the Netherlands as whole. We probably can however assume that reductions are very low, because policy developments are still in an early phase.

Apart from the investments supported within the framework of the CO_2 reduction plan and the ROB, efforts were aimed at getting a better understanding of the reduction potential and costs. For this aim a task force was formed with representatives from the government, manufactures and users of GIS and several projects were executed with financial support of the ROB. Total government expenditure for investments and other supporting work amounted to 0.24 million euro.

Special emphasis in most countries so far has been placed on emission reductions during the manufacturing and testing of the equipment. Future efforts will be focussed on reduction during handling of HFC and service and maintenance of existing equipment, the identification of very leaky individual pieces of equipment and the execution of proper procedures at the end-of-life of equipment.

5.5 HFC-23 emissions from the production of HCFC-22

HFC-23 is a by-product of the production of HCFC-22 through over-fluorination. The emissions of HFC from the production of HCFC-22 decreased by 90% in the period 1990-2003. Reductions result from the installation of an *after burner* by the Dutch producer of HCFC-22 in the Netherlands (DuPont). Reductions at the end of 2003 amount to 5.3 Mton and the accumulated reductions for the period 1990-2003 amounts to 32 Mton. In order to be able to obtain an environment permit for the production of HCFC-22 DuPont had to install an after burner. Without an after burner DuPont was not able to meet the requirements laid down in the permit.

The first after burner was installed in 1997, but due to technical problems was replaced twice and in 2000 a reserve unit was installed as well. The Reduction Plan on non-CO_2 greenhouse gases supported activities and investments towards installing a new after burner and the installation of a reserve unit, resulting in additional emission reduction of 2 Mton. Total investments costs amount to over 10 million euro and the government supported investments in the reserve unit with 0.3 million euro. Total national costs are 11 million euro.

Compared to the assumptions in the Option document the actual investments were higher (because a reserve unit had to be installed) and the lifetime of the combustion chamber is much lower than anticipated. Reductions are in the same order of magnitude as included in the Option document.

Manufacturers within the EU-15 have installed and successfully operate thermal oxidation facilities at six plants within EU-15. This has been accomplished as part of voluntary agreements or by unilateral action of manufacturers. Another important development that could lead to substantial global reductions is the implementation of destruction techniques within the framework of CDM projects.

5.6 HFC emissions from the production and use of foams

HFCs can be used as a blowing agent for the production of foams. HFCs emissions occur during the production phase, and, at a lower rate, during the use and disposal of foams. Under EU Regulation as of the January 1, 2004 HCFC are banned. This means that foam producers had to search for alternatives for the use of HCFC as a blowing agent. HFC is one of the possible alternatives. Before 1 January 2004, the use of HFC as blowing agents in the Netherlands was probably very limited because reported emissions for the period 1990-2003 are zero (RIVM, 2004a)[7].

Because of the high costs for HFCs and current shortage of HFCs on the market, foam producers are stimulated to use alternatives such as CO_2/H_2O and pentane; it is currently cost-effective to switch to alternative blowing agents instead of HFC. Furthermore producers might anticipate to regulations in this field. It is however currently unknown, which type of foam is used in the Netherlands as of January this year, and how many producers switched to alternatives before this date. This means that achieved reductions for the period 1990-2003 cannot be determined.

Within the framework of the ROB a task force with representatives from the sector and government to investigate reduction measures and policy options and follow market developments. Furthermore two projects were financially supported aimed at developing (system for) alternative blowing agents. Total government expenditure related to these projects is 0.2 million euro.

From the costs available from the projects supported by the ROB one can conclude that the use of alternative blowing agents instead of HFCs is a very cost-effective option (i.e. the cost are even negative), and therefore cheaper than anticipated during the time the Option document was written. At the time of writing the Option document it was still assumed that in the absence of policies all producers would switch to HFC, whereas current trends show that market conditions force users to search for alternatives without strict policies in place. However reductions cannot yet be substantiated with figures because of lack of monitoring data.

Not much information is available on the actual emissions of HFC from foam production. What can be observed (but no substantiated with a lot of quantitative information) is that in other countries , apart from the high costs to obtain HFC, producers also turn away from HFC to avoid later regulatory risks (e.g. in Germany, Austria and Denmark).

5.7 HFC emissions from refrigeration and stationary air conditioning

HFCs are used as fluids in refrigeration and air conditioning. Emissions occur during (re-)filling of the installations, leakage in the application phase and when installations are dismantled. Emissions of HFCs from stationary cooling in the Netherlands have increased by a factor 10 in the period 1995-2003 (see Figure 7). This increase resulted from policies to put a ban the use of CFCs and HCFCs for cooling (Montreal Protocol). On the other hand environmental policies ensured that emissions are much lower than they would have been without policies.

The enactment of regulations on leak-free refrigeration equipment (*RLK*) combined with the enforcement of this legislation by the STEK (Association for the Recognition of Refrigeration Engineering Firms) was crucial for the achieved emission reductions. The STEK was set up to control emissions of CFCs and HCFCs but also works and applies for HFCs. The regulation includes a number of measures aimed at regular inspection of installations, training of personnel, and procedures for installation, handling and maintenance. At the time the legislation (RLK) and the STEK system were introduced the average leakage rate in the Netherlands was 30%. The leakage rate has been decreased to 4.5% in 1999. In countries, which do not have a system like STEK the average leakage rate is currently approximately 15%. Assuming that the Netherlands in the absence of the STEK would have had an average leakage rate of 15% the level of HFC emissions would have been approximately 1.2 Mton higher in 2003. Total cumulative reductions in the period 1995-2003 are approximately 3.9 Mton.

No detailed information is available on the number of installations that switched to natural refrigerants. Experts estimate that in the last couple of years between 2% and 5% switched. This would have led to reductions of 0.1 to 0.2 Mton CO_2-eq in the period 1990-2003. Investments in installations using natural cooling agents were financially support within the framework of the ROB (total granted budget 4 million euro) and by means of fiscal measures (total estimated granted budget 3 million euro). The cost-effectiveness for the government is estimated at 5-12 euro/ton CO_2-eq. Investments related to projects that applied for financial support in the period 1990-2010 is estimated at 21-25 million (it must be noted that actual investments will probably be higher because not all investors applied for financial support).

Within the framework of the ROB furthermore a task force was established with representatives of the sector and the government to follow market and policy developments and investigate reduction options.

In the Option document it was assumed that it would be technically possible for all installations put into operation after 2000 to reach a leakage rate of 1%. Although the leakage rate has diminished considerably, this situation has not reached yet. The costs-effectiveness of implemented installations using natural cooling agents lies in the range assumed in the Option document. In the Option document it was furthermore assumed that all new installations as of 2005 use an alternative cooling agent. There is a slight increase in systems running on alternative cooling agents, but the scenario in the option document seems to have been too optimistic.

Dutch regulations mainly focussed on reducing leakage of refrigerant. In other countries more attention is paid to the use of natural cooling agents and regulations in place or are being prepared to ban the use of HFC in new cooling systems. In Germany e.g. only the announcement that regulation would be introduced to ban HFC as of 2010 already affected the market and the implementation of systems using natural cooling agents increased.

5.8 HFC emissions from automotive air conditioning

HFCs are also used as refrigerants in automotive air conditioning. Emissions of HFCs from automotive air conditioning in the Netherlands have increased by a factor 16 in the period 1995-2003 (see Figure 7). This increase results from policies to put a ban on the use of CFCs for automotive air conditioning.

So far no reduction measures have been implemented in the Netherlands. Efforts in the Netherlands were aimed at the European level, which resulted in the European F-gases regulation (EC, 2003)[22]. Governments recently agreed on a six-year phase out of cooling agents with a GWP above 150 for automotive air conditioning starting in 2010.

Within the framework of the ROB one project was executed with a total budget of 0.2 million euro.

5.9 Other sources

The most important other source for HFC emissions is in the use of HFCs in technical and medical aerosol applications. HFC emissions from aerosol applications have shown an increase as of 1995 but decreased again as of 1999. This is caused by the fact that HFCs are fairly costly, which stimulated the sector to look for alternatives. Hydrocarbon alternatives were developed for the use of HFCs in PU one-component-foams, which are 10 to 20 times cheaper than HFCs (RIVM, 2004b)[23].

5.10 Overall picture F-gases

Table 4 provides an overall picture of measures and costs to reduce emissions of F-gases. Total reductions at the end of 2003 accumulated to approximately 8 Mton CO_2-eq. The table shows that the largest reductions have been achieved by installing an after burner with the producer of HCFC-22. Further, large reductions have been achieved through good housekeeping measures with cooling installations and through the modernisation process in the aluminium industry.

[22] EC (2003) Proposal for a Regulation of the European Parliament and the Council on certain fluorinated greenhouse gases. Brussels, 11.8.2003. COM(2003) 492 final. 2003/0189 (COD)

[23] RIVM (2004b). Oral communication Kees Peek date October 6, 2004.

Table 4 Overall picture of (cumulative) reductions and costs to reduce emissions of F-gases in the period 1990-2003

Emission source	**Reduction measure**	**Gross emission reductions in 2003**	**Cumulative gross emission reductions 1990-2003**	**Cumulative invest Ments**	**Cumulative government expenditure**	**Gross cost-effect. for the government**	**National cost-effect.**
		Mton CO_2-eq		**Million euro**		**€/ton CO_2-eq**	
PFC emissions aluminium production	Switching from SWPB to PFPB	1.6-1.7	3.2-3.3	46	1.5	0.10	-0.10
PFC emissions semi-conductor industry	Several reduction measures on pilot scale	0.0084	0.0084	0.5	0.3	11	18
SF_6 emissions electricity sector	Replacement of GIS	Unknown	Unknown	Unknown	0.2	N.A.	35
HFC-23 emissions production of HCFC-22	Installation of an after burner	5.3	32	10	0.3	0.006	0.3
HFC emissions production and use of foams	Use of alternative blowing agents	Unknown	Unknown	Unknown	0.2	N.A.	< 0
HFC emissions from stationary cooling	Good housekeeping	1.2	3.9	18	0.8	0.2	20
	Use alternative refrigerants	0.05-0.1	0.1-0.2	21-25	7	10-24	-5 - +30
HFC mobile air conditioning	N.A.	N.A	N.A	N.A	0.2	N.A.	N.A.
TOTAL		~8 + pm	~39 + pm	95-100 + pm	~11		

Almost all reductions were achieved within sectors that already had measures planned (through requirements in their permits) or in place (long) before specific non-CO_2-greenhouse gas policies came in place (i.e. before the Climate Change Action Plan (CCAP) was published). Activities initiated within the Reduction Plan on non-CO_2 greenhouse gases however turned the actions toward the climate change aspect of these measures and resulted in speeding up the process of implementation of reduction measures. What furthermore can be noticed is that the government expenditures for sectors where large reductions have been achieved were relatively low.

Total government expenditures for the period 1990-2003 accumulated to approximately 11 million euro. Main part of the expenditures went to grants that stimulated the use of alternative refrigerants.

Table 5 provides a comparison between the realised costs and effects and the expectation in the Option document and the Climate Change Action Plan (CCAP). The table shows that with the exception of HFC emissions from the production of HCFC-22 production the Option document lacked detailed data and that a comparison between estimated and realised costs and effects is still difficult because of lack of data.

Table 5 Comparison between realised costs and effects and expectation in the Option document.

Emission source • **Reduction measure**	**Comparison between realised and expected reductions and costs in the Option document and the climate change action plan (CCAP)**
PFC emissions aluminium production • Switching from SWPB to PFPB	In the Option document reductions with one of the producers were already taken into account into the baseline scenario. Estimated reductions with the second producer lie in the same range as realised. The Option document did not hold cost figures because of lack of data, so no comparison can be made. The realised effect lies in the same order of magnitude as the expected effect.
PFC emissions semiconductor industry • Several reduction measures on pilot scale	Because of lack of reliable data on reduction options the average reduction costs for the society as a whole (national cost-effectiveness) were assumed to be in the range of 0-23 euro/ton CO_2-eq. Reduction measures are not yet implemented on a full scale but tests on pilot scale indicate that a cost-effectiveness of around 12 euro/ton CO2-eq will be possible.
SF_6 emissions electricity sector	Because of lack of reliable data on reduction options the average reduction costs for the society as a whole (national cost-

Emission source • **Reduction measure**	**Comparison between realised and expected reductions and costs in the Option document and the climate change action plan (CCAP)**
• Replacement of GIS	effectiveness) were assumed to be in the range of 0-23 euro/ton CO_2-eq. Because efforts to reduce emissions in this sector are so far limited only data for one implemented project are available no comparison between estimated and realised costs and effects can be made yet.
HFC-23 emissions production of HCFC-22 • Installation of an after burner	In the Option documents the national costs were estimated at 0.13 euro/ton CO_2-eq. Investment costs for the after burner were at that time estimated by DuPont to be 7.7 million euro and the lifetime of the installation was assumed to be 15 years. The actual investments are higher and the lifetime of the combustion chamber is much lower than anticipated at the time the Option document was written. Reductions are in the same order of magnitude as included in the Option document.
HFC emissions production and use of foams • Use of alternative blowing agents	Because of lack of reliable data on reduction options the average reduction costs for the society as a whole (national cost-effectiveness) were assumed to be in the range of 0-23 euro/ton CO_2-eq. From the limited data on the project level it can conclude that measure to reduce the use of HFC from foam production are cost-effectiveness (i.e. the cost are negative), and therefore cheaper than anticipated during the time the Option document was written. The Option document forecasted an enormous increase in the emissions of HFCs if no policies would be introduced. Current developments however show that without any binding policies the market for foams is already moving away from HFCs.
HFC emissions from stationary cooling • Good housekeeping	The national costs according the Option document for reduction of leakages are 22.7 euro/ton CO_2 eq. These only included the cost for hardware to reduce leakages. It is not possible to compare this figure with the costs we calculated for the introduction of the STEK, as we only had figure for the whole introduction of the system of good housekeeping. In the Option document is was assumed that it is technically possible for all installations put into operation after 2000 to reach a leakage rate of 1%, this is however currently not yet common practice.
HFC emissions from stationary cooling • Use alternative refrigerants	In the Option document the national cost for application of alternative cooling agents in new stationary cooling installation are rated at about 4.5 euro/ton CO2 eq. Basic assumption for this estimation was that a cooling installation on NH3 is 20-30%

Emission source • **Reduction measure**	**Comparison between realised and expected reductions and costs in the Option document and the climate change action plan (CCAP)**
	more expensive than a comparable installation on HFC. The costs-effectiveness of implemented reduction measures lies in this range. In the Option document it was assumed that all new installation as of 2005 use an alternative cooling agents. This is not the trend currently observed in the Netherlands.

6 Overall picture and lessons learnt

6.1 Introduction

This chapter first provides an overall summary of the costs, effects and effectiveness for the sources described in the chapter 3 to 5. Secondly an overall picture is provided of the analysis of the implementation context. Finally a few lessons for further policy development are included.

6.2 Costs and achieved reductions

Table 6, Figure 9 and Figure 10 provide an overview of total achieved gross emissions reductions and associated costs in the period 1990-2003 per emission source for the Netherlands.

The cumulative gross reductions for the period 1990-2003 were approximately 63 Mton CO_2-eq. The top-4 of measures accounting for 95% of the cumulative reductions is:

1. Installation of an after burner with the producer of HCFC,
2. Collection and utilisation of landfill gas
3. Reduction measures in the oil-and gas industry
4. Good housekeeping measure in the cooling sector

Total investments aimed at reducing emissions of non-CO_2 greenhouse gases amount to approximately 149 million euro in the period 1990-2003. It must be stressed that investment figures are surrounded by large uncertainties, because of limited and partly unreliable data. For some sectors no estimates could be made at all because of lack of data. The most important investments missing in our overview are the investments in the oil and gas industry. From our analysis the top-4 of measures accounting for 85% of the investments over the period 1990-2003 are:

1. Reductions of PFC emissions in the aluminium industry.
2. Collection and utilisation of landfill gas
3. Switch to natural cooling agents with stationary cooling installations
4. Good housekeeping measure in the cooling sector

Table 6 Overall picture of important indicators for the reduction measures implemented in the Netherlands in the period 1990-2003

Emission source	Reduction measure	Gross emission reductions in 2003[24]	Cumulative gross emission reductions 1990-2003[25]	Cumulative investments 1990-2003 [26]	Cumulative gross national cost 1990-2003	Cumulative government expenditures 1990-2003	National cost-effectiveness	Gross cost-effectiveness for the government
		(Mton CO_2-eq)	(Mton CO_2-eq)	(Million euro)	(Million euro)	(Million euro)	(€/ton CO_2-eq)	(€/ton CO_2-eq)
CH_4 from cattle farming	N.A.	0	0	0	0	1.7	N.A.[27]	N.A.
CH_4 emissions from manure management	Anaerobic (co)- digestion of manure	0.01	0.02-0.03	4.5-5.0	1.5-1.7	3.8-4.1	50-80	140-180
CH_4 emissions from landfill sites	Collection and utilisation of landfill gas	1.5	17	35-55	41-77	13-19	2-5	1-2
CH_4 emissions from the oil- and gas industry	Several measures	1.0[28]	6.8[29]	Unknown	< 0	0.5	< 0	0
CH_4 from gas engines	N.A.	0	0	0	0	0.05	N.A.	N.A.

