RESTRICTED - COMMERCIAL
AEAT-4180: Issue 3

Options to Reduce Nitrous Oxide Emissions (Final Report)

A report produced for DGXI

November1998

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1. Introduction

This report is one of the final reports under a study completed by AEA Technology Environment for DGXI on the control and reduction of greenhouse gases and ozone precursors. Four gases were included in the study, the two direct greenhouse gases, methane and nitrous oxide, and the ozone precursors, nitrogen oxides (NO_x) and non-methane volatile organic compounds. In the initial phase of the study, inventories of these gases for all Member States were reviewed and updated. In the second phase of the study, measures to control and reduce emissions of these gases were identified, their technical feasibility examined, and wherever sufficient cost and performance data was available, the cost-effectiveness of the measures (in terms of ECU (1995) per tonne of pollutant) was also estimated.

This report assesses anthropogenic nitrous oxide (N_2O) emissions and strategies to control them. Section 2 discusses the properties of N_2O, sources and sinks for the gas, and a global budget for emissions. Section 3 considers emissions within the EU, and sets these into context against global N_2O emissions and emissions of the two other direct greenhouse gases (carbon dioxide and methane). It also identifies the important emission sources within the EU. Section 4 summarises actions which are already proposed by Member States to reduce emissions.

Sections 5 and 6 of the report consider in detail options for the reduction of emissions from the agricultural and chemical sectors, while Section 7 considers the options to reduce emissions from combustion processes. The cost-effectiveness of the different measures is then evaluated in Section 8. For the non-agricultural sectors, costs have been calculated using an annualised cost methodology. All costs are expressed in 1995 ECUs and have been calculated using an 8% discount rate to annualise costs to ensure consistency with previous work on the cost of carbon dioxide reduction options. Full details of the costing methodology, exchange rates, deflators and other factors used are given in Appendix 1. Section 9 contains projections of N_2O emissions up to 2020 under a ‘business as usual’ scenario and under a ‘with measures’ scenario, and Section 10 contains a summary of the report.

2. N_2O as a Greenhouse Gas

Nitrous oxide (N_2O) is an important long-lived greenhouse gas that is emitted predominantly by biological sources in soil and water. It is also the primary source in the stratosphere of the oxides of nitrogen, which play a critical role in controlling the abundance and distribution of stratospheric ozone. Estimates from ice core measurements suggest that the pre-industrial atmospheric concentration of N_2O was about 275 ppbv (with a range of 260 to 285 ppbv). By 1994 this had increased by about 15% to a level of 312 ppbv (IPCC, 1995).

2.1 GLOBAL SOURCES AND SINKS

An estimate of the global sources and sinks of N_2O made by the IPCC in 1994 is given in Table 2.1. Overall, the sources and sinks of N_2O are not well quantified and many uncertainties remain. Natural sources are probably twice as large as anthropogenic ones.

Table 2.1 Estimated Sources and Sinks of Nitrous Oxide (Tg N per year)

	Range	Likely
Observed atmospheric increase	**3.1 - 4.7**	**3.9**
Sinks		
Photolysis in the stratosphere	9 - 16	12.3
Removal by soils	?	
Total sinks	**9 - 16**	**12.3**
Implied total sources (atmospheric increase + total sinks)	**13 - 20**	**16.2**
Identified Sources		
Natural		
Oceans	1 - 5	3
Tropical soils		
Wet forests	2.2 - 3.7	3
Dry savannahs	0.5 - 2.0	1
Temperate soils		
Forests	0.1 - 2.0	1
Grasslands	0.5 - 2.0	1
Total identified natural sources	***6 - 12***	***9***
Anthropogenic		
Cultivated soils	1.8 - 5.3	3.5
Biomass burning	0.2 - 1.0	0.5
Industrial sources	0.7 - 1.8	1.3
Cattle and feed lots	0.2 - 0.5	0.4
Total identified anthropogenic sources	*3.7 - 7.7*	*5.7*
TOTAL IDENTIFIED SOURCES	**10 - 17**	**14.7**

Source: (IPCC, 1995)

The main **anthropogenic** sources globally are agriculture (from the use of fertilisers and from the development of pasture in tropical regions), biomass burning, and a number of industrial processes such as adipic acid and nitric acid production. These sources and their relevance in the EU are discussed further in Section 3. Sources whose magnitude have not been estimated in Table 2.1, or may have been underestimated, are tropical agriculture, biomass burning, and temperate grasslands.

The major **natural** sources of N_2O are soils and oceans. In soils two processes - nitrification and denitrification - can lead to the release of N_2O. The flux of the N_2O is affected by both the type of soil and environmental conditions. Quantifying emissions from soils is thus difficult, due to the heterogeneity of terrestrial ecosystems and the variability of the factors that control the fluxes. In the case of oceans, it is still unclear whether N_2O is produced primarily from nitrification in near surface waters or denitrification in oxygen deficient deep waters.

N_2O is primarily removed from the atmosphere in the stratosphere by photolysis (breakdown by sunlight). This reaction is a primary source of the oxides of nitrogen (in the stratosphere), which play a critical role in controlling the abundance and distribution of stratospheric ozone. A secondary removal process (which accounts for about 10% of removal) is through a reaction with excited oxygen atoms. There is some evidence that soils may represent a small sink for the gas (IPCC, 1995), but, to date, there is not enough data to evaluate this.

2.2 LIFETIME AND GLOBAL WARMING POTENTIAL

The best estimate of the atmospheric lifetime of N_2O is 120 years. The direct radiative forcing of N_2O is estimated to be 0.14 Wm^{-2} (compared to values for CO_2 and CH_4 of 1.56 Wm^{-2} and 0.47 Wm^{-2}) and it has the global warming potential (GWP) relative to CO_2 shown in Table 2.2. The GWP of the other direct greenhouse gas methane, which has a much shorter lifetime of 12.2 years is also shown in Table 2.2 for comparison.

The long atmospheric lifetime of N_2O has implications for achieving stable atmospheric concentrations of the gas. If emissions were held constant at today’s levels, the atmospheric concentration of N_2O would rise from 311 ppbv to about 400 ppbv over several hundred years, increasing its incremental radiative forcing by a factor of four over its current level. In order for atmospheric concentrations to be stabilised near current levels, anthropogenic sources would need to be reduced by more than 50% (IPCC, 1996).

Table 2.2 Global Warming Potentials of Nitrous Oxide and Methane

Gas	Direct Effect for Time Horizons of :		
	20 years	100 years	500 years
N_2O	280	310	170
Methane	56	21	6.5

Source: IPCC, 1996

3. Sources of N_2O in the EU

3.1 EMISSIONS OF N_2O

National estimates of N_2O emissions by sector for EU Member States in 1990 and 1994 are shown by country in Tables 3.1a and b. Overall, EU emissions fell by 6% from 1114 kt to 1049 kt. As shown in Table 3.2, emissions of N_2O within the EU are much lower than emissions of the other direct greenhouse gases, CO_2 and CH_4. Even after allowing for its higher global warming potential, anthropogenic emissions of N_2O are still a relatively minor contribution to total anthropogenic greenhouse gas emissions in the EU, and are equivalent to about 10% of CO_2 emissions. Anthropogenic EU emissions of N_2O are about 12% of estimated anthropogenic global emissions (9 Mt[1]) reported in Table 2.1.

Table 3.2 Anthropogenic Emissions of CO_2, CH_4 and N_2O in the EU in 1994

Direct GHG	Emissions (kt) in 1994	GWP (100 years)	Global Warming Equivalence - emissions * GWP (equivalent kt of CO_2)
CO_2	3,215,558	1	3,215,558
CH_4	21,930	21	460,530
N_2O	1049	310	325,190

Source: Member States and EU Second Communications to the FCCC.

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[1] 1 tonne of N_2O emissions expressed in terms of N (as in Table 2.1) is equivalent to 1.57 tonnes of N_2O.

Table 3.1a Estimated Emissions of N_2O in EU Member States in 1990 (kt)

	A	B	DK	FIN[1]	FR	GER	GRE	IRE	IT	LUX	NLS	P	SP	SW	UK	EU15
Agriculture	3	11	33	9	55	96	8	23	75	0	22	7	64	0	104	511
Production processes	1	11	0	3	90	83	1	3	22	0	32	2	10	3	95	356
Transport	3	1	0	2	4	11	1	0	4	0	5	1	2	3	4	41
Public heat and power	0	2	1	1	2	15	1	1	29	0	1	0	10	1	6	72
Industrial combustion	0	2	0	1	4	4	0	0	9	0	0	0	5	2	3	31
Other fuel combustion	1	3	0	1	4	7	1	1	12	0	0	1	3	1	2	36
Land use change and forestry	3	0	0	0	18	0	0	1	21	0	0	0	0	0	0	42
Waste	0	0	0	0	3	4	0	0	1	0	1	3	0	0	0	12
Other	1	1	0	0	2	6	0	0	0	0	4	0	0	0	0	14
Total	**12**	**31**	**34**	**17**	**182**	**226**	**14**	**29**	**173**	**1**	**64**	**14**	**94**	**9**	**215**	**1114**

Table 3.1b Estimated Emissions of N_2O in EU Member States in 1994 (kt)

	A	B	DK	FIN[1]	FR	GER	GRE	IRE	IT	LUX	NLS	P	SP	SW	UK	EU15
Agriculture	3	11	30	9	52	86	8	19	76	0	26	7	58	0	98	484
Production processes	1	12	0	3	77	81	1	3	19	0	32	2	8	2	73	313
Transport	4	1	1	2	6	19	2	1	5	0	7	1	3	3	7	61
Public heat and power	0	3	1	2	2	13	1	2	19	0	0	0	10	1	6	59
Industrial combustion	0	2	0	1	4	4	0	0	6	0	0	0	5	3	3	28
Other fuel combustion	1	3	1	1	5	5	2	1	10	0	0	1	3	1	2	33
Land use change and forestry	3	0	1	0	18	0	0	1	22	0	0	0	0	0	0	44
Waste	0	0	0	0	4	4	0	0	1	0	1	3	0	0	0	13
Other	1	1	0	0	2	6	0	0	0	0	5	0	0	0	0	14
Total	**13**	**32**	**34**	**18**	**169**	**218**	**14**	**26**	**157**	**1**	**70**	**14**	**87**	**10**	**188**	**1050**

Notes: [1] No breakdown of no-transport fuel related emissions given, so emissions allocated on basis of average split between public heat and power, industrial combustion and other fuel combustion.

Sources: Member States and EU Second Communications to the FCCC.