[24] This is the emissions reduction achieved in the year 2003 compared to the pre-defined reference situation
[25] This is the cumulative annual emission reduction achieved in the period 1990-2003 compared to the reference situation.
[26] These are the cumulative annual additional investments that were made in the period 1990-2003 to implement the reduction measures. Investments are the additional compared to the investments that would otherwise have been made (the reference situation)
[27] N.A. = Not Applicable. This means that the cost-effectiveness cannot be calculated (e.g. because no emission reductions have been achieved yet and the cost-effectiveness is infinite)
[28] These are the reduction at the end of 2002 instead of 2003
[29] These are the reduction in the period 1990-2002

Emission source	**Reduction measure**	**Gross emission reductions in 2003**[24]	**Cumulative gross emission reductions 1990-2003**[25]	**Cumulative investments 1990-2003** [26]	**Cumulative gross national cost 1990-2003**	**Cumulative government expenditures 1990-2003**	**National cost-effectiveness**	**Gross cost-effectiveness for the government**
		(Mton CO_2-eq)	**(Mton CO_2-eq)**	**(Million euro)**	**(Million euro)**	**(Million euro)**	**(€/ton CO_2-eq)**	**(€/ton CO_2-eq)**
N_2O from industry	N.A.	0	0	2.7	N.A.	1.4	N.A.	N.A.
N_2O from agricultural soils	N.A.	0	0	0	0	2.3	N.A	N.A
PFC emissions from aluminium production	Switching from Side-Worked Prebake to Pointfeeder Prebake	1.6-1.7	3.2-3.3	46	-0.4 - -0.3	1.5	-0.10	1
PFC emissions from the semiconductor industry	Several reduction measures on pilot scale	0.0084	0.0084	0.5	0.1	0.3	18	11
SF_6 emissions from the electricity sector	Replacement of old Gas Insulated Switchgear (GIS) with GIS with lower leakage rate	Unknown	Unknown	Unknown	Unknown	0.24	35[30]	N.A.
HFC-23 emissions from the production of HCFC-	Installation of an after burner	5.3	32	10	11	0.3	0.3	0.006

[30] National cost-effectiveness and government expenditures are based on numbers for one project that applied for financial support within the framework of the ROB.

Emission source	Reduction measure	Gross emission reductions in 2003[24]	Cumulative gross emission reductions 1990-2003[25]	Cumulative investments 1990-2003 [26]	Cumulative gross national cost 1990-2003	Cumulative government expenditures 1990-2003	National cost-effectiveness	Gross cost-effectiveness for the government
		(Mton CO_2-eq)	(Mton CO_2-eq)	(Million euro)	(Million euro)	(Million euro)	(€/ton CO_2-eq)	(€/ton CO_2-eq)
22								
HFC emissions from the production and use of foams	Use of alternative blowing agents	Unknown	Unknown	Unknown	Unknown	0.2	< 0	N.A.
HFC emissions from stationary cooling	• Good housekeeping measures • Use alternative refrigerants	1.2 0.05-0.1	3.9 0.1-0.2	18 21-25	76[31] -1 - +6	0.8 7	20 - 5 - +30	0.2 10 - 24
HFC mobile air conditioning	N.A.	N.A	N.A	N.A	N.A	0.2	N.A	N.A
All sources	N.A.	N.A	N.A	N.A		3.7[32]	N.A	N.A
TOTAL		**~11+pm**	**~63+pm**	**~149+pm**	**128-173 + pm**	**37-44**		

[31] Apart from the start up cost of 18 million euro, the estimated annual running costs are 5.4 million euro leading to total national cost for the period 1990-2003 of 76 million euro. It must however be noted that not all these cost can be attributed to the reduction to HFCs, because the good house keeping measures were introduced with the aim to minimise leakage of substances falling under the Montreal Protocol.
[32] This includes government budgets for assingments within the ROB which cannot be attributed to specific emission sources or measures

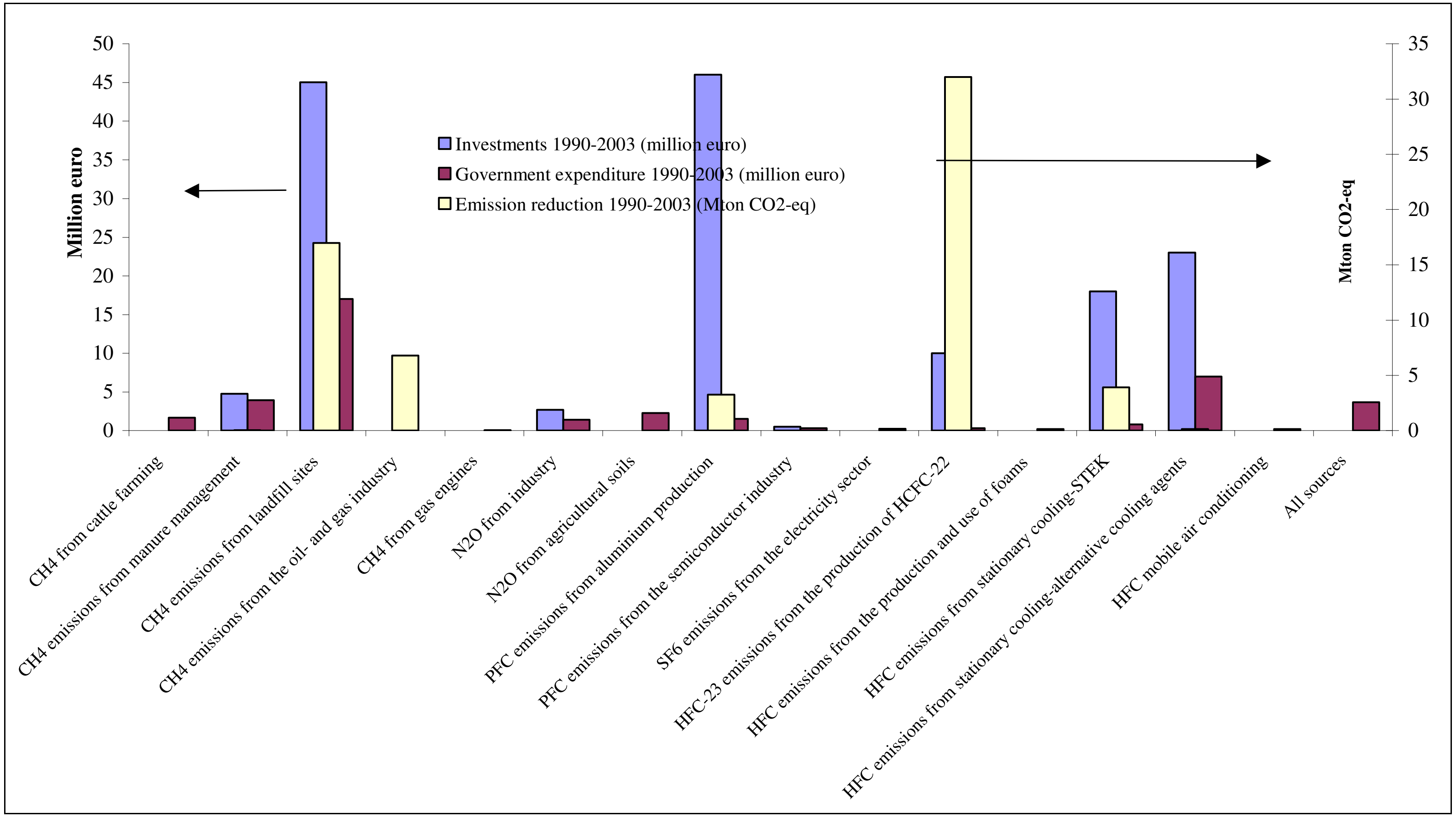

Figure 9 Gross cumulative investments, government expenditure and gross achieved reductions for the period 1990-2003 aimed at reducing emissions of non-CO_2 greenhouse gases.

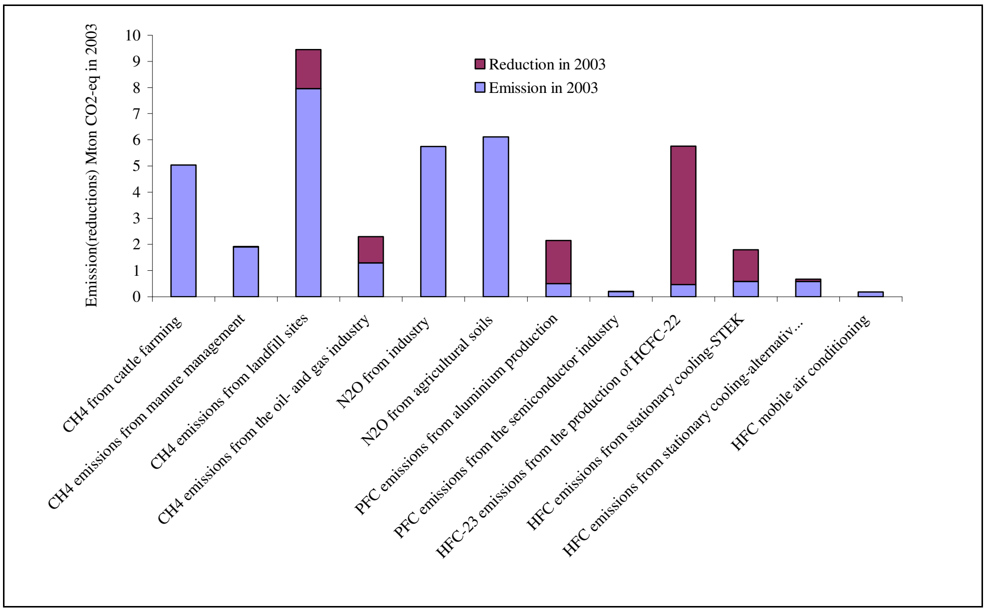

Figure 10 Emissions and achieved reductions in 2003 for the different emission sources.

Figure 11 provides a split of the achieved reductions into different categories for the national cost-effectiveness. The figure shows that the bulk (94%) of the reductions were achieved against a national cost-effectiveness below 5 euro per ton CO2-eq.

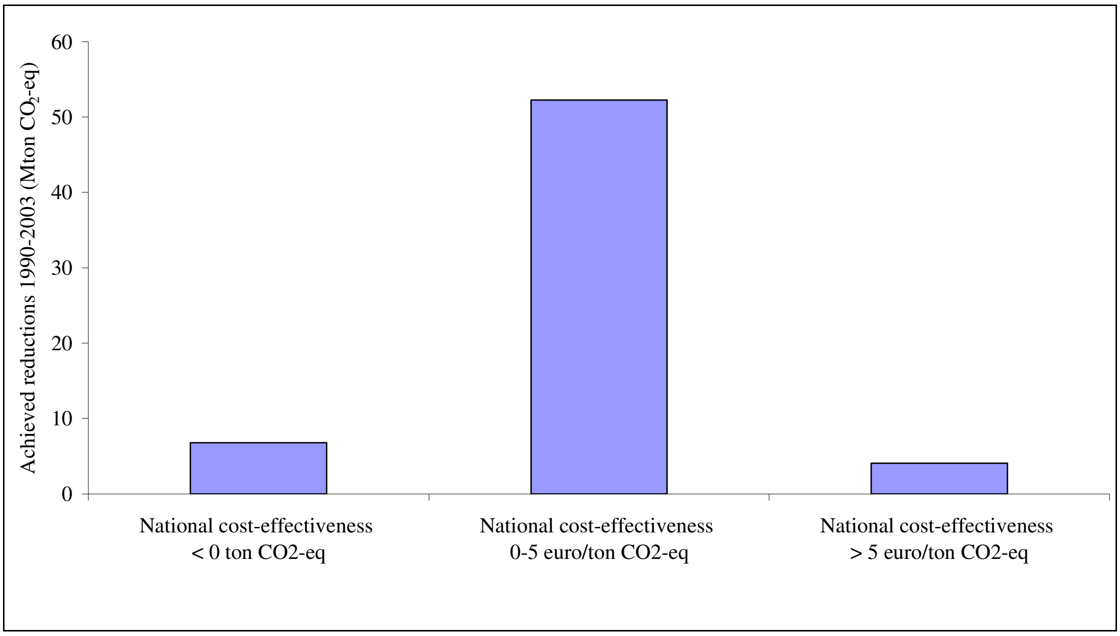

Figure 11 A split of achieved reductions (~63 Mton) into different categories of national cost-effectiveness in the period 1990-2003.

6.3 Government expenditure

Total government expenditure in the period 1990-2003 is estimated at almost 37-44 million euro. Approximately 70% of the budget went to support investment in reduction measure whereas 30% was used to finance all kind of activities to support the implementation of reduction measures (this is the chart pie 'ROB other activities in Figure 12).

More than 40% of the government expenditure went to support of implementation of reduction measures at landfill sites. Most of these costs were made in the beginning of the '90. Almost 17% of the government expenditures were spent to support the market transition to natural cooling agents, which so far led to limited reductions.

Figure 12 provides an overview of the divisions of the government expenditures for the period 1990-2003 over the different government instruments. The figure shows that main part of the government expenditure consisted of investments support and financing all kind of activities within the ROB programme, and the energy tax exemption for renewable energy production with landfill gas projects.

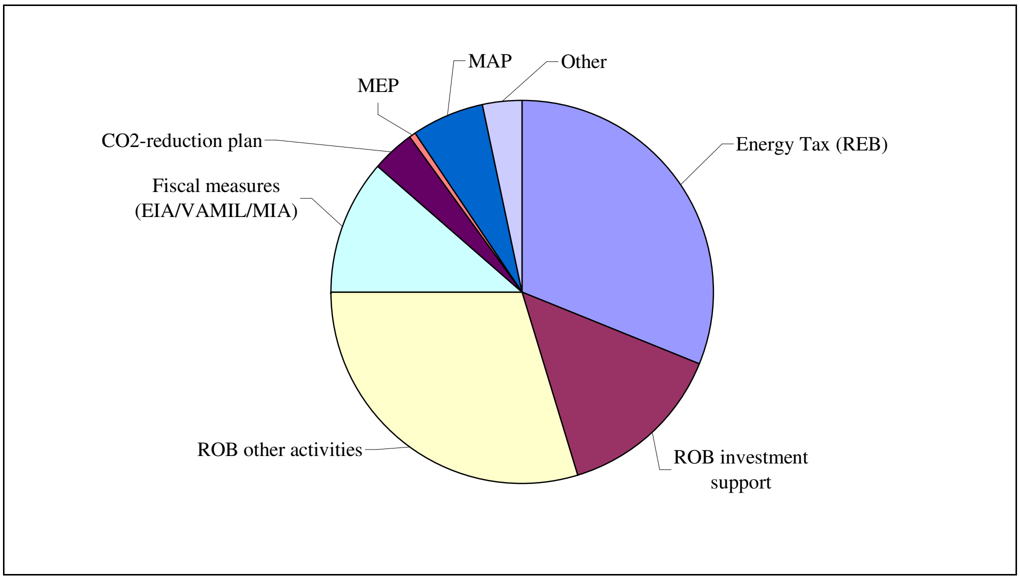

Figure 12 Division of total government expenditures for the period 1990-2003 (~40 million euro) over the different government instruments.

Figure 13 provides an overview of the gross and net cost-effectiveness for the government. As explained in chapter 2 the gross cost-effectiveness does not account for investors that would also have implemented the measure in the absence policy instruments. In this case nearly all reductions (>99%) have been achieved against gross governments costs below 5 euro per ton CO_2-eq and the overall cost-effectiveness for the government is approximately 0.08 euro/ton CO2 eq.[33].

However part of the emission reductions would also have been realised in case the government had not introduced policy measures to reduce emissions of non-CO_2 greenhouse gases. We therefore also made an estimate of the net cost-effectiveness, by making an estimate of the share of reductions that also would have been realised in the absence government policies. We assumed that the investments in the aluminium industry would also have been made in the absence of financial support from the government because these investments are cost effective. Furthermore the investment in an afterburner with the producer of HCFC-22 would also have been made in the absence of non-CO_2 greenhouse gas policies and financial support because the after burner had to be installed in order to comply with fluoride emission standards set in the environmental permit. Furthermore part of the investments in the use of alternative cooling agents and at landfill sites would also have taken place without financial support from the government. It is hard to determine a number but the average share of free riders with subsidies schemes lies over 30% (Beer de et al, 2000)[34]. Taking the net gross effectiveness the overall cost-effectiveness for the government amounts to ~*1.7 euro per ton of CO_2-eq*[35].

[33] The overall gross cost-effectiveness for the government was calculated by depreciating totaL government expenditure (~40 million) againt an interest rate of 4% and devide this by total achieved gross reduction at the end of 2003 ~11 Mton.
[34] Beer et al (2000). Effectiveness of energy subsidies. Research into the effectiveness of energy subsidies and fiscal measures in the Netherlands in the period 1988-1999. Ecofys, 2000.
[35] The overall net cost-effectiveness for the government was calculated by depreciating totaL government expenditure (~40 million) againt an interest rate of 4% and devide this by total achieved gross reduction at the end of 2003 ~11 Mton.