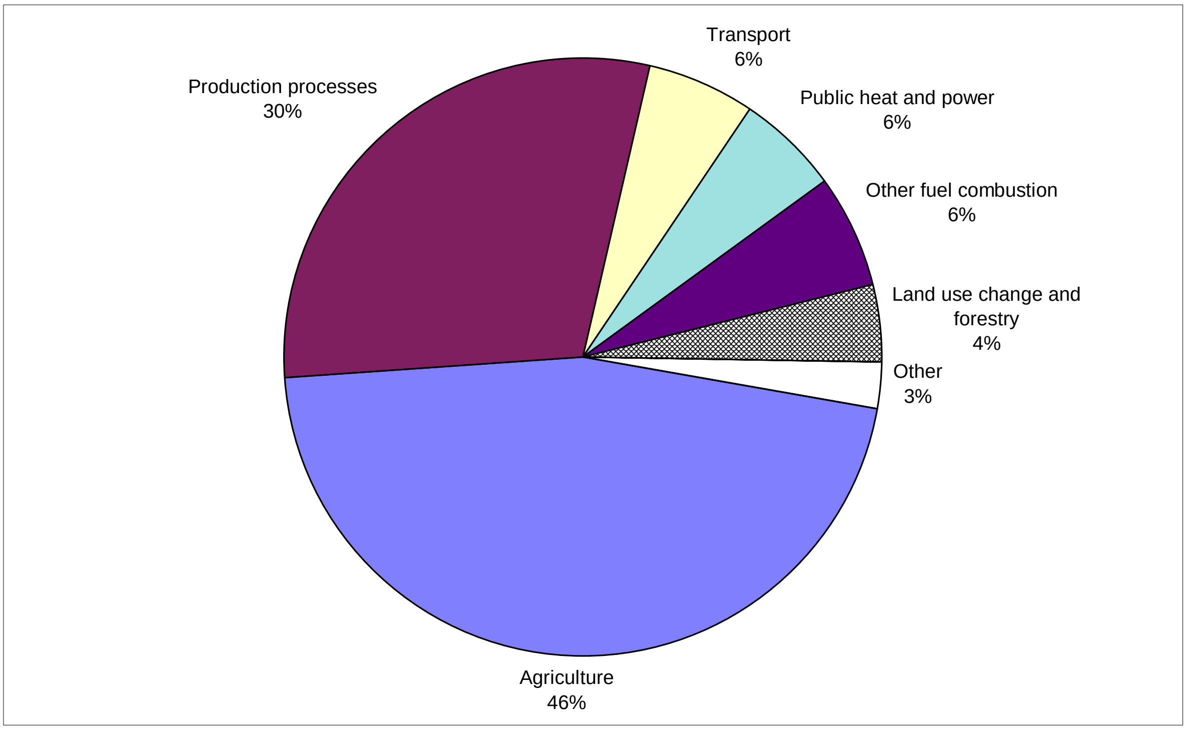
The proportion of anthropogenic emissions arising from individual sectors in 1994 is shown in Figure 3.1 and Table 3.3 for the EU as a whole, and in Figure 3.2 for individual Member States. Within the EU there are two major sources, agriculture and industrial processes (adipic and nitric acid production), and these accounted for 76% of anthropogenic emissions in 1994 (46% and 30% respectively). Emissions from fossil fuel combustion in all types of boilers, power plant and industry accounts for 12%, and road transport a further 6%. Each of these sources are discussed in more detail below in Section 3.3.

Table 3.3 Emissions of N_2O by Sector in 1994 in the EU (kt)

Sector	kt	% of total
Agriculture	484	46%
Production processes	313	30%
Transport	61	6%
Energy Industry	59	6%
Industrial combustion	28	3%
Other fuel combustion	33	3%
Land use change and forestry	44	4%
Waste	13	1%
Other	14	1%
Total	**1049**	**100%**