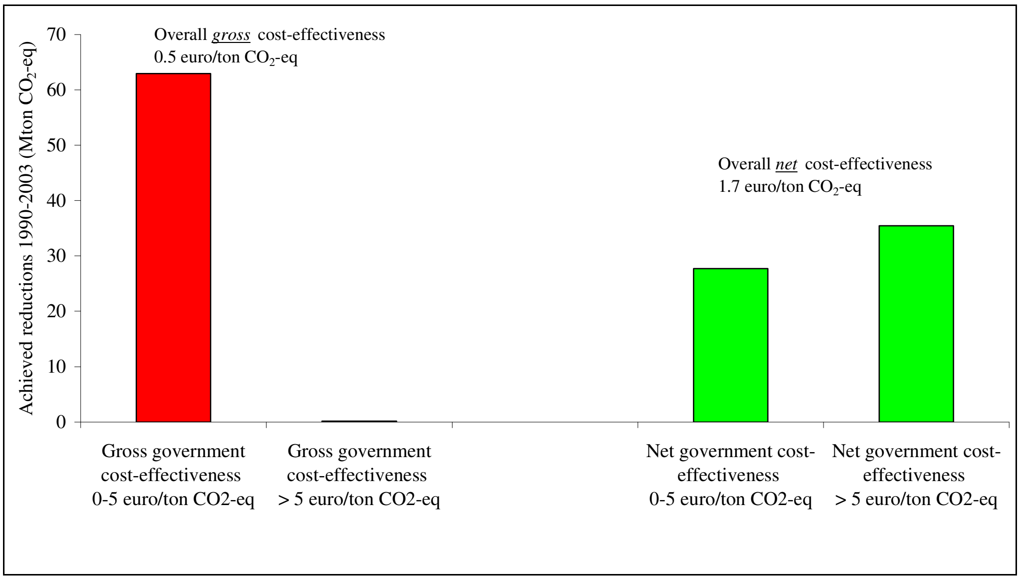

Figure 13 A split of achieved reductions (~63 Mton) into different categories of *gross* and *net* cost-effectiveness for the government in the period 1990-2003.

6.4 Overall picture on the implementation context

There are substantial differences between the estimated costs and emission reductions mentioned in the Option document (ECN, RIVM, 1998)[2] and reductions and costs resulting from the analysis in this report. They arise from changes in the implementation context since the time the Option document was drawn up.

6.4.1 Structure and characteristics of the sector

Differences with respect to effect of *"autonomous" market developments*

- E.g. in the Option document it was assumed that in the absence of strict policies foam producers all would use HFC as a blowing agents. Because of (i) the current tight market for HFC leading to high prices producers, and (ii) to avoid the risks of regulations producers are already switching to alternatives like CO_2, butane and pentane without strict policies in place.

Differences with respect to the *pace* in which technologies were expected to be introduced to the market.

- E.g. in the Option document it was assumed that all new cooling installations as of 2000 would be using natural cooling fluids and/or new installations would have a leakage rate of 1%. Current trends however show that this is not the case and that not all sold cooling installations use natural cooling agents.

6.4.2 Feasibility (company level)

Differences with respect to the *type* of applied technology.

- E.g. in the Option document it was assumed that no co-digestions of manure would take place in the Netherlands because of the strict regulations with respect to the use of remains from the co-digestion process. Analysis of the developments in the period 1990-2003 however shows that co-digestion of manure is the only way to make this options profitable because if without the use of co-digestions products methane production is much lower. The options documents furthermore assumed that the produced methane would be used in boilers to produce heat, whereas current developments are to use to methane in a gas engine to produce heat and electricity. These differences led to different pictures for environmental and financial yields to reduce emissions from manure management.

Differences with respect to *feasibility* and *investments costs* of reduction measures.

- E.g. the costs anticipated in the Option document to install an after burner to reduce the emissions of HFC from the production turned out to be much higher than anticipated. It furthermore turned out to be more difficult to install a reliable after burner.

Differences with respect to the pace in which *permits* for co-digestion could be arranged.

6.4.3 Government policies

Differences with respect to the applied *government policies*

- Government policies affect the cost-effectiveness for the end-user and the cost-effectiveness for the government itself. E.g. government policies in the field of renewable energy production led to chances in the cost-effectiveness of manure co-digestion and use of landfill gas for energy production.

6.5 The role of government policies

Government policies have played an important and crucial role in the realisation of emission reductions in the Netherlands. Main part of the reductions in the period 1990-2003 were triggered by government policies already in place (or well under way) before specific attention was paid to the impact of these substances on climate:

- Environmental permit requirements for the producers of HCFC-222 and aluminium to limit emissions of fluoride and other pollutants, resulting in reductions of HFC and PFC emissions.
- Voluntary agreements with the oil and gas and the aluminium industry to improve their energy efficiency, resulting in reductions of CH_4 and PFC emissions.

- Dumping regulations to reduce emissions of methane from landfill site, which were introduce to reduce local safety hazards from the potential build up and explosion of methane and also reduces odours associated with landfill sites.
- Introduction of good housekeeping measures within the cooling sector to reduce emissions of substances regulated under the Montreal Protocol (CFCs), which also contributed to relative reductions of HFC emissions.

Characteristic of these policies is that all of them were not introduced with the specific aim to reduce the emissions of non-CO_2 greenhouse gases but to solve other environmental and health issues. With the publication of the Climate Change Action Plan in 1999, which held the policies for the Netherlands to achieve its Kyoto targets, the Reduction Plan on non-CO_2 greenhouse gases. This plan aims to speed up the implementation of measures to reduce the emissions of non-CO_2 greenhouse gases. For this aim it works amongst others on (i) enforcing the effectiveness of instruments already in place (e.g. with the producer of HCFC-22 resulting in an additional reduction of 2 Mton compared to the reference situation in 2003, and the aluminium industry), (ii) removing barriers for the implementation of reduction measure (e.g. with respect to rules for co-digestion) and (iii) raising awareness and increasing knowledge on reduction measures.

On the other hand government regulation also hampered the implementation of reduction measures in the Netherlands. Because of lack of transparent regulation with respect to substances that can be used to co-digest with manure and long lead times to obtain the necessary permits. In countries with transparent regulation in place (like e.g. Denmark and Germany) market penetration of anaerobic co-digestion of manure is significantly higher.

Specific policy development to limit emissions from F-gases used in production processes and installations is still in an early phase. Just recently the European F-gas Regulation was introduced and countries introduced specific policies. Effect of these policies are not yet divisible in the emission inventories as most of them have long transition periods to provide the sector with opportunities to search for alternatives.

6.6 Differences between the Netherlands and other countries

The Netherlands already achieved large reductions in the field of non-CO_2 greenhouse gases. A further aim of the project was to analyse efforts in other countries in sectors in which the implementation of reduction measures in the Netherlands are lagging behind. Main sectors were policy development and market conditions in other countries are more favourable than in the Netherlands for the implementation of reduction options are:

- *Co-digestion of manure*. The implementation context of anaerobic co-digestion of manure is due to different government policies and structure of the sector more favourable in Germany and Denmark. The cost-effectiveness of co-digestion of manure is due to higher levels of financial support from the government in Germany and Denmark better than in the Netherlands. Rules regarding the use of remains from the co-digestion process have been clearly defined for a number of years and due to the large number of installation already in place there is a lot of experience with authorities and procedure run more smoothly. A further advantage compared to the Netherlands is that the average size of farms in Germany and Denmark are larger and they have more land to spread the manure.

- *Alternative cooling agents*. Use of natural cooling agents in stationary cooling equipment wasn't a focus point in Dutch climate change policies. The Netherlands mainly focussed on reducing leakage rates and no regulations were announced or introduced to stimulate the shift to natural cooling agents like e.g. in Germany, Austria and Denmark. According to experts only the treat of government regulations in these countries led to the shift towards the use of natural cooling agents. Because of lack of data this can however not yet be substantiated with numbers.
- *Alternative blowing agents*. The same counts for alternative blowing agents. The treat of government regulations on HFC in other countries made producers turn toward alternatives. Because of lack of data this can however not be substantiated with figures.

6.7 Lesson learnt

The following lessons can be learnt from the analysis in this report:

- Government policies have played a crucial role in initiating reduction of non-CO_2 greenhouse gas emissions in the period up to 2003 in the Netherlands. In the absence of government policies most measures would not have been implemented because there is no 'autonomous' drive to implement these measures. Government policies will also play a crucial role in achieving further reduction in future years.
- Dutch government policies introduced in the beginning of the nineties (or even before) have been successful in reducing the emissions of non-CO_2 greenhouse gases. Activities within the Reduction Plan on non-CO_2 greenhouse gases amongst others build on these existing instruments to speed up the implementation of measures or increase reduction efforts.
- Government policies often have long lead times before their effect is visible in a decrease of emissions on the national level. Instruments already long under discussion triggered main part of the reductions achieved at the end of 2003 before actual climate change policies were introduced. This means that the new policies initiated under the reduction plan for non-CO_2 greenhouse gas emissions are not yet visible in reductions on a national level because time has been to short for the policies to fully carry over into actual implemented reduction measures.

- The concept of cost-effectiveness is a useful tool in the hands of the government to evaluate ex-ante and ex-post the efficiency and effectiveness of her own policies and make comparisons across sectors and gases in order to set priorities in her climate change policies. The current definition used in preparing government policies seems appropriate for this evaluation.
- The concept of cost-effectiveness is however far more difficult to apply in discussions between the government and individual companies because companies often use of much broader definition of costs which can lead to a completly different picture on the cost-effectiveness of reduction measures. This means that figures for cost-effectiveness found in literature have to be interpreted carefully before conclusion can be drawn and comparisons can be made with other sectors and measures. Furthermore measures that seem cost-effective from an end-users point of view are not implemented automatically because they have to be weighed against other investments of the company (which may be more profitable) or may be hampered by other barriers. This means that discussion on the company level will focus on the complete implementation context and not just on the 'bare' cost-effectiveness.
- Comparison between ex-ante (Option document) and ex-post evaluations (current projects) show that the ex-ante evaluation was mainly hampered by lack of data on the costs of reduction measures, which sometimes turned out to be cheaper (e.g. foams sector) and sometimes turned out to be more costly (e.g. the installation of an after burner). Furthermore the implementation context changed, which led to differences in anticipated reductions and costs. This means that the government should closely watched market circumstances in order to be able to timely anticipate with changes in policies.
- Analysis of the implementation context in other countries showed that the Dutch government could speed up the reductions of non-CO_2 greenhouse gases in the field of alternative cooling agents, co-digestion of manure and foams.
  - Alternative cooling agents and blowing agents are currently proven technology and setting clear targets and regulations for the use these alternatives could speed up the implementation.
  - Lack of good regulations with respect to co-digestion of manure was the main barrier for the implementation of this option in the last couple of years. With the publication of the 'white lists' of substances that can be used to co-digest an important step was made to speed up implementation.
- Furthermore the monitoring with respect to the use of HFC should be improved. Because of lack of good monitoring data it is unknown what the current use of HFC in the foam sector and it cannot be clearly judged if policies need to be intensified.

Annex I: Assessment of reduction measures

This annex includes a detailed overview of result of the analysis of the implementation measure per selected reduction measures. Furthermore all sources are included which were used for the calculation of reduction effects and costs. The following information is included in the tables:

Emission source
• [Description of emission source]
Emission reduction measure
• [Description of reduction measure]
Reference situation
• [Description of the references situation]
Short description of the reduction option
• [Short description of reduction measure, amongst other explaining main technical details]
NETHERLANDS
Actual cost-effectiveness in the Netherlands
•
Comparison of actual and forecasted cost-effectiveness in Option document
•
Factors influencing implementation and cost-effectiveness in the Netherlands
1. Government policies
• [Analysis of factors mentioned in Table 1]
2. Structure of the sector
• [Analysis of factors mentioned in Table 1]
3. Feasibility
• [Analysis of factors mentioned in Table 1]
4. Market Implementation in the Netherlands
• [Analysis of factors mentioned in Table 1]

CH_4 emissions from manure management

Netherlands

Emission source
• CH_4 emissions from manure management
Emission reduction measure
• Anaerobic manure (co-)digestion
Reference situation
• It is assumed that in the absence of policies aimed at reducing the emission of methane the manure is stored in either a storage tank or a cellar (or a combination of both). • Temporally storage of the manure in a tank and/or a cellar is required in order to comply with manure policies aimed at reducing the amount of nitrogen emitted to underground water. • The biogas is used to produce heat and electricity. It is assumed that the heat would otherwise have been produced with a natural gas fired boiler with an efficiency of 90% and that the electricity would otherwise have been produced with the average power production mix in the Netherlands.
Short description of the reduction measure
• In case of anaerobic (co-)digestion the stored manure goes to a digester either on the farm itself (small-scale digestion) or is transported to a large-scale digester where the manure of several farms is processed. • The manure is in most cases mixed with substrates e.g. waste from the agricultural industry to increase methane production this is called co-digestion. At least since in 2003 the positive list with co-substrates was introduced. • The manure is digested at temperature between 25-45°C (mesospheric digestion) and manure stays between 15 and 40 days in the digester. • The produced methane is in the Netherlands mostly used in co-generation plants to produce electricity and heat. Part of the produced heat and electricity is used for the manure processing plant and the remaining part is delivered into the grid.
Actual cost-effectiveness in the Netherlands
• Table 7 provides an overview of typical values, including the resulting national cost-effectiveness and the cost-effectiveness for the government, for the three types of manure digesters currently operational in the Netherlands. Exact numbers for these installations are not available.

Table 7 Cost figures for three different types of digesters. Source: (Tijmensen et al, 2002)[36].

		Small-scale digester - no co-digestion	Small-scale digester - with co-digestion	Large-scale digester - with co-digestion	Remarks
Processed manure	ton year	4,600	4,000	30,000	
Processed manure	ton/year.kWe	150	79	59	
Processed co-substrate	ton year	0	800	6,000	
Processed co-substrate	ton/year.kWe	0	16	12	
Produced biogas	ton/year.kWe	3,158	3,947	4,000	[1]
Produced electricity	kWhe/year.kWe	6,000	7,500	8,000	
Reduction CH4 from storage	ton CO2-eq/year.kWe	14	7	5	[2]
Reduction CO2 from electricity production	ton CO2-eq/year.kWe	4	5	5	[3]
Reduction CO2 from heat production	ton CO2-eq/year.kWe	2	2	0	[4]
Investments	euro	€ 200,000	€ 250,000	€ 2,200,000	
Size of cogeneration unit	kWe	31	51	510	
Investments	euro/kWe	€ 6,538	€ 4,934	€ 4,314	
Government contributions	euro	€ 40,000	€ 50,000	€ 660,000	
Government contributions	euro/kWe	€ 1,308	€ 987	€ 1,294	
Profits from MEP	euro/year	€ 17,803	€ 36,860	€ 395,760	
Profits from MEP	euro/kWe.year	€ 582	€ 728	€ 776	[5]
Service and Maintenance costs + cost for co-digestion products and disposal of remains	euro/kWe.year	€ 654	€ 740	€ 647	
Lifetime	year	10	10	10	
Pay back time		10	7	6	[6]
National costs	euro/kWe	€ 1,122	€ 873	€ 727	
National cost-effectiveness	euro/ton CO2-eq	€ 58	€ 69	€ 78	

[1] Assuming digestion of pig manure with a production of 28 m3 of biogas per m3 pig manure. In system were cow manure is digested the biogas production is of the same order of magnitude.

[2] Calculated according to the TEWI approach resulting in a CH4 reduction of storage of 91 kg CO2-eq/ton of manure (Tijmesen et al, 2002)

[3] Reference for electricity production is the average power mix, including transmission and distribution and 2.5% is used to operate the manure digester

[4] Reference is a natural gas fired boiler with an efficiency of 90% and 25% of the heat is used to keep the manure digester in operation. For large scale digestion it is assumed that heat cannot be put to good use.

[5] The MEP is fixed for 10 years for all electricity produced, I.e. also own consumption to operate the digester.

[6] Simple pay back time = investments / (annual savings - annual costs)

[36] Tijmensen et al (2002) Anaerobic Manure Digestion at farms in existing storage systems (Mestvergisting op boerderijschaal in bestaande systemen). Ecofys, CLM, IMAG, Utrecht, The Netherlands, February 2002.