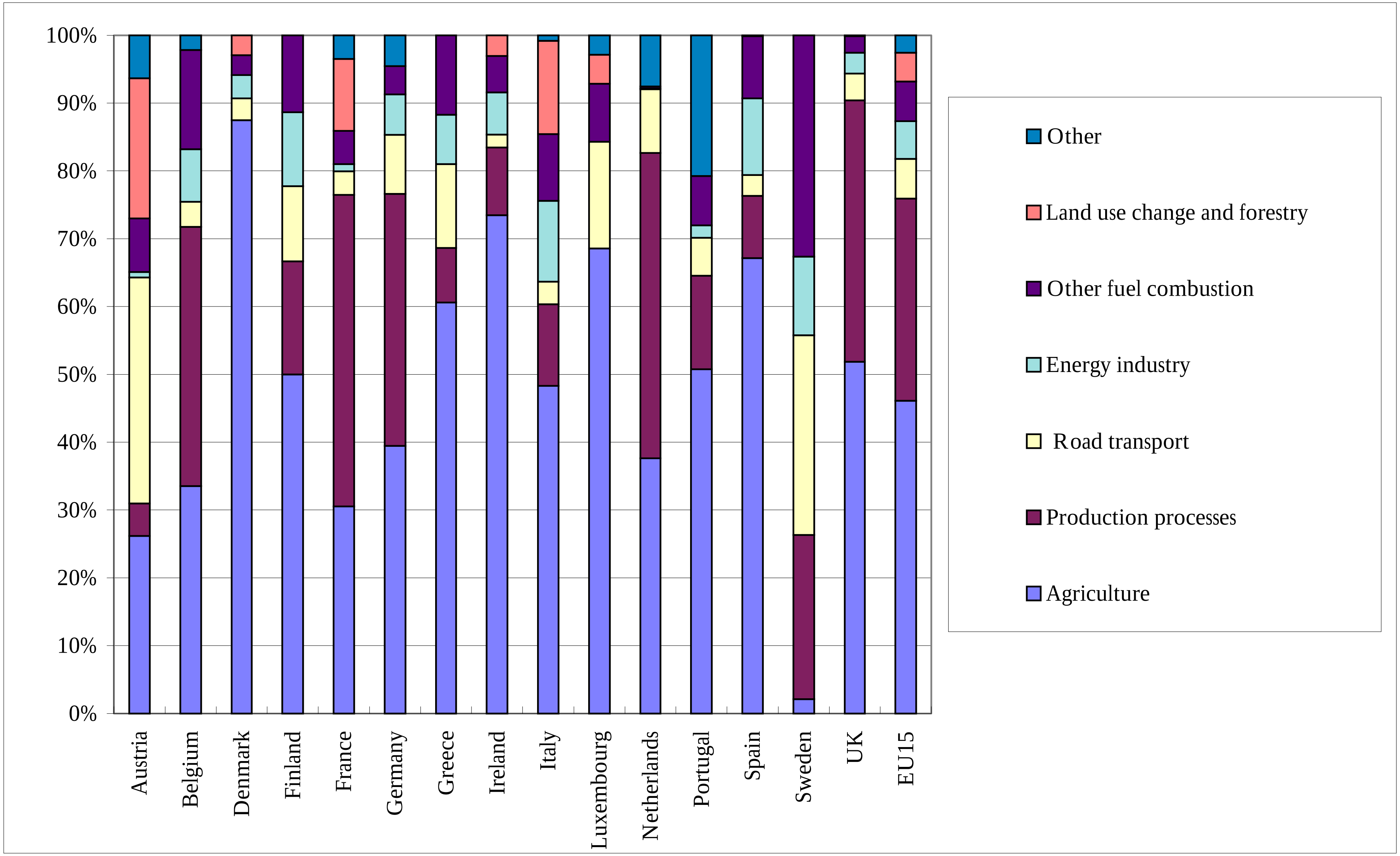
Source: Member States and EU Second Communications to the FCCC.

Figure 3.1 Anthropogenic N_2O Emissions in the EU in 1994 (Total = 1049 kt)



Source: Member States and EU Second Communications to the FCCC

Figure 3.2 Sources of N_2O Emissions in EU Member States in 1994



3.2 CHANGES IN EMISSIONS 1990 TO 1994

As indicated above, emissions fell by 6% between 1990 and 1994 from 1114 kt to 1049 kt. Trends in individual sectors and countries are shown in Figures 3.3 and 3.4.

Figure 3.3 Changes (1990 to 1994) in Anthropogenic N_2O Emissions by Country

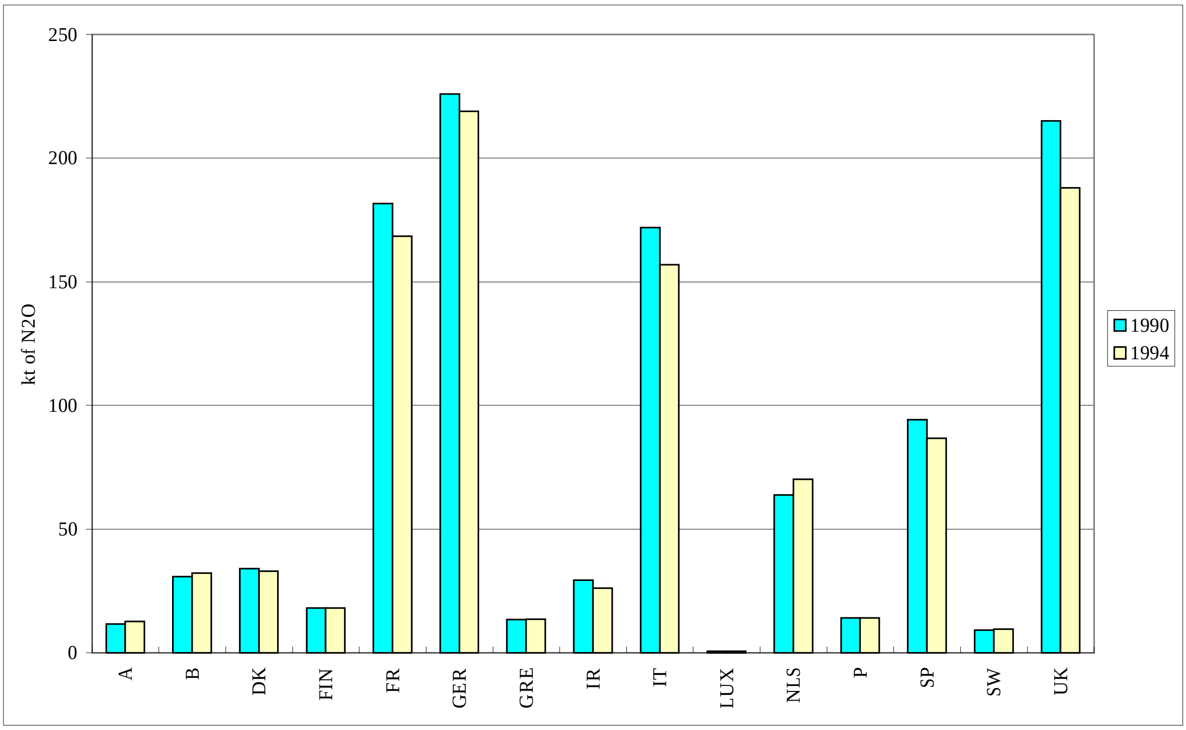
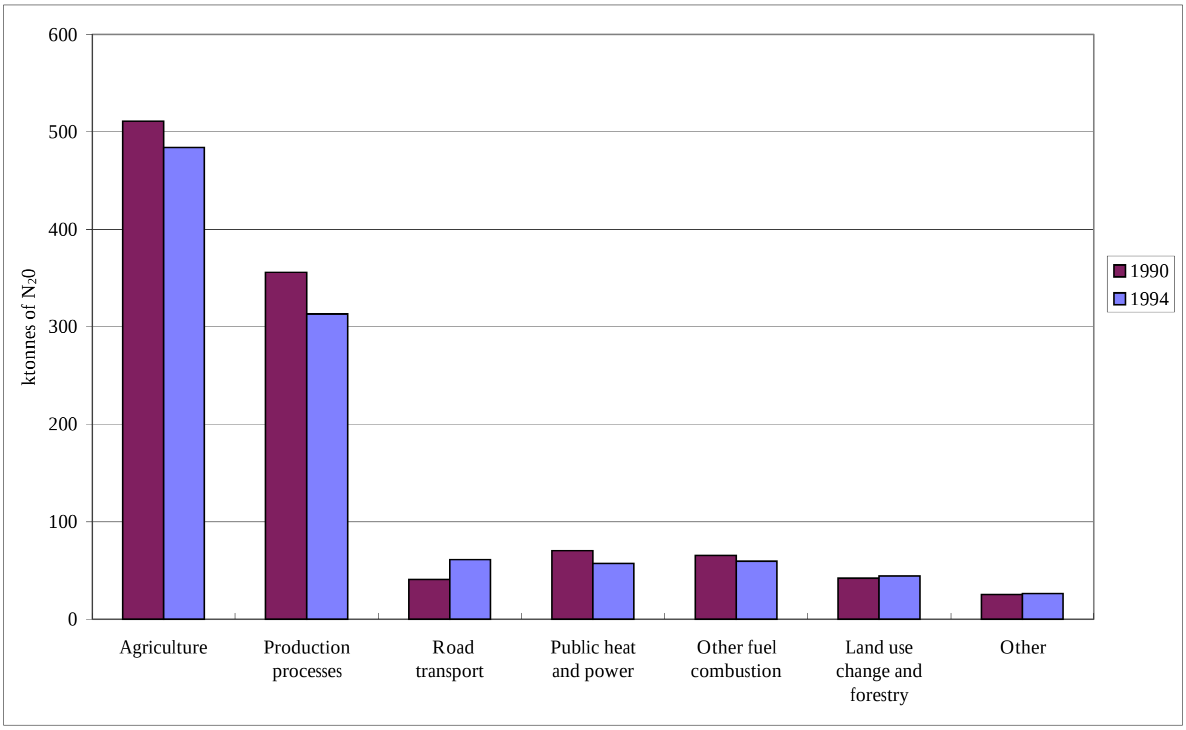


Figure 3.4 Changes (1990 to 1994) in EU Anthropogenic N_2O Emissions by Sector



The main reasons the fall in emissions are:

- A drop of 42 kt (12%) in emissions from ***production processes***. While several countries have plans to reduce emissions from adipic and nitric acid production (see Section 4), these are believed to have had a limited impact by 1994, and the reduction is more likely to be due to a fluctuation in production levels.
- ***Agricultural emissions*** fell by 27 kt (5%). The main reason for this was a reduction in the consumption of inorganic nitrogenous fertilisers which fell by 6% in the EU between 1990 and 1994 (FAO, 1997).
- Emissions from ***fuel combustion*** fell by 15 kt, mostly in the public heat and power sector. This is thought to due to the increased use of gas, which has a lower emission factor than other fuels.

These reductions are partially offset by a 50% increase (of 20 kt) in emissions from the ***transport sector.*** This is to be expected, as the number of vehicles with catalytic converters (which have higher emissions) is increasing (e.g. the percentage of cars with catalytic converters rose from 0 to 23% in the UK between 1990 and 1994) and the total number of vehicle kilometres in Europe is also increasing.

The pattern of changes across Member States is generally influenced by the relative importance of the above sectors in the national emissions total. Thus, all those countries with adipic and nitric acid plant (France, Germany, UK and Italy) show a significant reduction in total emissions, due to the fall in emissions from these sources.