Emission source
• CH_4 emissions from manure management
• Investments. The investments include the once-only costs for the digester, co-generation unit, storage of digested manure, transport facilities and installation costs. It must be noted that the investments costs do not include cost to obtain the permits (which can be considerable) or to obtain land (in case of large scale digestion). Total investments relating to the (co)-digesters currently installed in the Netherlands are approximately 4.5 to 5 million euro. • Government contribution to investment. o Financial support of Novem (the Netherlands Agency for Energy and the Environment) was available, provided that the application met certain criteria. In the programs BSE/ DEN (sustainable energy), ROB (Reduction non-CO_2 greenhouse gas) and CO_2 reduction plan (CO_2-reductieplan) subsidy was granted for demonstration and market introduction projects. Total amount of grants supplied by the ROB for manure co-digestions amounts to approximately 2.6 million euro (this includes subsidies for project ranging from feasibility studies to demonstration projects) (SenterNovem, 2004e)[37]. Furthermore one project was financially supported within the CO_2 reduction plan with 88.000 euro (SenterNovem, 2004d)[38] o Other sources of financial support are fiscal instruments such as the EIA, MIA and VAMIL (EIA: Energy Investment Tax, MIA: Environment Investment, VAMIL: Free Depreciation of Environmental Investment Scheme). Anaerobic digestion is listed in the Energy and Environment list and not only eligible for the EIA or the MIA but also for the VAMIL (at least until the end of 2003). Some operators have also profited from the EINP (Energy Investment Scheme for the Non-profit sector) by setting up a foundation. Within the timeframe of this project we were not able to collect all the necessary information to draw up a detailed picture of government expenditures related to these fiscal measures (and subsidies in case of the EINP). The main problems is that: § Investments in anaerobic manure co-digestion can be (and are) reported under different items on the EIA list. This means we cannot get a detailed picture of investment in digesters. § The definition of investments for the EIA is often narrower then for the MIA (within the framework of the MIA not only the installation but also the building in which the installation is stalled is defined as investments in anaerobic co-digestion). This makes it difficult to get a good picture of the actual in-

[37] SenterNovem (2004e). Information received by e-mail from Mr E ter Avest date 25 November 2004
[38] SenterNovem (2004d). Oral information from Mr A de Kok date 24 November 2004

Emission source
• CH_4 emissions from manure management
vestments. § In order to be able to profit from these fiscal measures firms need to make profit. The last couple of year's profits in the pigs and cattle-breeding sector were very low or non-existent. Therefore firms could only profit form these fiscal measures by setting up special lease construction with financial institutes (banks), which in return consume part of the tax profit. The actual tax deduction is not known. o Considering the before mentioned points we were only able to make an estimate of the government expenditures for the period 1990-2003. From experience with different projects we estimated that the average profit from tax deduction measures for farmers operating a small-scale digester amount to ~20% and that operators of large-scale digesters will be able to profit ~30% tax deduction. Furthermore assuming that all projects applied for fiscal supports this results in an estimated government support of 0.9-1 million euro. • Profits from MEP. Subsidy on the electricity produced by anaerobic manure digestion. For 2005 the MEP subsidy is 0.097 €/kWh for 10 year fixed for all produced electricity. There is no obligation to deliver to the grid so this also includes own consumption. The MEP was introduced at July 1, 2003 at a level of 0.068 €/kWh (and raised in the following years). The estimated government support until the end of 2003 amounts to approximately 0.2 million euro. • Total government expenditures (ROB, fiscal measures, MEP and CO_2 reduction plan) in the period 1990-2003 estimated at approximately 4 million euro million euro. This results in a cost-effectiveness for the government in the period 1990-2003 of 140-180 euro/ton CO_2-eq. (it must be noted that this cost-effectiveness is much higher than reported for individual project, because for our calculations we also took into account government expenditures for projects that have not led to emissions reductions, such as feasibility studies and measurements).
Comparison of actual and forecasted cost-effectiveness in Option document
• Information in the Option document for cost-calculations was taken from (Jager et al, 1993)[39]. Investment costs for mesophilic farm-scale digester including energy production were assumed to be in the range of € 230-450 (DFl 500-1000) per m³ processing capacity (investments numbers in euro/kWe as used in our calculations are not available). • In the current calculations the investment for farm-scale digesters are 625 € per m³ processing capacity (400 m3 co-digester with investments of 250.000) and for large-scale digesters 610 € per m³ (3600 m3 co-digester the investment is

[39] Jager et al D en K Blok (1993). Cost-effectiveness of emisson reducing measures for methane in the Netherlands. Ecofys, Utrecht, 1993.

Emission source
• CH_4 emissions from manure management

2.200.000).
• The largest difference in investments arise from the fact that in calculation for the Option document it was assumed that the biogas was used in a boiler (which was already available and did not require additional investments) instead of a cogeneration unit which is currently common practice. Investments for the cogeneration unit are about 1/3 of the total investments.
• It is hard to compare the calculated cost-effectiveness in the Option Documents with the cost-effectiveness calculated in this project, because:
  o In the Option document it was assumed that almost no co-digestion would take place in the Netherlands, leading to an assumed low methane production per ton of manure.
  o In the Option document it was assumed that the biogas would be used in a boiler instead of a co-generation plant.

Factors influencing market implementation and cost-effectiveness in the Netherlands
1. Government regulations
• **Regulations regarding use of remains from co-digestion**. Implementation in the Netherlands is mostly hampered by government regulations relating to the use of all kinds of products for co-digestion (which is essential to make anaerobic digestion profitable). Current fertiliser regulations, dating from 1947, are a huge barrier for the use of co-substrates in the digester, because under the current regulations the remains of the digestion process, a mixture of manure and co-substrate, is not included under the fertiliser regulations. This means that the remains can only be transported or sold after an exemption to the fertiliser law is granted. This is very time consuming procedure. The Dutch government decided to tackle this obstacle by introducing a so-called "White list" of products that may be used as co-substrate. Firms using products on this list do not need to apply for exemption to the fertiliser law. • **Procedure to obtain environmental permits**. The permit procedure is very complex and local authorities and provinces often lack knowledge of manure digestion resulting in a delay of the procedure (Tijmensen et al., 2002)[36]. In case of co-digestions it is sometimes e.g. unclear which authorities are responsible for granting a permit, and if more then 100 ton of biomass is process per day an environment impact assessment is required. The environmental permit procedure often takes over a year. • **Regulations with respect to sanitation**. Lack of regulations with respect to sanitation results in somewhat reserve with agricultural farmers to use remains from the co-digestion process on their land. • **Building permit**. In the law co-digestion of waste is defined as an industrial activity. This means that a farm gets a new function requiring a change in zoning plan. Sometime local authorities judge that co-digestion of up to 10-20% fall within the current activities of a farm and do not require a change of the

Emission source
• CH_4 emissions from manure management
zoning plan. There is a lack of clarity at this point leading to differences on this point between local authorities. • **Financial support:** Financial support for investments in anaerobic digestion is mainly based on fiscal instruments (MIA, EIA en VAMIL). In order to be able to profit from these fiscal measures firms need to make profit. The last couple of year's profits in the pigs and cattle-breeding sector were very low or non-existent. Therefore firms could only profit from these fiscal measures by setting up special lease construction with financial institutes (banks), which in return consume part of the tax profit. • **Specific policies in the field of non-CO_2-greenhouse gases**. Within the framework of the ROB several studies were performed and grants were available.
2. Structure and characteristics of the sector

• **Size of farms:** The average size of cattle farms in the Netherlands is 48 cattle (6% of the farms have over 100 cattle), the average size pig farms is 410 meat pigs (6.5% of the farms have over a 1000) and 120 sows (CBS, 1996 en 2000)[40].
• **Availability of land to spread manure**. In particular pig farms in the Netherlands own little land compared to the number of stock, and therefore have no possibility to spread all the manure on their own land. This is an obstacle in the implementation of co-digestion as the farm needs to account for the quality of the remains of the digestion process because it is spread on the land of another farmer.
• **Profitability sector:** Profitability of the farming sector has been very low or even negative in the last couple of years leaving little room for investments (Tijmensen et al., 2002)[36]
• **Structure of the market for products to co-digest.** The market for products that can be used to co-digest come from households, auctions, local authorities, waters board and the food industry. The market is characterised by:
  • A large number of players ranging from large to small
  • Competitive position;
  • Image problems relating to food and feed scandals
  • Instable prices and market because of constantly changes regulations.
  • A limited number of large players (Cargill, Unilever) control the whole chain
  • Because of large variety of markets it is hard to close long-term contracts.

3. Feasibility
• **Level of investments:** The profitability of the sector is very low leaving little room for investments. • **Payback time:** Table 7 shows that anaerobic digesters that do not make use of

[40] CBS (1996 and 2000) Download from Statline.

Emission source
• CH_4 emissions from manure management
co-digestion have a pay back time of ~10 years. In the Netherlands currently only one such plant is in operations at an experimental farm. Digesters making use of co-digestion have payback times of approximately 6-7 years. It must be noted that the payback time can vary considerable from plant to plant. Pay back time is strongly influence by assumption on the cost for co-digestion products and cost to dispose of the remains of the digestion process. • **Image of the technique**. Anaerobic digestion long had a negative image in the Netherlands because of problems with digesters in '70 and beginning of the '80 (technical problems and bad profitability).
4. Market Implementation in the Netherlands
• Annual biogas production from manure in the Netherlands in 1999 was approximately 3 million m^3, resulting in a market penetration of approximately 0,2% (full market potential is defined as the situation in which the manure of all cattle and pigs is digested) (Tijmensen, 2003)[41]. The market share has not grown substantially since then. • One large-scale co-digester is in production since 2002. This installation digests 22,000 ton of manure and 3,000 ton of verge grass (as co-substrate). A few small-scale farm digesters in the range of 40 to of 100 kW are currently operational. Largest part of the digested manure comes from pig farms. Total reductions at the end of 2003 are approximately 0.01 Mton and cumulative reductions in the period 1990-2003 are approximately 0.02 Mton. • Furthermore several manure co-digesters are currently under development: approximately 15 farm-scale and 8 large-scale digesters. The expectations are that 50 % of these systems will be in operation in 2005, but that the other half will not be operational before 2006 due to the problems with obtaining permits.

Comparison with other countries

Market implementation of anaerobic co-digestion of manure is still low in the Netherlands. Market implementation in the Netherlands was mainly hampered by strict policies and regulation with respect to use of remains from co-digestion and long lead times to obtain environmental permits and building permits. Furthermore, with a pay back time of 6-10 years, investments do not always meet internal investments criteria. Two countries with a much higher market implementation of anaerobic co-digestion of manure in Europe are *Denmark* and *Germany*. The implementation context of these two countries in analysed in more detail.

[41] Tijmensen (2003) International comparison of anaerobic manure digestion (Internationale vergelijking mestvergisting). Ecofys, Utrecht, The Netherlands. November, 2003

Denmark[42]

1. Government regulations

• **Regulations regarding use of remains from co-digestion.** Regulations with respect to co-digestion are very transparent in Denmark and clearly laid down in one document.
  • A maximum of 25% of substrates e.g. waste from the agricultural industry may be co-digested with the manure to increase methane production.
  • For each type class of substrates used for co-digestion it is clearly defined how it can be applied or what treatment is required before it can be applied to agricultural grounds.
• **Financial support**. Anaerobic digestion is financially supported in several ways.
  • In the '80 investment grants of 40% were available, but was cut down to 20%. If a co-digester is installed financial support is also granted for investment in the storage tanks for manure (storage of manure is mandatory under Danish regulations).
  • Loans are available with low interest rates
  • Energy companies are obliged to buy the produced electricity against tariffs set by the government. Government subsidy equals 0.036 euro/kWh.
• **Nitrogen policies.**
  • In Denmark it is assumed that plants can more easily take up nitrogen in digested manure, and costs saving are achieved because less artificial fertilizer is needed.
  • Furthermore the large-scale digesters are used to redistribute nitrogen. Farmers receive an amount of digested manure to put on their land equally the amount they are allowed to put on their land to stay within the regulations of the nitrogen regulations.
• **Waste policies.** Organic waste needs to be recycled or burned. In case of burning a tax is levied of 28-42 euro/ton of waste. Organic waste can also be used to co-digest and because of the high taxes for burning operation of co-digestion installation can ask for compensation.
• **Permit.** Because of the large number of installation that already applied for a permit there is a lot of experience and knowledge with the authorities.

2. Structure and characteristics of the sector
• **Size of farms:** The average size of farms in Denmark is larger than in the Netherlands. 20% of the dairy farms have over 100 cattle and 13% of the pig farms have over a 1000. • **Availability of land to spread manure**. Danish law obliges farmers to have enough land available to spread the manure. If farmers do not have enough land they are forced to show signed contract that they are able to spread the manure on the land of other farmers.

[42] All information is taken from Tijmensen (2003) and checked and updated by Tijmensen date 29 November 2004.

• **Profitability sector:** Profitability of the farming sector is slightly positive in Denmark. • **District heating.** Denmark has an extensive district heating system, which contributed to the market development of large-scale manure digestion. These digesters (but small-scale digesters as well) deliver the produced heat to the district heating system and are compensated with 11 euro/GJ of delivered heat (large scale).
3. Feasibility
• **Cost-effectiveness:** In Denmark the profitability of anaerobic manure digestion is better than in the Netherlands. The investments support from the government is higher and other additional yields like income from waste processing firms that want to avoid taxes and income from the sale of heat which are mostly not available in the Netherlands. • **Level of investments.** On average farms are bigger in Denmark and more profitable, leaving more room for investments.
4. Market Implementation
• Annual biogas production from manure in the Denmark in 2001 was approximately 65 million m^3, resulting in a market penetration of approximately 7% (full market potential is defined as the situation in which the manure of all cattle and pigs is digested). • In 2002 approximately 20 large-scale digesters (processing 75% manure and 25% co-substrate) and 47 small-scale digesters were in operation. Largest part of the biogas production (90%) is produced with the large-scale digesters.

Germany

1. Government regulations
• **Permits**. Every installation needs a building permit. The trajectory to obtain a permit for a manure digesters is approximately 4 months, if substrates are used to co-digest the whole trajectory can take 1 year. Because of the large number of installation that already applied for a permit there is a lot of experience and knowledge with the authorities. • **Regulations regarding use of remains from co-digestion.** Regulation with respect to the use of remain of co-digestions are clearly defined. Regulations differentiate between three types of co-substrate; organic material deriving from the agricultural sector, energy crops and bio-waste. Only for co-substrates falling under the category bio-waste a special permit is required. Furthermore a positive list is available of types of bio-waste for which a permit will be issued without further testing. • **Financial support.** On the national as well as the regional level financial support is available. This includes investments support through grants and soft loans. Furthermore electricity produced by means of biogas and delivered to the grid is financially supported within the framework of the Erneubarer Energien Gesetz (EEG). Within the EEG for a fixed period of 20 year the compensation

is 0.097 (for installation > 500kWe and < 5 MWe) to 0.101 (for installations < 500 kWh) for each produced kWh of electricity.

2. Structure and characteristics of the sector

- **Size of farms:** The average size of farms in Germany is larger than in the Netherlands and Denmark. 50% of the dairy farms have over 100 cattle (in total 8000 farms) and 17% of the pig farms have over a 1000 (in total 3500 farms).
- **Availability of land to spread manure**. Most German farms have enough land available to apply their own manure.
- **Profitability sector:** Profitability of the farming sector is not very good.
- **Availability of co-substrate.** The most frequently used co-substrate is maize grown on fallow lands, which makes rather cheap.

3. Feasibility

- **Cost-effectiveness:** In Germany the profitability of anaerobic manure digestion is better than in the Netherlands. Especially guaranteed 20 year compensation through the Erneubarer Energien Gesetz (EEG) makes investments if an installations attractive (compared to the 10-year compensation within the MEP for the Netherlands).
- **Level of investments.** On average farms are bigger in Germany but are not as profitable as in Denmark.

4. Market Implementation

- Annual biogas production from manure in the Germany in 2002 was approximately 736 million m^3, resulting in a market penetration of approximately 18% (full market potential is defined as the situation in which the manure of all cattle and pigs is digested).
- At the end of 2002 approximately 1900 installations were in operation with a total capacity of 234 MWe. Between 10% and 15% of the installations are large-scale industrial installations using over 50% of co-substrates. The remaining are farm scale digesters of which 40% applies co-digestion.

CH_4 emissions from landfill sites

The Netherlands

Emission source
• CH_4 from landfill sites
Emission reduction measure
• Collection and utilisation of landfill gas (for energy production)
Reference situation
• It is assumed that in the absence of environmental policies landfill gas would not have been collected and utilised for energy production.
Short description of the reduction option
• The measure includes the installation of an impermeable barrier to contain the site, and placing an impermeable cap to prevent the landfill gas migrating from the site laterally or through the surface of the landfill. In addition a network of gas recovery wells is installed in which the gas is recovered. • The collected landfill gas is either o Flared, o Used for production of heat and electricity in a co-generation plant, or o Upgraded to substitute natural gas.
NETHERLANDS
Actual cost-effectiveness in the Netherlands
• The total investment costs for landfill gas collection and utilisation projects in the period 1990-2003 are estimated to range from 35 and 55 million euro. The estimate were derived from a survey including 33 landfill sites of which 22 returned the survey with figures on investment costs to: capture the landfill site, install the collection system and install equipment to utilize (or flare) the collected biogas. The survey included project that were executed in the period 1989-1996, but because investments at landfill sites were limited in the period 1996-2003 this provides a good estimated of the total investments for the period 1990-2003 (Tebodin, 1996)[43]. • The financing of project to collect and utilise landfill gas are very site specific. In general the landfill gas extraction part of the project is financed from collected dumping tariffs and contributions from households. In addition governmental programmes and energy companies financially supported the utilisation of landfill gas for energy production (e.g. gas engines) (Foundation of Waste companies, 2004)[44], (Essent Wijster, 2004)[45] (Tebodin, 1996). • During the early nineties until 2000 the Environmental Action Plan

[43] Tebodin (1996) Cost effectivenessof landfill gas collection and utilisation, assignment by Advise Centre Landfill gas and Association of Waste treatment companies, december 1996
[44] Foundation of Waste Companies (Vereniging Afvalbedrijven) (2004) Oral information Edwin Schokker, AVN, October 2004
[45] Essent Wijster (2004) Oral information Gert van der Stal, Mr Overzet, 5 November 2004

Emission source
• CH_4 from landfill sites
(MAP) of the energy companies financially supported utilisation of landfill gas for energy production. The exact financial support from MAP in the period 1990-1996 is unknown. Based on information from the Tebodin study and the known figures in the period 1997-2000 (EnergieNed, 2004)[46] the financial support is estomated to be 2-4 million euro. • Furthermore energy production from landfill gas is considered as renewable energy and was exempted from Regulated Energy Tax (REB). Total tax exemption from REB is estimated to accumulated to 10-15 million euro for the period 1996-2003. • In addition the energy investment deduction scheme (EIA) is also available for landfill gas collection and utilisation projects. The total awarded financial support in the period 1997 – 2003 is estimated at 0.6 million euro, assuming that investors were able to profit from an 18% investment deduction (Senter, various)[47]. • Other, more indirect, financial contributions by the government concern the task force within the ROB programme and the establishment of the Advice Centre for landfill gas. The ROB programme is aimed at getting more insight on the possibility to increase the amount of collected methane and support demonstration projects. Total costs for these project amounts to 0.7 million euro. • This results in a national cost-effectiveness of 3-5 euro/ton CO_2-eq and a cost-effectiveness for the government of 1-2 euro/ton CO_2-eq.
Comparison of actual and forecasted cost-effectiveness in Option document
• In the Option document two measures were included - Improved methane oxidation in top layers of land fill sites with a cost-effectiveness of 0-5 euro/ton CO_2-eq. - Stimulate generation of landfill gas by percolate water infiltration with a cost-effectiveness of 0-2 euro/ton CO_2-eq. • The measures mentioned in the Option document are not yet implemented on the full-scale and therefore no comparison can be made.
Factors influencing implementation and cost-effectiveness in the Netherlands
1. Government policies
• **Waste policies (separate waste collection)**. General objective is to reduce the amount of dumped waste considerably. The dumped amount of waste decreased from 13 Mton in 1992 to 5 Mton in 2003. The intention is that waste is only dumped at landfill sites if there are no other waste treatment options available. In addition there is a policy of separate waste collection and a ban of dumping specific types of hazardous waste.

[46] EnergieNed (2004) Emails from Roel Kaljee, November and December 2004
[47] Senter (various). Annual report Energy Investment Deduction Scheme for the year 1998-2002.

Emission source
• CH_4 from landfill sites

• **Dumping regulations:**
  o The tariffs for dumping of non-hazardous waste increased from several euro per ton in 1975 to about € 100 (excluding VAT) in 2000. The main component of the tariff is the tax on environmental basis (WbM).
  o National emission directive (NER, 1994) and dumping order soil protection (1998). These regulations states that at new sites:
    § Already during dumping of waste arrangements have to be made to extract the landfill gas.
    § Landfill gas has to be utilised inside or outside landfill site.
    § Specific emission requirements apply for flaring.
• **Financial support:** The government financially supported investment in utilisation of landfill gas for energy sued.
  • *(MAP)* 1991-1995 Subsidy was available from the Environmental Action Plan of energy companies (total budget for the period 1990-2003 (2.5-3.5 million euro)
  • (*REB*) 1996-2002 Electricity from landfill sites was considered as green electricity (total budget for the period 1990-2003 10-15 million euro)
  • *(MEP)*: in 2003 no subsidy was available as from 1 July 2004 there is subsidy available for the generated electricity from landfill gas (0.6 euroct/kWh)
  • (EIA) 1997-2003 Favourable energy investment deduction scheme was in place for landfill gas extraction and utilisation projects (total financial support about 0.6 million euro)
  • *(ROB)***.** Financial contribution for demonstration projects. When landfill gas is used for energy generation, the next step is to increase the landfill gas production from the site. Within this framework several feasibility studies and demonstration projects were carried out (ERM, 2000)[48,] (Grontmij, 2004)[49], (Afvalzorgdeponie, 2004)[50]. Other demonstration projects concern e.g. methane oxidation in top layers

[48] ERM (2000). Minimising of methane emissions at landfill sites (Het minimaliseren van methaanemissies op stortplaatsen). ERM, TNO, Afvalzorg Deponie, Haskoning, AVM, Essent milieu, ECN, Grontmij, September 2000

[49] Grontmij (2004) Demonstration project accelerated winning of landfill gas (Demonstratieproject vervroegde stortgasonttrekking bij afvalverwerking). Stainkoeln bv, Novem – project number 375004/0030, 24 May 2004

[50] Afvalzorg Deponie BV (2004). Demonstration of a clean closed burner (Demonstratie clean enclosed burner voor arm stortgas). Afvalzorg Deponie, July 2004

[51] Oonk (2001) Improved methane oxidation in top layers of land fill sites (Verbeterde methaanoxidatie in toplagen van stortplaatsen), TNO-MEP, R-2001

[52] Afvalzorg Deponie BV (2003), Methane emission reduction through injection of air in the top layer of land fill sites (Methaanemissiereductie door luchtinjectie in de toplaag van stortplaatsen, Demonstratie van het Smell-Well systeem op stortplaats Braambergen), April 2003

Emission source
• CH_4 from landfill sites
(Oonk, 2001)[51], (Afvalzorgdeponie, 2003)[52], All these techniques are not yet implemented on a large scale. Total budget for these demonstration projects amounts to 0.7 million euro. • Furthermore the government supported the foundation of an information centre for landfill gas. The budget is unknown. • Total government expenditures are estimated at 13-19 million euro.
2. Structure of the sector
• **Ownership structure**: Local and regional authorities own most landfill sites. The association of waste companies estimated that approximately 25% of the land sites is private property. The investments at landfill sites are mainly driven by national legislation and the strictness of the requirements depend strongly on the location of the site (e.g. site close to building area) (Foundation of waste companies, 2004). Energy companies often own installations for landfill gas utilisation and leasing constructions are very common as well. • **Information exchange within the sector.** In beginning of the '90 the Advice Centre for Landfill gas was founded. Their main task was to stimulate landfill gas utilisation projects. They brought together stakeholders (landfill sites, energy companies) and collected all required information to implement projects (landfill gas production, composition of landfill per site, economic models etc.) (SenterNovem, 2004b)[53]. • **Profitability of the sector:** The room for investments within the waste dumping sector is decreasing because of the governmental policy to discourage dumping of waste, resulting in decreased income from waste taxes and a worsening of the profitability of landfill gas projects (Essent Wijster, 2004)[45].
3 Feasibility
• **Level of investment:** Because of government regulations investment were done in order to comply with government regulations. Total investments on average amounted to 1-2 million euro per site, including investments to cover the site and collect the methane, but also equipment to utilize the landfill gas for energy production (Tebodin, 1996)[45]
4. Market Implementation in the Netherlands
• Nowadays landfill gas of all large sites is collected, compared to about 10 sites in the early nineties. In 2003 32% of the collected gas (173 million m^3) was flared and 68% was utilised for energy production (this includes upgrading to natural and the production of heat and electricity in a gas engine) (CBS/Novem, 2003)[54]. Measures to increase methane production from landfill site are not yet implemented on a large scale (they are still in the demonstra-

[53] SenterNovem (2004b) Oral information Kees Kwant SenterNovem, 14 October 2004
[54] CBS/Novem (2003). Monitoring Duurzame Energie (Monitoring of Renewable Energy).

Emission source
• CH_4 from landfill sites
tion phase). • At the end of 2003 51 dumping sites were covered with a layer and the landfill gas is collected (AOO/VVAV, 2004)[55]. • Total calculated reduction at the end of 2002 is 1.5 Mton CO_2-eq. This includes emission reductions of methane and reduction related to energy production. The accumulated emission reduction for the period 1990-2003 accumulates to 17 Mton CO_2-eq.

Comparison with countries

Landfill gas from all large sites in the Netherlands is collected and utilised. The important driving forces to realise these projects were national dumping regulations, (financial) stimulation from the energy companies in combination with good and centralized information exchange.

Most (Western) Northern European countries have many landfill gas collection and utilisation projects. Denmark, Sweden and Germany have like the Netherlands an (almost) saturated market. Due to high pay back tariffs for electricity from landfill gas in Denmark there are many landfill gas collection and utilisation projects at relative small sites in this country. The realisation of landfill gas projects in the United Kingdom and France lags somewhat behind (LFGConsult, 2004)[56].

United Kingdom

1. Government regulations
• **Non Fossil Fuel Orders (NFFOs)** The Electricity Act of 1989 introduced the Non-Fossil Fuel Obligation which required the electricity supply companies in the UK to secure specified amounts of new generating capacity from non-fossil sources, including renewables. Proposals of renewable energy projects compete with each other through a tender process. The technical, economic, commercial and legal aspects of a project were examined and subsequently the government selected the cheapest schemes to secure the required capacity within each technology band. If a project competed successfully, it was awarded a contract to generate at its contracted capacity for a period of up to 15 years receiving its final bid price for each kWh generated. Operators had five years from the signing date of the contract to start the 15-year price commitment. The NFFO rounds were in 1990, 1991, 1995, 1997 and 1998. • **Renewables Obligation (RO)** The Renewable Obligation is the key policy mechanism by which the government is encouraging renewable energy now.

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[55] AOO/VVAV (2004) Waste Processing in the Netherlands, data 2003, 2004
[56] LFGConsult (2004) Oral information Hans Willumsen, LFGConsult, Denmark, november 2004

The first round was April 2002-2003. In order to provide a stable and long-term market for renewable energy, the RO will remain in place until 2027. Yearly targets have been set up to 2011. Each supplier will have to sell a target proportion of their sales from renewables, or prove that someone else has done so on their behalf. Electricity from generation stations built under the NFFO arrangements is eligible for the Obligation, if they meet its requirements.
2. Structure and characteristics of the sector
• **General characteristics** The number of operating landfill sites fell from about 2400 in 1994 to 2300 in 2003. However in consideration has to be taken that the latter sites are on the average larger. About two-thirds of land filled waste is biodegradable organic matter from households, businesses and industry. The UK's landfills contain a higher proportion of biodegradable waste than most other European countries. • **Ownership structure** Landfill sites are mostly owned by local authorities, but managed by waste contracting companies. In the last decade the sector has been consolidating (lots of company mergers and takeovers).
3. Feasibility
• Compared to other renewables and schemes the NNFOs were considered by policy makers a cheap and effective way to stimulate landfill gas projects. The policy instrument of NFFO has been successful: the number of project rose and the bid price (price required for projects to operate) fell. One point of criticism is that the NFFOs did not affect enough sites; only the most profitable landfill gas generation sites were stimulated.
4. Market Implementation
• The NFFOs in total contracted 329 landfill gas projects. These projects had a total declared net capacity (DNC) of 700 MW. The majority of landfill gas project were implemented. Not all project were implemented due to planning or grid connection issues. In March 2004 226 projects (somewhat fewer sites) were still live and their DNC was 475 MW. • The electricity generated from landfill gas increased from 139 GWh in 1990 to 3276 GWh in 2003. • In 1990 the waste to landfill sites was 75.7 M ton, the recovered CH_4 (flared or utilised) was 0.382 Mton, resulting in 1117 kton CH_4 emissions (23.5 M ton CO_2 eq.). In 2002 the waste to landfill was 56.7 M ton, the recovered CH_4 (flared or utilised) was 2958 Mton, resulting in 420 kton CH_4 emissions (8.8 M ton CO_2 eq.). Both the power generation schemes and increasingly stringent regulation on CH_4 emissions and flaring have contributed to increased CH_4 recovered. Over time the fall in waste land filled will have an increasingly impact.

CH_4 emissions from the oil- and gas industry

The Netherlands

Emission source
• CH_4 from oil- and gas production
Emission reduction measure
• Reduction of purge gas streams • Recovery and utilisation of process emissions as a fuel gas • Minimising of strip gas in glycol dehydration
Reference situation
• It is assumed that in the absence of environmental policies no reduction measures would have been implemented.
Short description of the reduction options
Several measures to reduce the amount of methane that needs to be vented were implemented. The most important being: • Reduction of purge-gas streams. Purge gas is normally applied in vent and flare systems to prevent air from entering the system. As the amount is often unnecessarily high, reduction in methane emissions from this process can be achieved by reducing the amount of purge gas used. A second option is to use an alternative purge gas, such as nitrogen. • Recovery and utilisation of process emissions as a fuel gas. Recovery and utilisation of process emissions as a fuel gas is an option if the quality of the gas is sufficiently high. Both micro gas turbines and gas turbine engines are demonstrated technologies on- and offshore. • Minimising of strip gas in glycol dehydration. Natural gas is used as a strip-gas in the glycol regenerator. This means that it is added to the product gas, which has been dissolved in glycol and it then comes off with the product gas when it is regenerated from the glycol. It is possible to minimise methane emissions form the strip gas by changing the design and operation of the process. Measures include reducing the amount of used strip gas, increasing the temperature at which the glycol is regenerated and using alternative stripping gases.
NETHERLANDS
Actual cost-effectiveness in the Netherlands
• No information is available on the costs-effectiveness of the different options implemented in this sector[57].
Comparison of actual and forecasted cost-effectiveness in Option document
• In the Option document the national cost-effectiveness for utilisation of gas at new drilling stations was estimated at -2.3 euro/ton CO_2-eq. (-5 DFl/ton CO_2-

[57] Despite several request for information on investments costs, firms did not provides us with details on investments levels.

Emission source
• CH_4 from oil- and gas production
eq.). An average investment is 450,000 euro (1 million DFl) per platform, which leads to a reduction of 400 ton CH_4 emission per year. • In the Option document it was assumed that large parts of the reduction would be achieved autonomously, because new drilling station are put into operation and old ones are demolished (this was at the time of writing the options document not yet included in the reference scenario). • Furthermore it was assumed that the reduction potential in 2010 is limited because of a strong decrease in production volumes.
Factors influencing implementation and cost-effectiveness in the Netherlands
1. Government policies
• **Environmental policies: environmental covenant.** The Dutch government negotiated an environmental covenant with the oil and gas industry in 1995. The aim was to reach a 10% CH_4 emission reduction in 2000 compared to 1990. This target was exceeded and a 65% CH_4 emission reduction was achieved in 2001 compared to 1990. Subsequently agreements about additional measurements were made within the covenant. • **Environmental policies: voluntary agreement on energy efficiency.** Other stimulating policy instruments were the long-term agreements concerning improvement of the energy efficiency. Besides energy saving measures these agreements stimulated the implementation of measures for CH_4 emission reduction as well (e.g. less venting). Due to the environmental covenant and long term agreements the sector was stimulated to explore the possibilities for methane emission reduction. Nogepa stresses that long-term agreements were a strong incentive for reductions measures (Nogepa, 2004)[58]. • **Environmental policies: special emission regulation (NeR)**. Within the framework of the Special emission Regulation in 2000 all installation within the oil and gas industry had to comply with the state-of-the-art technology. • **Specific policies in the field of non-CO_2 greenhouse gases**. As the result of activities within the framework of the Reduction Plan on non-CO_2 greenhouse gases measure to reduce the emission of CH4 were explicitly included in the voluntary agreements.
2. Structure of the sector
• **Size and number of firms**: In the Netherlands there are in total 65 firms in the oil- and gas industry (CBS, 2004b)[59]. This includes production as well as distribution companies. The 10 large international companies are the productions companies, which are member of the Dutch oil and gas exploration and production association, called Nogepa. • **International competition:** There is international competition between the companies, but in the light of the comparison between the Netherlands and

[58] Nogepa (2004) Oral information Cees van Oosterom, Nogepa, 8 October 2004 and 16 November 2004

[59] CBS (2004b) Information from www.cbs.nl Statline, 18 November 2004

Emission source
• CH_4 from oil- and gas production
other countries the competition within the international companies themselves is just as important. For instance in BP oil extraction offshore in the North Sea has to compete with oil extraction aboard (e.g. in Angola and Argentina) (Nogepa, 2004).
3. Feasibility
• **Cost-effectiveness of measures.** Most measures are cost-effective and maybe would in the long run also have been implemented in the absence of environmental policies. However these policies forced companies to have a thorough look into reduction measures and probably led to pre-investments in reduction measures. • **Level of investments:** It can furthermore be concluded that the level of additional investments was probably not a big issues as achieved reductions exceeded the reduction targets in the environmental covenants.
4. Market Implementation in the Netherlands
• In 1990 venting of gas was standard, because of safety regulations and the policy that venting is better than burning (e.g. safety, bird protection). • The measures implemented in the period 1990-2003 resulted in a reduction of methane emission with 65%, while the production level almost stayed on the same level (Nogepa, 2003)[60]. • Total reduction achieved in the period 1990-2003 amounts to 0.97 Mton CO_2-eq at the end of 2003, and accumulated reductions amount to 6.8 Mton CO_2-eq.

Comparison with other countries

Since 1990 the methane emissions in the gas and oil industry were considerably reduced (with 65%) in the Netherlands. Voluntary long-term agreements were the important framework from which stimulation of environmental and energy saving measures took place.

Another important gas producing country in Europe is the United Kingdom. In 2001 several companies, organised in the United Kingdom Offshore Operation Organisation, participated in a voluntary programme to reduce emissions from flaring. Furthermore gas flaring is controlled by the DTI through a 'Flare Consent', which puts a ceiling on the amount of gas each facility can flare each year. This has already led to emission reductions. Next to this the sector furthermore committed itself to improve their energy efficiency. Most measures are still in the research and planning phase and have not been implemented yet (UKOOA, 2004)[61]. As for the Netherlands no information is available on the cost-effectiveness of measures.