3.3 COMPARISON OF INVENTORY DATA

Estimates of nitrous oxide emissions in the EU are available from two sources:

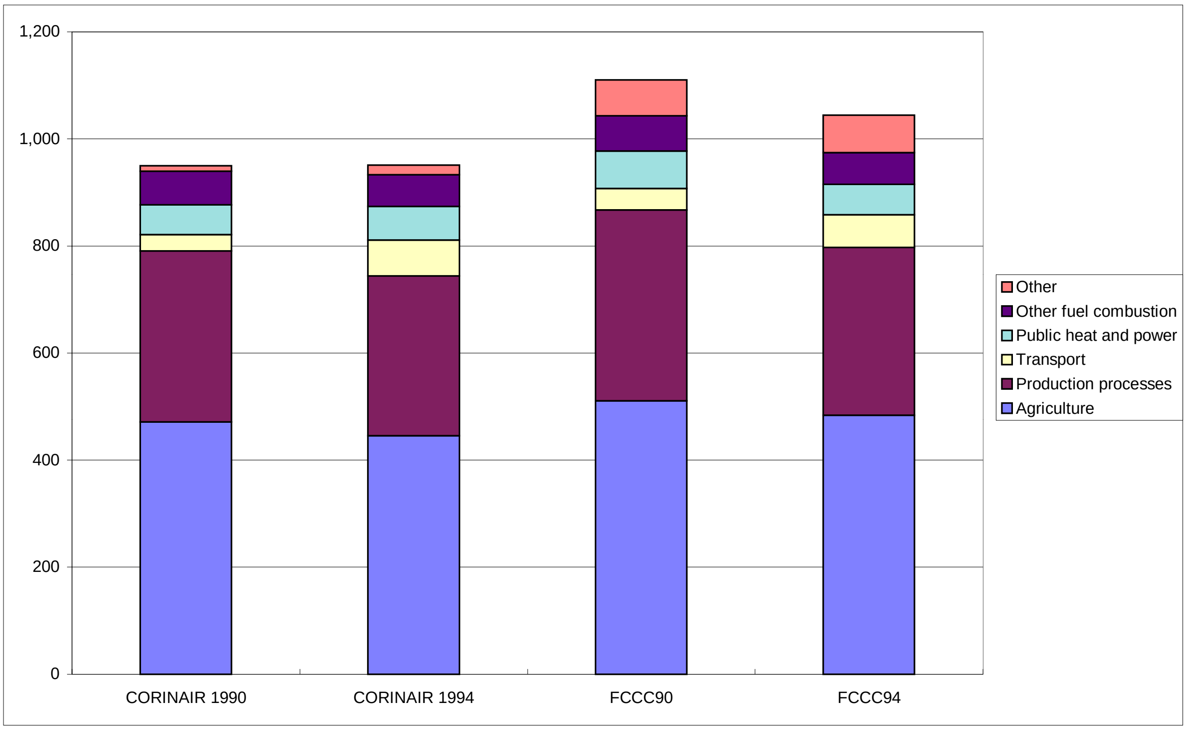
- **CORINAIR** - the Europe wide emissions inventory compiled by the European Environment Agency from national inventories supplied by countries. Data is available for 1990 and 1994, and 1995 data will be available shortly. Data is presently being compiled for 1996.

- **FCCC submissions** - the IPCC has issued guidelines for the compilation and reporting of inventory data by counties to the Framework Convention on Climate Change. Data for the EU Member States compiled for this purpose is available for 1990 and 1994 and in some cases also for intervening years and for 1995. 1996 data is now becoming available.

In general, emissions data compiled for the purposes of reporting to the FCCC has been used as the basis of analysis and reporting in this report, since it is the basis on which Member States and the EU’s compliance with the Kyoto targets under the FCCC will be agreed. In some cases, however, a more detailed breakdown of sources is available from the CORINAIR inventory and this has been used to aid analysis; these cases are clearly indicated in the text.

Figure 3.5 shows the breakdown of EU nitrous oxide emissions by source for 1990 and 1994 given by CORINAIR and by the submissions to the FCCC. A more detailed breakdown of the CORINAIR data for 1990 and 1994 is given in Appendix 2. There are significant differences between the two inventories, and the CORINAIR estimate total (anthropogenic) emissions in 1990 is about 15% lower than emissions estimates taken from FCCC submissions. CORINAIR estimates show almost no change in total emissions by 1994 (compared to the 6% fall indicated by FCCC submissions), so for 1994 the CORINAIR estimate is 10% below the estimate based on FCCC submissions. The main differences are thought to be due to methodological differences in the way that the emissions estimates are derived, particularly in the agricultural sector, where the IPCC have substantially revised the methodology for estimating emissions. The EEA, through its Air Emissions Topic Centre and the UNECE Emission Inventory Task Force are actively working on improving the reporting of emissions in Europe and resolving the differences between the two datasets.

Figure 3.5 Comparison of EU Nitrous Oxide Emissions by Source for 1990 and 1994



3.4 EMISSION SOURCES BY SECTOR

3.4.1 Emissions from Agriculture

Nitrous oxide is produced from agricultural soils mainly by the microbial processes of **nitrification** and **denitrification** (Mosier, 1993). There is a strong relationship between mineral nitrogen levels in the soil and emissions of N_2O, which applies whether the nitrogen originates from fertiliser or manure application, mineralisation in the soil or atmospheric deposition. For inorganic fertilisers, it is estimated that between 1 and 3% of the nitrogen applied, is released as N_2O. The mechanisms leading to N_2O release and the influences which soil type, type of fertiliser and soil conditions may have are discussed in more detail in Section 5.

3.4.2 Emissions from Industrial Processes

The two main industrial processes leading to N_2O emissions are adipic and nitric acid production, and together these accounted for 30% of emissions in 1994. Based on data from CORINAIR90 (a similarly detailed breakdown of the CORINAIR94 data is not yet available), adipic acid was responsible for almost three quarters (73%) of industrial process emissions, and nitric acid for almost all of the remainder (26%).

Adipic acid is a raw material used mainly in the manufacture of 6,6 nylon which is used in industrial carpets; some adipic acid is also used in the manufacture of some low temperature lubricants. The starting point for the acid is cyclohexane, which is used to produce ‘KA’ (a mixture of cyclohexanol and cyclohexanone), which is then oxidised with nitric acid to produce adipic acid. N_2O is a side product of this final oxidation step (Olivier, 1993). In the EU, adipic acid is produced in 4 countries, Germany, France, Italy and the UK.

Nitric acid is a raw material mainly used as a feedstock in fertiliser production, but also in the production of adipic acid and explosives. Most nitric acid is manufactured by the catalytic oxidation of ammonia, during which N_2O is produced as a by-product. Measurements by Du Pont have shown emission factors of 2 -9 g N_2O per kg of nitric acid produced, but it is not known how representative this factor is. Nitric acid is produced widely in the EU, with 9 countries reporting emissions from this process in 1990 (Belgium, Denmark, Finland, France, Greece, Portugal, Spain, Sweden and the UK).

Some other chemical processes have also been identified as potentially leading to N_2O emissions. These are generally processes involving a nitrogen compound, or a catalytic reduction step. Within the EU other industrial processes reported as leading to emissions in CORINAIR90 included:

- petroleum products processing;
- acrylonitrile production;
- ethylene production;
- fluid catalytic cracking;
- furnace steel plant;
- aluminium production;
- paper and pulp processes.

However, emissions from these processes were estimated to be only 1% of the total 1990 industrial process emissions.

3.4.3 Emissions from Combustion of Fossil Fuels

Nitrous oxide is produced directly from the combustion of fossil fuels, mainly as a by-product of the so called “fuel-NO mechanism”, although a number of other mechanisms may contribute to its formation and destruction. The mechanisms are fairly well understood, and it is possible to forecast, at least in a qualitative manner, N_2O emissions from different combustion sources and flue gas treatment techniques.

N_2O emissions due to the fuel-NO mechanism are highest for combustion temperatures of about 730°C; for combustion temperatures below about 530°C or above 930°C, almost zero or negligible amounts of N_2O are emitted. Emissions may also be affected by other factors, for example, increasing the pressure of the combustion gases or the oxygen concentration, tends to increase the emissions.

Other mechanisms which may affect emissions arising from combustion processes are less well studied. They include:

- the destruction of N_2O on bound carbon atoms in graphite and coal char;
- the formation of NO_x from char bound nitrogen atoms;
- the formation of N_2O from NO and reduced sulphates;
- catalytic N_2O formation and destruction in fluidised bed combustion due to limestone ($CaCO_3$) which is added to capture the sulphur present in the coal and reduce SO_2 emissions.

N_2O may also be formed and destroyed where catalysts are used to abate NO emissions in flue gases.

In practice the characteristics of these mechanisms mean that emissions from the conventional combustion of fossil fuels in power stations, boilers etc. are very low (de Soete, 1993), as the flame temperature is high (well beyond 1000°C). Situations where this is not the case are:

- **Fluidised bed combustion (FBC)**. Fluidised bed combustion is a ‘clean coal technology’ with a higher efficiency than conventional pulverised fuel combustion and lower emissions of NO_X due to a lower combustion temperature[2]. However the lower combustion temperature in the bed leads to higher N_2O emissions. Emissions decrease with increasing bed temperature, and increase to a certain degree with increasing oxygen concentration. Lower rank coals (brown coals and lignites, peat wood and oil shales produce less N_2O than bituminous coal. Circulating fluidised beds have often been found to have higher emissions than bubbling fluidised beds, possibly due to the longer residence time in the former.

- **Non Catalytic Selective Reduction (NCSR).** In non catalytic selective reduction (NCSR) chemicals such as ammonia, urea, or cyanuric acid are injected into the flue gas to reduce NO. This leads to some emissions of N_2O, which are higher in the case of urea or cyanuric acid than in the case of ammonia. A more expensive, but more effective technique for reducing NO emissions in flue gases is selective catalytic reduction (SCR), where ammonia is injected into the flue gas in the presence of a catalyst, commonly titanium oxide

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[2] Emissions of SO_2 are also low due to the addition of limestone to the bed.

based, to reduce NO and NO_2 to nitrogen and water. Little experimental data is available, but SCR appears to have little effect on N_2O emissions (de Soete, 1993).

3.4.4 Emissions from Transport

Emissions from fuel combustion in transport are very low, apart from situations where overall reducing conditions occur e.g. in the case of three-way catalysts in petrol vehicles, and cases where overall oxidising conditions exist e.g. emission abatement of diesel engines and lean-burn spark ignition engines. For cars fitted with a new three way catalyst, emissions may be 4 to 5 times higher than cars with no catalyst; as the catalyst ages, emissions tend to increase and emission factors for cars with medium aged catalysts may be 10 to 16 times higher than cars with no catalysts (Olivier, 1993).

3.4.5 Emissions from Waste Treatment and Disposal

This is currently a very minor source of N_2O in the EU. Sources within this category include:

- The incineration of waste. Emissions from the incineration of municipal waste are generally low, and of the same order as those arising from conventional fossil fuel combustion. As with fossil fuels, emissions are higher when FBC is used, and appear to be particularly high when the fuel is sewage sludge. Measurements have shown that emissions from the FBC of sewage sludge are much higher than from the FBC of coals (Werther *et al*, 1995).
- Burning of agricultural residues e.g. straw burning.
- Waste water treatment: emissions arise from denitrification units in wastewater treatment plants.