[60] Nogepa (2003), Annual Environmental report 2001 (Milieujaarrapportage 2001), Fo-industry, DenHaag/Gouderak, 10 April 2003
[61] UKOOA (2004). Website http://www.ukooa.co.uk/ visit data 29 November 2004

PFC emissions from aluminium production

Netherlands

Emission source
• PFC emissions from primary aluminium production
Emission reduction measure
• Switching from Side-Worked Prebake to Pointfeeder Prebake
Reference situation
• For the calculations it is assumed that in the absence of environmental policies the aluminium producers would not have switched from Side-Worked Prebake to Pointfeeder Prebake. • It must however be noticed that switching from Side-Worked Prebake to Pointfeeder Prebake was part of a modernization of the production facilities and expansion of the production capacity. Both Dutch producers increased their production capacity with almost 20% through this modernisation process. This means that large parts of the modernisation project would also have been implemented in the absence of environmental policies (Anonymous, 2004)[62].
Short description of the reduction option
• Modern primary aluminium production facilities use the Pointfeeder Prebake (PFPB). This technology uses multiple "point feeders" and other computerised controls for precise alumina feeding. A key feature of PFPB plants is the enclosed nature of the process resulting in very low fugitive emissions from these cells and a reduction of the PFC emissions with on average 95% (Harnisch et al, 2000)[63]. Furthermore the technology leads to significant savings on electricity use.
NETHERLANDS
Actual cost-effectiveness in the Netherlands
• The following figures are costs for the modernisation at Pechiney (Pechiney, 2004)[64]. o Investment costs to switch from Side-Worked Prebake to Pointfeeder Prebake: 35 million euro. These are the costs that can be attributed to the switch from .Side-Worked Prebake to Pointfeeder Prebake. It is must be noted that not all costs can be attributed to the reduction of PFC Total investment costs for the modernisation process were approximately 133 million euro. o Government contribution from the ROB was 0.2 million euro and from

[62] Anonymous (2004). PFK uitstootreducties bij primaire aluminiumssmelters in Nederland. Hoe miliemaatregelen de productie verhogen (PFC reduction with primary aluminium producers in the Netherlands. How environmental measures increase production).
[63] Harnisch et al (2000). Economic Evaluation of Emission Reduction of HFCs, PFC and SF6 in Europe. Ecofys, Cologne, Germany. April, 2000.
[64] Pechiney (2004). Centrale Middenvoeding in Aluminiumproductie (Point Feeder Prebake in Aluminium production). Pechiney, September 2004 (Confidential)

Emission source

- PFC emissions from primary aluminium production

    the CO_2-reduction plan 1.3 million euro.
    - o Savings on electricity: in total annual savings of 40 GWh are reached. Pechiney did not provide figures on cost per unit of used of electricity, we assumed that the cost for Pechiney lie in the range of 0.04 to 0.06 euro/kWh, leading to annual savings of 1.6 to 2.4 million euro. For the calculation of the national cost for electricity production were assumed to be in the range of 0.03-0.035 euro/kWh.
    - o Achieved reduction of PFC are 1,2 – 1,3 Mton CO_2-eq per year and 0.01-0.02 Mton of CO_2 because less electricity is consumed (the lower range reflect the situation in which a natural gas fired power plant with an efficiency of 50% is taken as a reference and the upper range reflect the situation in which the average mix is taken as the reference)
    - o This results in a national cost-effectiveness of ~1 euro/ton CO_2-eq and a cost-effectiveness for the government of +0.10 euro/ton CO_2-eq.
- No detailed figures on the investment level at Aldel are available, it is only mentioned that Aldel did not receive financial support from the government (Anonymous, 2004)[62] and that total investment for the modernisation were 73 million euro (Milieumagazine, 2001)[65]. Assuming that the cost-effectiveness of the modernisation process at Aldel lies in the same range as for Pechiney total investments for Aldel lies in the range of 11-12 million euro and total investment in the aluminium industry in the period 1990-2003 accumulate to 46-47 million euro.

Comparison of actual and forecasted cost-effectiveness in Option document

- The Option document does not hold number on the cost-effectiveness because of lack on reliable data.
- In the Option document the reduction measure implemented at Aldel were already taken into account.

Factors influencing implementation and cost-effectiveness in the Netherlands

1. Government policies

- **Integrated Pollution and Prevention Control (IPPC)**. The European IPCC directs the future permitting of industrial facilities, and considers Centre Worked Prebake Cells as the best available technology (BAT). EU countries have to take the BAT into consideration when issuing operation permits to industrial production facilities.
- **Environmental covenant**. The Dutch government negotiated environmental covenants with a large number of industry sectors amongst which the aluminium industry. These covenants held reduction targets for a large number of environmental pollutants. Next to reductions of PFCs and CO_2 switching from Side-Worked Prebake to Pointfeeder Prebake also leads to (relative) reduc-

[65] Milieumagazine (2001). "Het hele productieproces moest over de kop". Milieumagazine 11-2001.

Emission source
• PFC emissions from primary aluminium production
tions of the emissions of fine particulars, NO_x, fluoride and NMVOC (PFC falls under the definition of VOCs). • **Environmental Permit.** In the environmental permit of both aluminium producers' maximum emission levels for PFC are included. • **Financial support**: Pechiney received financial support within the framework of the ROB and from the CO_2-reduction plan. The total amount of government support however amount to 1.4% of the total investment. • **Specific non-CO_2-greenhouse gases**: No specific policies were introduced in this area in the Netherlands, apart from the financial support from the ROB programme and the CO_2 reduction plan for Pechiney.
2. Structure of the sector
• **Size and number of firms**: There are two aluminium smelters in the Netherlands. The limited number of firms made it relatively easy for the Dutch government to come to bilateral agreements with the firms on limiting emissions. • **International competitiveness.** The aluminium industry is facing strong international competition. Investment decisions on modernization of the production facility are therefore strongly influenced by the profit margins on aluminium. Profitability is strongly influenced by the access to cheap electricity because ~ 1/3% of the cost price of aluminium is determined by energy costs. • **Innovative character:** The production of primary metal is a fairly mature technology with very long investment cycles. Incremental innovations are mainly implemented in new smelters. Key objectives include increasing the size of smelters, increased cell throughput and increased automation leading to productivity gains. Inert anode technology is being tested but unlikely to be implemented on a widespread scale in the near to mid-term.
3. Feasibility
• **Cost-effectiveness of the measure (payback time)**: It is difficult to calculate the cost-effectiveness for the end-users, as no information is available on the additional revenues resulting from the increase in production levels. If only the savings on electricity are taking into account and using a discount rate of 12% the cost-effectiveness for the end-user is approximately 2 euro/ton CO_2. • **Level of investments**: Investments in the modernisation and expansion of the production facilities are part of normal investments cycles in order to keep up with the international competition. However, major retrofits of smelters take place after typically 20-30 years if the production site remains attractive in respect to electricity costs. Old smelters usually have no remaining capital costs. Therefore they usually become the target for retrofitting only if other environmental obligations make this unavoidable or major productivity gains can be achieved from increased automation.
4. Market Implementation in the Netherlands
• Both Aluminium producers in the Netherlands (Aldel and Pechiney) switched

Emission source
• PFC emissions from primary aluminium production
from Side-Worked Prebake to Pointfeeder Prebake. Aldel already implemented the measure in 1998 and Pechiney concluded the modernisation in 2003 (Anonymous, 2004) • Emissions of PFCs have decreased by 0.4 Mton at Aldel (Aldel, 2003)[66]and with 1.2-1.3 Mton CO_2-eq with Pechiney (Pechiney, 2004)[64]. For Pechiney this amount is corrected for additional natural gas input due to the increase of the production of aluminium. It however excludes the CO_2 reduction due to savings on electricity input, these amount to 40 GWh per year, equalling a reduction of 0.01 Mton CO_2 (taking as a reference a natural gas fired STEG with an efficiency of 55%). Total reductions at the end of 2003 amount to 1.6-1.7 Mton CO2-eq. Accumulated reduction in the period 1990-2003 are 3.2-3.3 Mton.

Other countries

Emissions of PFC have decreased drastically in the last decade in the Netherlands. The same trend is observed in other European countries. In the period 1990-2003 a large number of aluminium smelters closed in Europe, and at the remaining production facilities modernizations were carried out resulting in large decrease of PFC emissions (Harnish et al, 2001)[63]. There is no strong dedicated PFC regulation in EU countries. There are a number of voluntary agreements around (e.g. France, Germany and Norway) and a number of other countries regulate emissions under the Integrated Pollution and Prevention Control.

[66] Aldel (2003) Public Annual Environmental Report (Publiek Milieujaarverslag. Aldel, Delfzijl, 2003

PFC emissions from the semiconductor industry

The Netherlands

Emission source

- PFC emissions from the semiconductor industry

Emission reduction measures

1. Optimising the Chamber Clean Processes
2. Replacement of C_2F_6 by in particular NF_3 or C_4F_8O in Chamber Clean
3. Installation of after burners or other abatement techniques

It must be noted that these reduction measures are not yet implemented on a large scale with the Dutch producers of integrated circuits, but are currently tested on a limited number of operational units.

Reference situation

- It is assumed that in the absence of environmental policies no measure would have been implemented to reduce the emission of PFCs.

Short description of the reduction option

- Philips is currently investigating 5 different reduction options and will decide afterwards which reduction options can qualify for Best Known Methods (BMKs) and will be implemented on a full scale (in the Netherlands but in other production site of Philips as well).
- The investigated measures include:
- Replacement of C_2F_6 by NF_3/Remote plasma system in CVD chamber cleaning (dedicated machines). Reduction potential > 95%.
- Replacement of C_2F_6 by C_4F_8O in CVD chamber cleaning. Reduction potential > 80% (dedicated machines).
- Installation of low energy consuming/low cost after burners. Possible reduction potential 60%.
- Implementation of new plasma etching technique including local atmospheric abatement. Reduction potential > 99%.
- Addition of new local low-pressure plasma abatement to existing etching machine. Reduction potential > 95% (Philips, 2004a)[67].

NETHERLANDS

Actual cost-effectiveness in the Netherlands

- The project *currently* executed by Philips and in which the 5 measures are investigated through implementation and testing on a small scale leads to a reduction of 0,0084 Mton. Total costs for the project are0.5 million euro and the government support is 0.2 million euro. This results in a national cost-effectiveness of 18 euro/ton CO_2-eq.
- As already stated the reduction measures are not yet implemented on the full scale, so only data are available on the expected cost-effectiveness. Philips

[67] Philips (2004a) Information taken from the project descriptions drawn up to apply for financial support within the ROB date 12 march 2004 (Date at which request was received by SenterNovem)

Emission source
• PFC emissions from the semiconductor industry
estimates the following costs if the measures are implemented on *full scale* in the Netherlands: • Total investments: 8,1 million euro (or 8.7 if the costs of the research phase)[68] • Total estimated annual additional costs are estimated at 200,000 euro. • Total reduction 87%. Applied to 2003 emission total reduction 187 kton. • Depreciation period investments 4 years. • National costs-effectiveness: 12 euro/ton CO_2-eq. • Furthermore, it should be noted, that additional investments must be made for the treatment of products, generated by PFC abatement, i.e. wet scrubbers to reduce HF and SiF_4 emissions, and liquid fluoride treatment to reduce fluoride emissions from wet scrubbers and wastewater. As these measures are in place for other fluoride streams, it is very difficult to estimate to which degree these measures are to be attributed to PFC emission reduction. However, the cost impact may be substantial depending on the local situation. ~~It furthermore must be noted that not all measures are implemented with the aim just to reduce PFC emissions, which means that in principle not all costs can be attributed to the reduction of PFCs~~.
Comparison of actual and forecasted cost-effectiveness in Option document
• The option document does not hold detailed figures on costs to reduce emissions of SF_6 from the semiconductor industry. Because of lack of detailed figures costs were assumed to be in the range of 0-50 DFl/ton CO_2-eq (0-23 euro/ton CO2-eq). • In the Option document it was assumed that the semiconductor industry sector would grow with 15% per year, whereas Philips currently expect to achieve an annual growth in the output of IC of 10%.
Factors influencing implementation and cost-effectiveness in the Netherlands
1. Government policies
• **European F-gases regulation**. Recently environmental ministers agreed on rules to limit emissions and application of fluorinated gases. The regulation is aimed at improving containment by setting minimum standards for inspection and recovery. It does not comprise relevant measures affecting PFC emission levels from the semiconductor industry. • **Environmental permit.** In the environmental permit of Philips Semiconductors an absolute cap is included on the emissions of PFCs (a cap is set for each separate PFC gas). An update of the permit is being prepared

[68] Investments costs: A) replacement of C2F6 by NF3 as etching gas 110,000 euro per chamber B) replacement of C2F6 by C4F8O in the CVD production step 12,000 euro per tool C) installation of an after burner 110,000 euro per tool D) application of new plasma etching technique no additional investments E) Adding new plasma abatement to existing etching machine 60.000 euro per chamber

Emission source
• PFC emissions from the semiconductor industry
for 2005, in this permit a new cap will be set which probably includes the emission reduction which VROM earlier anticipated in Part I of the Climate Action Plan. This will probably result in a cap of 0.22 Mton in 2010. • **Specific non-CO_2-greenhouse gases policies (financial support).** Due to the introduction of the non-CO_2 greenhouse policies in the Netherlands attention got drawn to the emissions of PFCs. Within the framework of the ROB research started into the feasibility and cost-effectiveness of reduction measures. Amongst others a task force was formed and Philips executed a project to investigate the feasibility (Philips, 2004b)[69] and tests concrete reduction measures at her production facility (Philips, 2004a). Total government costs for this sector so far amount to 0.3 million euro (these costs do not include the personnel costs for the members of the tasks forces)
2. Structure of the sector
• **Size and number of firms:** There is one producer of semiconductors in the Netherlands. • **International voluntary agreement.** The members of the World Semiconductor Council (WSC) in 1999 have committed themselves to reduce PFC emissions with 10% in 2010 compared to 1995 levels (WSC, 2004) Philips as a member of the European Semiconductor Industry Association committed itself to this objective. Progress towards the target is monitored on a regional level e.g. for Europe in order to avoid disclosing confidential business information. Emissions from the industry have continued to rise in some countries. However, the quick capital and technology turnover within the industry make it quite plausible that the global targets will be met by means of a voluntary technology transition. • **Innovative character/environmental image***:* The semiconductor sector is a very innovative sector in which the turn over rate of production equipment is relatively high. This means that new production equipment with lower PFC emissions can be introduced on the short term, once this equipment is available. Production equipment is produced only by a very small number of suppliers. Specific products with their specific production technology are generally not produced longer than a few years. • **International competition:** The timely adoption of specific new production technologies is crucial for the competitiveness of this industry. Specific end-of the pipe abatement costs can be high but do not significantly affect the economics of a specific production process because of the very high investment costs associated to semiconductor production technologies.
3. Feasibility

[69] Philips (2004b) Research into the feasibility of the reduction of PFC s through optimisation of the production process (Onderzoek naar de haalbaarheid van de reductie PFK emissies door middel van procesoptimalisatie). Phlips Semiconductors, Nijmegen, The Netherlands. March 2004.

Emission source
• PFC emissions from the semiconductor industry
• **Level of investments/Cost-effectiveness:** The measures that are currently investigated are not cost-effective for Philips, because they do not create any revenues. It must be noted that the investments include (Philips, 2005)[70]: 1. Hardware and installation costs, 2. Infrastructure costs (gas supply, energy supply) (If there is no space or if specific safety precautions are to be taken the costs may be substantial)., 3. Running costs, 4. Qualification costs (per process (release) this may be in the order of 50-100 kEuro) **5.** Production loss. • In the amount mentioned in the table under cost effectiveness only cost items 1 and 2 are included. This means that the actual **negative** cost-~~effectiveness~~ **impact** will even be higher (but was not further quantified so far by Philips). • **Local constraints:** There is a big difference in the costs of reduction measure between new and existing production locations. New productions locations can be built according to the newest insights, whereas for existing locations investments are needed for item 1 to 5 mentioned under the previous point. This can lead to large differences in the cost-effectiveness for new and existing locations.
4. Market Implementation in the Netherlands
• There is one producer of semiconductors in the Netherlands (Philips Semiconductor in Nijmegen). At the end of 2003 no reduction measures were implemented, i.e. no absolute reductions were achieved. However, due to earlier optimisation of C2F6 chamber cleans the normalized emissions were significantly lower. • In 2004 a project stated in which reduction measure are implemented and tested on a small scale. The small-scale implementation will result in an annual reduction of 0.0084 Mton.

[70] Philips (2005). Information received from Mr Thewissen, Philips date 11 February 2005.

SF_6 emissions from the electricity sector

The Netherlands

Emission source
• SF_6 emission from gas-insulted switchgear (GIS) used in the electricity sector
Emission reduction measure
• Installation of new gas-insulted switchgear (GIS) with a lower leakage rate.
Reference situation
• It is assumed that in the absence of environmental policies no reduction measures would have been implemented with the aim to reduce the emission of SF_6 from gas-insulated switchgear.
Short description of the reduction option
• The reduction measures implemented in the Netherlands are aimed at reducing emissions in the user phase by replacing high-voltage gas insulated switches (GIS) with new switches with a lower leakage rate. • Within the framework of the ROB one user applied for financial support for the replacement of old GIS by new GIS with a lower leakage rate. With this replacement annual leakage of SF_6 decreased from 106 kg per year (leakage rate of 12%) to less than 4 kg per year (leakage rate of < 0.5%) (SenterNovem, 2004c) [71]
NETHERLANDS
Actual cost-effectiveness in the Netherlands
• Only information is available from the user that applied for financial support within the ROB (SenterNovem, 2004c)[71]. o Additional investment costs for the replacement of 8 high-voltage gas insulated switches was 1.4 million euro. These are investments costs compared to the reference situation in which the GIS would have been renovated instead of replaced with new GIS. In case of revision of the GIS according to the applicant it was unsure if reductions could be achieved. o Savings on purchase costs of SF6 are negligible, and service and maintenance costs are unchanged. o Government support from the CO_2-reductionplan amounted to 140.000 euro. o Total reductions 2,5 ton CO_2-eq per year. It must be noted that the project involves the replacement of GIS that had reached the end of its technical lifetime (30 year) (Delta, 2004)[72]. This means that (part of) these reductions would also have been reached in the absence of environmental policies. New equipment currently

[71] SenterNovem (2004c). Project information received from Senter Novem date 25 Oct 2004.
[72] Delta (2004). Oral communication with Mr van der Weele of Delta date 5 November 2004

Emission source
• SF_6 emission from gas-insulted switchgear (GIS) used in the electricity sector
on the market has much lower leakage rates than equipment installed 30 years ago. Lowering of the leakage rates is an autonomous process, which is only partly triggered by environmental policies. o National cost-effectiveness amounts to 39 euro/ton CO_2-eq. These can probably be considered as typical costs for these types of measures. • No data are available on the number of GIS that were replaced with new equipment in the period 1990-2003, and that otherwise would have been renovated. This means that we are not able to calculate the reduction for the Netherlands as a whole. What however can be noted that the reduction are probably limited, because policies are still in an early stage of development and replacement of GIS is not yet triggered by these policies. • Total government expenditures include grants from the CO_2 reduction plan (0.14 million euro) and support for a number of other projects within the ROB (0.1 million euro).
Comparison of actual and forecasted cost-effectiveness in Option document (€/ton CO_2-eq)
• The Option document does not hold detailed figures on the costs to reduce leakage of SF_6 from gas insulated switchgear. Because of lack of detailed figures cost were assumed to be in the range of 0-50 DFl/ton CO_2-eq (0-23 euro/ton CO_2-eq).
Factors influencing implementation and cost-effectiveness in the Netherlands
1. Government policies
• **European F-gases Regulation**. Recently environmental ministers agreed on provisions to limit emissions and application of fluorinated gases. The Regulation is aimed at improving containment by setting minimum standards for inspection and recovery. The containment and end-of-life provisions of the proposed EU-Regulation will affect switchgear applications. Impacts on emissions during the use-phase will be minor because of the already fairly stringent procedures within the sector. Most effect will be seen in changes of end-of-life procedures. • **Environmental permit**. The environmental permit, of the user that applied for financial support within the ROB, included monitoring requirements for the emissions of SF_6. The permit did not hold a cap of the maximum amount of emissions. • **Non-CO_2 greenhouse gas policies (financial support).** Due to the introduction of the non-CO_2 greenhouse policies in the Netherlands attention got drawn to the emissions of SF_6 and research started into the feasibility and cost-effectiveness of reduction measures. Within the framework of the ROB

Emission source
• SF_6 emission from gas-insulted switchgear (GIS) used in the electricity sector
two studies were executed aimed at getting a better understanding of the reduction potential and costs (Dorrepaal et al, 2001)[73] (Rutgers en van Rijn, 2004)[74]. • **Financial support:** Financial support is available within the CO_2-reduction plan and within the framework of the ROB (see for details above). Government contribution for the investments amounted to 10% of total investments. • **Liberalisation of energy markets** The effect of liberalisation on emission levels from SF6 electrical equipment may sometimes work against mitigation efforts: greater cost awareness may reduce pro-active maintenance, increase time pressure on service technicians and preclude early investments into new equipment replacing leaky old systems. However, handling procedures for high voltage equipment within utilities are generally strict because of high quality and safety requirements.
2. Structure and characteristics of the sector
• **Size and number of firms:** There are a large number of users. All major utilities plus major industrial companies which own their won substations. • **International competitions:** On specific national markets all manufactures of GIS have to comply with specific regulations relating to the leakage rates. This creates a level playing field at least among the big international companies like Areva, ABB, Schneider and Siemens. In new grid sections mid- and high-voltage range SF_6 switchgear sometimes competes with the older air insulated technology. SF_6 technologies generally exhibit higher specific investment costs per piece of equipment, which is commonly offset by reduced costs of ownership, greatly reduced space requirements and increased reliability. • **Innovative character of the sector:** GIS with low leakage rates are already on the market and do no require large research and development efforts from the sector. Research into alternative technologies like vacuum technology for higher voltages is still in their infancy.
3. Feasibility
• **Level of investments**: Replacement of old GIS is part of the normal investment cycle of users of GIS. Only if GIS are replaced before the end of their lifetime or if they otherwise would have been renovated, the level of investment could play a decisive role in the investment decision. • **Cost-effectiveness:** The measure to replace the GIS before the end of their lifetime instead of renovating the GIS is not cost-effective, because it hardly

[73] Dorrepaal et al (2001) The use of SF_6 in the transport and distribution of electricity: comparison and the Dutch situation with an LCA executed in Germany (Gebruik van SF6 bij transport en distributie van elektriciteit: vergelijking van een in Duitsland uitgevoerde LCA met de Nederlandse situatie). Kema. Arnhem, juli 2001

[74] Rutgers w, T van Tijn (2004). Effectiveness of local SF6 leakage detection techniques (Effectiviteit SF6-lekdetectietechnieken en richtlijn voor gebruik op locatie). Kema, Anrhem, maart 2004.

Emission source
• SF_6 emission from gas-insulted switchgear (GIS) used in the electricity sector
creates revenues. It must however be noted that replacement also is administered by needs to reduce space requirements for GIS e.g. in case of future expansion as new GIS is more compact as old equipment.
4. Market Implementation in the Netherlands
• No information is available on the amount of gas-insulated switches that was replaced before the end of the lifetime or not renovated but renewed due to the introduction of non-CO_2-greenhouse gas policies. Expectations are that the replacement rate is low, because policies are of recent date and do no yet hold formal commitments for the sector. • So far one company applied for funding within the ROB. This company replaced 8 high-voltage gas insulated switches leading to an annual reduction of 2.4 ton of CO_2-eq. The first switch was replaced in 2002 the last one will be replaced in 2005 (SenterNovem, 2004c)[71]

Comparison with other countries

No substantial reductions have been established in the Netherlands and the development of new policies is still in a very early stage. Special emphasis in *most countries* so far has been placed on emission reductions during the manufacturing and testing of the equipment. Future efforts will be focussed on a reduction of handling losses during service and maintenance of existing equipment, the identification of very leaky individual pieces of equipment and the execution of proper procedures at the end-of-life of equipment.

There are few to no international examples on regulations with respect to the leakage rate of SF_6 from new GIS. For manufacturers –which are mostly from Europe and Japan - have voluntarily improved new equipment the leakage rate to less than 1% a year Existing Equipment is commonly not subject to any specific greenhouse gas policies. A control of emissions during decommissioning of old equipment is also frequently not regulated in most countries.

European countries that have established voluntary agreements with industry to monitor and reduce emissions from the manufacture and use of SF_6-equipment are e.g. *Germany* and *Norway.* In 1996 a voluntary commitments was reached with the manufactures association of in Germany. The debate in Germany is currently however stuck in extensive debate about new and strengthened voluntary agreement and vague rumours of market restriction for SF_6-mid-voltage systems. In March 2002 a voluntary agreement was reached between Norwegian government and user of SF_6. The agreement covers the complete life cycle of imported and domestically produced equipment. Voluntary targets are to achieve a reduction of 13% in 2005 and 30% in 2010.

HFC-23 emissions from the production of HCFC-22

The Netherlands

Emission source
• HFC-23 emissions from the production of HCFC-22
Emission reduction measure
• Installation of an after burner.
Reference situation
• It is assumed that in the absence of environmental policies the producer of HCFC-22 would not have installed an after burner.
Short description of the reduction option
• HFC-23 is a by-product of the production of HCFC-22 through over-fluorination. The HFC-23 emissions are reduced through thermal oxidation by installing an after burner.
NETHERLANDS
Actual cost-effectiveness in the Netherlands
• The actual national cost effectiveness were estimated at 0.3 euro/ton CO_2 eq. Since 1997 10.2 million euro is invested in the after burner. The emissions are reduced with 90% (from about 500 ton HFC-23 in 1995 to 50 ton HFC-23 in the last couple of years). The average lifetime of the installation is assumed to be about 10 years. • Only for the reserve unit subsidy was granted within the ROB programme. The subsidy amounted to 0.25 million euro. The cost-effectiveness for the government is 0.006 euro/ton CO_2 eq.
Comparison of actual and forecasted cost-effectiveness in Option document
• In the Option documents the national costs were estimated at 0.13 euro/ton CO_2-eq. (0.3 DFl/ton CO_2-eq). Investment costs for the after burner were at that time estimated by DuPont to be 7.7 million euro, the lifetime of the installation was assumed to be 15 years and emissions were assumed to be reduced with 90%. • The actual investments are higher and the lifetime of the combustion chamber is much lower than anticipated at the time the Option document was written. Reductions are in the same order of magnitude as included in the Option document.
Factors influencing implementation and cost-effectiveness in the Netherlands
1. Government policies
• **Environmental policies: permit regulations.** In order to be able to obtain an environment permit for the production of HCFC-22 DuPont had to install an after burner. Without an after burner DuPont would not be able to meet the requirements laid down in the permit.

Emission source
• HFC-23 emissions from the production of HCFC-22
Emission reduction measure
• Installation of an after burner.
• **Financial support**. Only for the reserve unit subsidy was awarded of 0.2 million euro from the ROB programme. • **ROB programme**: The ROB programme initiated research into further reductions. This resulted in a further sharpening of the emission standards in the environmental permit and an additional emission reduction of 2 Mton.
2. Structure of the sector
• **Size and number of firms:** There is one producer of HCFC-22 in the Netherlands (DuPont). Their thermal converter processes between 600 and 900 ton HFC-23 per year. • **International competition:** There are 10 European producers of HCFC-22. Most of them (6) also use thermal oxidation to destruct HFC-23. Except for one remaining plant in Greece all production plants within the EU have implemented measures to abate emissions of HFC-23. Globally competition on HCFC-22 is increasing due to new capacity in China.
3. Feasibility
• **Level of investments**: Total investments amounted to 10.2 million euro. Due to technical problems this investment is higher than expected at the start of the project. The investments were mainly driven by the fact that the company had to fulfil the requirements in their environmental permit. The specific investment level depends on the specifications of the afterburners, the need for back-up systems and the treatment of resulting destruction products. • **Cost-effectiveness**: For the producer of HFCF the investments do not generate any profits.
4. Market Implementation in the Netherlands
• DuPont installed its first after burner in 1997. Due to corrosion of several parts of the installation (e.g. fireproof covering, metal casing), the lifetime of the first installation was about one year, and the lifetime of the second installation one and a half year. It was decided that these problems had to be solved, so a new improved burning unit was developed. The third unit is in operation since November 2000. Also a reserve unit is in place to increase the running hours of the total installation (DuPont, 2004)[75]. • Through installation of an after burner HFC-23 emissions decreased by 90%: from 5.3 Mton CO_2 eq. per year to 0.585 Mton CO_2 eq. per year (DuPont, 2004)[76]. Total reductions in the period 1990-2003 amount to 32 Mton CO_2-eq.

[75] DuPont (2004) Oral information Harm Benjamins, DuPont, 11 October 2004
[76] Du Pont (2003) Reduction Non CO2 greenhouse gases through “Thermal Converter” (Reductie Overige Broeikasgassen door “Thermal Converter”), final report 375001/0040, 20 May 2003

Comparison with other countries

Through installation of an after burner the HFC-23 emissions are to a very large extent reduced (with 90%). The main driving force behind implementation of this abatement measure was that the plant had to fulfil the environmental permit.

Manufacturers within the EU-15 have installed and successfully operate thermal oxidation facilities at six plants within EU-15 (out of a total of 10). This has been accomplished as part of voluntary agreements or by unilateral action of manufacturers (Harnish, Gluckman, 2001)[77].

Another important development that could lead to substantial global reductions is the implementation of destruction techniques within the framework of CDM projects. The CDM Executive Board approved a baseline methodology (UNFCCC, 2004)[78] and several producers have plans to submit CDM projects (ENDS, 2004)[79].

[77] Harnish J, Gluckman R (2001). European Climate Change Programme Working Group Industry Work Item Fluorinated Gases Prepared on behalf of the European Commission (DG ENV and DG ENTR)
[78] UNFCCC (2004) http://cdm.unfccc.int/methodologies/PAmethodologies/approved.html visited 29 November 2004
[79] ENDS (2004)."DuPont: HFC-23 projects too lenient at present" 6 July 2004

HFC emissions from the production and use of rigid foams

The Netherlands

Emission source
• HFC emissions from the production and use of rigid foams
Emission reduction measure
• No information is currently available on the actually implemented measures to reduce HFC emissions from foam production. Within the framework of the ROB two reduction measures were investigated: 1. Limiting the use of HFC in blowing agents 2. Using alternative blowing agents
Reference situation
• It is assumed that in the absence of non-CO_2 greenhouse policies HFCs would have been used as blowing agents and that no measures would have been taken to either find alternatives or limit the use of blowing agents. • One can argue on the definition of the reference situation. As of January 1, 2004 there is a ban on the use of HCFC for foam production. This means that producers have to search for alternative blowing agents. Because of the high costs for HFCs and current shortage of HFCs on the market, foam producers were forced to use alternatives such as CO_2/H_2O and pentane. It is currently however unknown which blowing agents are used by producers in the Netherlands as of 1st of January this year. • Expert opinions are that in future year in the Netherlands 30% of the discontinuous and continuous produced rigid foam will be produced by means of alternative blowing agents[80] (RIVM, 2004c)[81] (SenterNovem, 2004b)[82].
Short description of the reduction options
• As already mentioned two measures were investigated within the framework of the ROB and no other information is available on the current situation in the Netherlands. The two projects include: 1. Limiting the use of HFC in the CO_2 blown foams by Resina (Resina, 2003)[83]. Resina is a developer, producers and seller of blowing agents. Before the ban on HCFC a mixture of 50% CO_2 and 50% HCFC was sold for most applications. Resina developed formulas for blowing agent with a limited amount of HFCs (HFC are only used as a support gas) for different application (continuous and discontinuous panels, moulding, form

[80] Because of safety regulation in-situ applications cannot switch to pentane, they have to switch to HFCs.
[81] RIVM (2004c). Oral Communication Kees Peek (RIVM) date 1 October 2004.
[82] SenterNovem (2004b). Oral Communication Eva Schoenmaekers (SenterNovem) date 6 October 2004
[83] Resina (2003) Reducing the climate effect by reducing the use of blowing agents in PUR systems (Reductie van het broeikaseffect door reductie van blaasmiddel in PUR systemen). Resina, Foxhol, The Netherlands. April 2003.

and spray foams). By introducing these formula's Resina itself reduces overall emissions on average with 66% (based on their sold mix of blowing agents and assuming that in the reference case HCFC-141b would have been used).

2. Using pentane as a blowing agent by PCC (PCC, 2001)[84]. PCC is a company delivering complete blowing systems for producers of foams. With this project PCC demonstrated the use of pentane as a blowing agent. When using pentane the use of HFC are completely avoided and therefore the reductions are 100%.

NETHERLANDS

Actual cost-effectiveness in the Netherlands

Only information is available on the costs to switch to alternatives from the two companies that applied for financial support within the framework ROB.

- Limiting the use of HFC in blowing agents.
  - Resina states that the costs to develop new formulas based on CO_2 amounted to 1 million euro. These are all development costs for Resina, and do not reflect the costs for implementation with the users of the blowing agents.
  - The report does not hold figures on the differences in costs between HCFC-141b blown foams and CO_2-blown foams (with a little bit of HFCs). Resina only states that HFCs blown foams are more expensive than the CO_2 blown foams. We therefore concluded that the measure is cost-effective (i.e. that the national cost-effectiveness is negative).
  - For the development of the formulas Resina received support from the ROB. We are not able to calculate the cost cost-effectiveness for the government, because we do not know (i) how widely the formulas developed by Resina will be applied and what the achieved emission reduction is (the reduction of greenhouse gases achieved by producers of foams that purchase their blowing agents with Resina is 266 kton of CO_2-eq. It must however be noticed that not all these reductions are achieved in the Netherlands because part of the blowing agent is exported) and (ii) if development of the new blend would not also had taken place if no grants had been available.
- Using pentane as a blowing agent.
  - PCC states that the costs for foam producers that want to switch to pentane are approximately 0.14 million euro. These include costs for pentane storage, a pentane-mixing unit and modifications to the PU mixing machine. Furthermore investment are also necessary in nitrogen purging for presses and moulds, extraction, explosion prevention, building modifications and lines. It must be noted that this only is valid for small user because larger users save a lot of money from using cheaper blow-

[84] PCC (2001) PUR foams without greenhouse gases ; demonstration for discontinuous production (PUR hardschuim zonder broeikasgassen; een discontinue productie demonstratie). Polymer Chemical Company BV, The Netherlands.

ing agents. Only small producers of specialty foam products have extra costs. • No figures are available provided on the absolute reduction that can be achieved on the company level. PCC only provides number on the price increase per m2 of foam, which indicates that pentane blow foams are cheaper than HFCs blown foams (calculations cannot be checked because of lack of provided data). • For the development of pentane blown systems PCC received a government grant 0.14 million (SenterNovem, 2004e)[37]. Because no numbers are available on the achieved reductions in the Netherlands the cost-effectiveness for the government cannot be calculated.
Comparison of actual and forecasted cost-effectiveness in Option document
• The Option document did not hold detailed figures on the cost-effectiveness of the described options, because they were not available. The Option document therefore used a range of 0-23 euro/ton of CO_2-eq (0-50 DFl/ton of CO_2-eq). • From the costs available from the projects supported by the ROB one can conclude that measure to reduce the use of HFC from foam production are cost-effectiveness (i.e. the cost are negative), and therefore cheaper than anticipated during the time the Options document was written. • The Option document forecasted an enormous increase in the emissions of HFCs if no policies would be introduced. Total emissions from substances banned under the Montreal Protocol were expected to increase to 5.8 Mton CO_2-eq in 2010. Current developments however show that without any binding policies the market for foams is already moving away from HFCs.
Factors influencing implementation and cost-effectiveness in the Netherlands
1. Government policies
• **Ban on the use of HCFC (Montreal Protocol)**. Due to the international ban on the use of HCFC for the production of foams, producers had to search for alternatives. • **European F-gases Regulation**. Recently environmental ministers agreed on provisions to limit emissions and application of fluorinated gases. However, except for additional monitoring requirements the rigid foams sector is not affected except for one-component foams, which will face marketing and use restrictions for HFC propellants. • **Non-CO_2 greenhouse gas policies.** Simultaneously with the ban on HCFC discussion on the climate effect of HFC started providing additional incentives to search for alternatives for HFC. The Netherlands established a tasks force with representatives from the sector and government to investigate reduction measures, policy options and follow market developments. • **Safety regulation:** If PU foams are manufactured using hydrocarbons additional safety measures have to be implemented to mitigate the additional fire and explosion risks. Foam products produced with hydrocarbons commonly exhibit a slightly reduces fire resistances. If a certain classification cannot be

achieved additional flame-retardants have to be added. • **Financial support:** Within the framework of the ROB two projects were financially supported for a total sum of 0.14 million euro. It must be noted that the two applicants were forced by market conditions to investigated alternatives for HFC and that the financial contribution was probably not decisive to start the projects.
2. Structure of the sector
• **Structure of the market: costs and supply of HFC**. Because of the current shortage and the high costs for HFCs, suppliers of blowing agents and blowing systems started research into alternatives for HFC. • **Large number of small producers**. The sector includes a large number of small producers that have limited room for investments. • **International competition**: The rigid foams market is generally very cost-sensitive. Users in the construction sector frequently make their decision on the basis of investment costs rather than life-cycle costs or on environmental grounds. They will react to very small cost differentials. In absence of specific regulation the market will generally favour HFCs in niche application and prefer the cheaper alternatives in bulk uses.
3. Feasibility
• **Requirements for foams in different applications**. Thickness of insulation material: there can be selected cases, e.g. in transport refrigeration, where an increase of insulation thickness as sometimes required for hydrocarbon foams is difficult to achieve. • **Cost-effectiveness**: Because of the relatively high costs for HFC for most producers it profitable to switch to alternatives.
4. Market Implementation in the Netherlands
• In the Netherlands there are approximately 8 large producers of rigid foam and 50-80 small producers. • As of the 1st of January 2004 HCFCs are banned as a blowing agent, it is however at this moment unclear which alternatives the producers apply. As already mentioned in section 5.6 emissions of HFC from foams are not yet visible in the emission inventories of the last couple of year, which could mean that users have switched to alternatives. • Expert within the sector itself can currently not provide insight in this matter. First numbers will become available when result from the HFC trading flow project are presented and the sector itself will make an inventory halfway 2005 (SenterNovem, 2004b)

Comparison with other countries

In the Netherlands it is not yet clear if reduction have been achieved, because HFC emissions of foam production are not yet visible in the emission inventories.

In countries like e.g. Germany the sector has shifted away from HFCs during the phase-out of ozone depleting substances and moved to hydrocarbons and CO_2 without any binding policy: mainly for cost reasons and to avoid later regulatory risks.

Other countries like Denmark and Austria have introduced legislations to ban the use of HFC for the production of several foams (Cheminfo, 2004)[85]. These countries however probably will need to relax their regulations because of the agreed European F-gases Regulation. It is not yet clear from monitoring figures if the announcement of upcoming regulation lead to a shift towards the use of alternatives. As in the Netherlands no detailed information is available on the costs for reduction measures.

[85] Cheminfo (2004). International Management Instruments Regarding HFCs, PFCs and SF6. Cheminfo for Environment Canada. March 2004.

HFC emissions from stationary cooling

The Netherlands

Emission source
• HFC emissions from stationary cooling equipment
Emission reduction measures
• Minimising leakage rates of cooling agents through good housekeeping measures. • Application of natural cooling agents in cold storage equipment.
Reference situation
• It is assumed that in the absence of greenhouse policies HFCs would have been used as refrigerants and that no measures would have been taken to either find alternatives or to minimise leakage rates. • It must be noted that the good housekeeping measures (minimizing leakage rates) was already introduced under the Montreal protocol aimed at phasing out the use of CFC and HCFC.
Short description of the reduction options
• Minimising leakage rates of cooling agents through good housekeeping measures. Good housekeeping measures include: o Quality improvements (accounting refrigerants, procedures for handling) o Technical requirements (requirements for design and procedures for installation and maintenance) o Training of personnel (Baedts, 2000)[86] • Application of natural cooling agents: NH_3, CO_2, propane en butane can be used as cooling agents, and compared to HFC they have a very low GWP. For instance for NH_3 and CO_2 have a GWP of respectively 0 and 1. In addition cooling installations using natural cooling agents are more energy efficient than systems using HFC as cooling agents This leads to lower energy consumption and lower indirect emissions of CO_2. For instance NH_3/CO_2 cascade systems have a 15% higher energy efficiency (Koppenol et al, 2003)[87].
NETHERLANDS
Actual cost-effectiveness in the Netherlands
• Minimising leakage rates of cooling agents through good housekeeping measures. The good housekeeping measures in the Netherlands were established by founding the STEK in the early '90 (Association for the Recognition of Refrigeration Engineering Firms). The STEK system organisatonally supported the legislation concerning leak-free refrigeration equipment (RLK)

[86] Baedt (2000) Government and Industry Partners for responsible use of refrigerants, STEK, presentation Eucrar 27 September 2000
[87] Koppenol et al (2003) Breakthrough of NH3/CO2 refrigeration systems in the Netherlands, Koude&Luchtbehandeling, nr. 6, June 2003

and the agreements of the Montreal Protocol. The costs of these national and international legislation are out of scope in this study. It must be noted that in principle the costs mentioned in this section cannot be totally attributed to the reduction of HFC, because the systems was initiated with the aim to reduce emissions from substances falling under the Montreal Protocol (Enviros, 2002)

- Total set-up costs to establish the STEK were 18.75 million euro. This included amongst others the founding of 6 test centres, which received a government funding of 0.75 million euro. The training costs were approximately 18 million euro and were covered by the sector itself.
- In addition to the costs to establish STEK, there are additional on-going costs to industry covering: annual accreditation, in-house training, additional equipment requirements and the labour costs of extra maintenance requirements. These are estimated at 5.4 million euro per year.
- The STEK has reduced leakages from on average 30% at the early nineties to an average of 4.5% per year[88]. Also the causes of remaining emissions are thoroughly investigated (TNO, 2001)[89].Under the assumption that in the absence of environmental policies the leakage rate would be on the same level as for EU countries that have no system like the STEK in place this would this would have resulted in a leakage rate of 15% (Enviros, 2002). This resulted in reduction of approximately 1.2 Mton in 2003[90]. The estimated total reduction over the period 1990-2003 amounts to ~3.9 Mton (assuming that the average leakage rate in this period was 10%).
- This assumption lead to a national cost-effectiveness of 20 euro/ton of CO_2 and total national costs in the period 1990-2003 of 76 million euro. The cost-effectiveness for the government amounts to 0.2 euro/ton CO_2-eq (as already noted this cost cannot be totally attributed to HFC reductions).

- Application of natural cooling agents. The cost-effectiveness of cooling systems using natural cooling agents can differ considerably per installation. For

[88] Enviros, (2002) Assessment of the Costs & Impact on Emissions of Potential Regulatory Frameworks for Reducing Emissions of HFCs, PFCs & SF_6, Draft Final Mark 5, EC002 5008, Enviros consulting limited, Canada, 2002
[89] TNO (2001) National investigation of flows of cooling agents in 1999, research by TNO on behalve of STEK, augustus 2001
[90] Potential emissions in 2003 for HFC were ~11.6 Mton and the average leakage rate was 5% (RIVM 2004d).
[91] SenterNovem (2004) Calculations based on number from several projects that applied for grants within the ROB programme (www.robklimaat.nl).
[92] Ecofys (2003). Evaluation of the Energy Investment Deduction Scheme for the horticulture sectors. Ecofys, 2003
[93] S.Lobregt Project Development (2004) Oral information Stefan Lobregt, 19 November 2004

projects that applied for financial support within the ROB programme the national cost-effectiveness ranges from -5 up to 30 euro/ton CO_2 eq (SenterNovem, 2004)[91]. The investment costs for NH_3/CO_2 cascade system is on average about 20-50% higher than for a cooling system on HFC. The pay back time of NH_3/CO_2 cascade system is usually less than 5 years (Koppenol et al, 2003). The government financially contributed to investments in natural cooling agents in the period 1990-2003.

- Demonstration and market introduction projects were financially supported within the ROB programme. Furthermore feasibility studies and other research projects were carried out within the ROB-programme. Total investment in projects that applied for grants within the ROB programme was over 21 million euro and government support for these projects amounted to 4 million euro.
- EIA/VAMIL. Cooling installations using CO_2/NH_3 could apply for EIA/VAMIL. EIA/VAMIL is a fiscal measure and the level of government supports is depending on the profit made by the sector applying for support. On average level of support was 18% of the total investments sum (Ecofys, 2003)[92]. Total reported investments in the period 1990-2003 amount to 16.5 million euro, resulting in an estimated government support of about 3 million euro (Senter, various)[47]
- This results in total government expenditures for the period 1990-2003 of approximately 7 million euro. Total investments related to project that applied for financial support lies in the range of 21-25 million euro. The estimate is surrounded with uncertainties because investors can apply for financial support within the ROB but next to that also for fiscal support. It is unknown how many applied for both but we assume that the majority of the investors that applied for ROB also applied for fiscal support.
- No information is available on the number and size of installations that switched from CFC and HCFC to natural refrigerants like ammonia and CO_2 instead of HFC under the influence of non CO_2-greenhouse gas policies. In the Netherlands there are about 100.000 cooling installations in the commercial and industry sector. It is estimated that around 2000 are running on NH_3. Only a limited number of systems use propane, butane or combination of NH_3/CO_2 as cooling agents (S.Lobregt Project Development, 2004)[93]. It is however unknown how many additional installations with natural cooling agents came into operation in the period 1990-2003. The sector itself estimates that in the last couple of years between 2% and 5% switched to natural refrigerant. This would lead to a reduction between 0.05 and 0.1 Mton CO_2-eq in 2003 (assuming that otherwise installation would have been used

with HFC with an average leakage rate of 15% (Enviros,2002)[88]) The estimated total reduction of the period 1990-2003 amounts to 0.1-0.2 Mton CO_2-eq. o These assumptions lead to a cost-effectiveness of the government of 10 – 24 euro/ton CO_2-eq. Total national costs for the period are estimated at -1 million and 6 million euro.
Comparison of actual and forecasted cost-effectiveness in Option document
• Minimising leakage rates of cooling agents: The national costs according the Option document for reduction of leakages are 22.7 euro/ton CO_2 eq. (50 Dfl/ton CO_2 eq.). To avoid leakage in an existing installation (capacity 100 kW) is assumed to cost 2270 euro. In the Option document is was assumed that it is technically possible for all installations put into operation after 2000 to reach a leakage rate of 1%, this is however currently not yet common practice. • Application of natural cooling agents; In the Option document the national cost for application of alternative cooling agents in new stationary cooling installation are rated at about 4.5 euro/ton CO_2 eq. (10 DFl/ton CO_2 eq.). Basic assumption for this estimation was that a cooling installation on NH_3 is 20-30% more expensive than a comparable installation on HFC. The costs-effectiveness of implemented reduction measures lie in these range. In the Option document it was assumed that all new installation as of 2005 use an alternative cooling agents. This is not the trend currently observed in the Netherlands.
Factors influencing implementation and cost-effectiveness in the Netherlands
1. Government policies
• **European F-gases Regulation**. Recently environmental ministers agreed on provisions to limit emissions and application of fluorinated gases. The regulation is aimed at improving containment by setting minimum standards for inspection and recovery. All medium and larger stationary air-cooling applications in Europe will be affected in respect to certification and training of service personnel and the recovery of fluids at the end-of-life. • **Ban on the use of CFC and HCFC**. Due to the international ban on the use of CFC and HCFC as cooling agents producers and users had to search for alternatives (EU verordening2037, 2000)[94]. Until the 1st of January 2004 it was allowed to use HCFC in new cooling installations. As of that date HCFC may no longer be used as cooling agents in new installations, and the sector (among others) switches to HFC. It is however still allowed to refill existing installation with HCFC (unless more than 50% of the cooling agent leaks out each year, then the installations has to be replaced/refurbished). • **Introduction of the STEK**. In the early nineties, the Ministry of Housing, Spatial Planning and the Environment launched a national action program to

[94] EU verordening 2037 (2000) Verordening betreffende de ozonlaag afbrekende stoffen van het Europees parlement en de raad, 29 juni 2000

end the use and production of CFC and HCFCs. The policy is based on cooperation with users of refrigerants and manufacturers of equipment containing refrigerants. A special organisation was founded called STEK (the Association for the Recognition of Refrigeration Engineering Firms). Main task of STEK is to operate a mandatory certification scheme to prevent refrigerants from being emitted into the environment. Ensuring that engineering firms work carefully according to fix procedures with refrigeration and air-conditioning equipment does this. • **Financial support**. o Until 2004 there was subsidy available within the ROB program, mainly for demonstration and market introduction projects of cooling systems using natural cooling systems. For instance about 20 NH_3/CO_2 cooling installations are realised with ROB subsidy. Total granted budget was 4 million euro. In 2004 the ROB subsidy for installations operating on natural cooling agents was lifted, because market introduction no longer needs to be supported (SenterNovem, 2004f)[95]. o In the period 2000 -2003 there was EIA subsidy for NH_3/CO_2 cascade cooling systems (total ~ 3 million euro). • **Safety policies**. Installations running on ammonia with a volume above 400 kg need a environment permit and in addition have to fulfil the extra requirements in the external safety order (automatic gas detection etc.). For installations on HFCK the safety rules take effect above a volume of 1000 kg (GTI, 2004)[96]. The more strict regulation may hamper the use of ammonia (Official Journal, 2002)[97]. Propane and butane have additional fireproof requirements. • **Non-CO_2-greenhouse gas policies**. Within ROB a special task force was established dealing with HFC relating issues. They discussed policy aspects, market developments and issued projects.
2. Structure of the sector
• The sector consists of considerable number of relatively small systems installed in a variety of sectors (from large cooling housing to small grocery stores). • Furthermore new installations penetrate relatively slowly because installations are mostly not replaced before they have reached the end of their technical lifetime that may reach 20-25 years.
3. Feasibility
• Good housekeeping measures to minimize leakages of cooling agents are (almost) cost effective. • The economic feasibility of the switch to natural cooling agents depends

[95] SenterNovem (2004f) Oral information Arend Koppenol, 11 November 2004
[96] GTI (2004) Oral information Erik Hoogendoorn, 26 November 2004
[97] Official Journal (2002) Draft regulation quality standards for external safety of installations (Ontwerpbesluit kwaliteitseisen voor externe veiligheid van inrichtingen) Official Journal No. 38, 22 February 2002

	strongly on the installation type (next to reference situation, cooling agents ed.)
4. Market Implementation in the Netherlands	
•	The use of HFC as a cooling agent has increased significantly in the last couple of years. E.g. the use of HFK 134a a cooling agent increased from 177 ton in 1994 to 1942 ton in 2003 (RIVM, 2004d)[98] (this is the amount of HFC currently applied in installations in the Netherlands).
•	The STEK is fully implemented in the Netherlands and has resulted in the decrease of the leakage rate with on average 30% in the beginning of the '90 to an average leakage rate of ~5% in 1999. The average leakage rate in 2003 is assumed to be at the same level. The estimated total reduction over the period 1990-2003 amounts to ~8 Mton (assuming that the average leakage rate in this period was 10%).
•	No information is available on the number and size of installations that switched from CFC and HCFC to natural refrigerants like ammonia and CO_2 instead of HFC under the influence of non CO_2-greenhouse gas policies. In the Netherlands there are about 100.000 cooling installations in the commercial and industry sector. It is estimated that around 2000 are running on NH_3. Only a limited number of systems use propane, butane or combination of NH_3/CO_2 as cooling agents (S.Lobregt Project Development, 2004)[99]. It is however unknown how many additional installations with natural cooling agents came into operation in the period 1990-2003. The sector itself estimates that in the last couple of years between 2% and 5% switched to natural refrigerant. This would lead to a reduction between 0.1 and 0.2 Mton CO_2-eq in 2003 (assuming that otherwise installation would have been used with HFC with an average leakage rate of 30%). The estimated total reduction of the period 1990-2003 amounts to 0.2-0.4 Mton CO_2-eq.

Comparison with other countries

Dutch policies to decrease emissions of HFC from stationary cooling installations are mainly aimed at minimising leakage rates. Through the introduction of the STEK leakage rates on average decease to 4.5%. In training programs within the STEK attention is paid to the switch towards natural cooling agents and within the ROB demonstration projects were financially supported. The switch to natural cooling agents is however not supported by national regulations, in contrast to several other European countries.

In Scandinavian countries there are severe tax regulations for cooling agents containing fluorine. In Denmark and Austria there are national laws in preparation to ban the use of HFC in new cooling systems as of 2007. However it is not yet clear

[98] RIVM (2004d) Oral information from Kees Peek date 10 November 2004
[99] S.Lobregt Project Development (2004) Oral information Stefan Lobregt, 19 November 2004

if these regulations would be consistent with Community common market requirements. The coming F-Gas Regulation puts strong emphasis on common market approaches (Cheminfo, 2004)[85]. In Germany e.g. only the announcement that regulation would be introduced to ban HFC as of 2010 already affected the market and the implementation of systems based using natural cooling agents increased. The frontrunner in Europe is Luxembourg, which has a regulation in place that obliges all new large cooling systems to operate on natural cooling agents (S.Lobregt Project Development, 2004)[99].