3.4.6 Miscellaneous Sources

A number of other sources of emissions have been identified, including:

- anaesthetic usage; N_2O is used for anaesthetic purposes;
- propellant usage; N_2O can be used as a propellant in aerosols;
- high voltage transmission lines, where the ionizing effect of corona loss can create N_2O.

These are all thought to be fairly minor sources of emissions.

3.4.7 Natural Emissions

N_2O may be emitted from uncultivated soils through the same processes which operate in agricultural soils, i.e. nitrification and denitrification. In aquatic and humid zones, there is a potential for high emissions, although this is normally limited by nitrogen content. Nitrogen input to uncultivated soils arises from atmospheric deposition of nitrogen compounds, and though leaching of nitrates into irrigation and groundwater. Thus ‘natural’ emissions are affected by anthropogenic activities, such as fertiliser use, NO_X emissions etc., and may be influenced to some extent by policy.

The pollution of inland and coastal waters by nitrates may also lead to emissions of N_2O.

4. Existing and Planned Policies and Measures

National reports submitted by the Member States under the FCCC were reviewed to identify existing and planned strategies for reducing N_2O emissions. Individual country plans are detailed below in Section 4.1 and EU wide measures in Section 4.2. Policies are summarised by sector in Section 4.3.

4.1 NATIONAL STRATEGIES TO REDUCE EMISSIONS

Austria: Austria has plans to reduce fertiliser applications through the targeted use of fertilisers and to extend the use of biological farming and integrated husbandry. The latter will be promoted under the Austrian Programme for the Promotion of Environmentally Compatible Agriculture, and the Austrian Ministry of Agriculture and Forestry already has a research project on "The Contribution of Agriculture to the Ozone Problem", which may help in the development of strategies to reduce emissions from agriculture.

A number of other options are also being reviewed:

- replacement of urea by ammonia in the non-selective catalytic reduction of NO_X from combustion plant;
- optimisation of the combustion temperature in fluidised bed combustion technology;
- feasibility of setting N_2O emission standards for combustion plant and industrial processes.

Denmark: Several measures have already been put in place to improve the handling and utilisation of manure and to decrease the total nitrogen input to the soil. These include:

- the establishment of rules for the application of manure and the utilisation of nitrogen in the manure;
- total applications of nitrogen are not allowed to exceed the nitrogen need of the crop (which is calculated in a standardised way).

The total amount of nitrogen fertiliser used decreased by about 8% from 1989 to 1992.

Finland: No specific policies to reduce emissions are in place, but it is thought that the development of an agri-environment support programme should improve the efficiency of use of chemical fertilisers and manure, and so reduce emissions.

France: A large proportion (60%) of France's emissions arise from adipic, nitric and glioxylic acid production, and it is planned to reduce these emissions by 75% (76.5 kt) by 2000 as shown in Table 4.1.

In the case of adipic acid there is only one production site in France, and this will be installing abatement technology which will also lead to significant reductions in NO_x emissions.

Table 4.1 Proposed Reductions in N_2O Emissions from French Industrial Processes

	Emissions (kt)			
Process	1990	2000	Reduction	
Adipic acid production	55.4	0.4	55.0	99%
Nitric acid production	38.1	25.6	12.5	33%
Glioxylic acid	9.0	0	9.0	100%
Total	102.5	26.0	76.5	75%

Emissions from nitric acid production have already fallen since 1990 (to 28 kt in 1993) as several plant have shut down. A regulation introduced in March 1993 limited emissions in new plant to 7 kg N_2O per tonne of nitric acid produced (reflecting emissions from the use of best existing technology) and limits will be set individually for each existing plant. Glioxylic acid is produced at two sites in France, and the manufacturer is installing abatement technology. N_2O emissions from the plant at the largest site should be eliminated by 1996, and from the smaller site by 2000.

In the field of agriculture, it is considered that the extensification brought about by the switch in CAP from yield based payments to area based payments and the introduction of set-aside are likely to reduce fertiliser use, although it is noted that some set-aside land may be used for the cultivation of non-food crops with similar nitrogen (and hence fertiliser) requirements. The introduction of nitrate sensitive zones (of about 10 Mha) to comply with the EU Nitrates Directive should reduce the application of organic nitrogen, which is often exceeded in intensive livestock areas. Local laws are also being introduced to ensure that applications of organic fertiliser do not exceed the absorption capacity of the soil. The final influence on fertiliser use which is identified is the ‘Fertimieux’ programme which was introduced in 1991. This aims to prevent water pollution by improving agricultural advice and hence practice, for example, by introducing ‘best practice’ management of fertilisers, animal wastes and intercropping. In 1994, about 20,000 farmers, responsible for an area of about 1 Mha (mainly in nitrate vulnerable zones) participated in the programme.

The impact of each of these measures on fertiliser use is summarised in Table 4.2. In total it is estimated that they will reduce fertiliser use and hence N_2O emissions by 14% by 2000, with the largest reductions coming from compliance with the Nitrates Directive and set-aside.

Table 4.2 Reductions in French Fertiliser Use from Various Measures

Inorganic and organic fertiliser use in 1990 (million tonnes N)	3.8
Impact of set-aside (assumed to lead to a 10% reduction in cultivated area)	-0.11
Impact of de-intensification	-0.1
Impact of Nitrates Directive	-0.31
Impact of “fertimieux” programme	-0.02
Total estimated reduction in fertiliser use	-0.54 (-14%)
Estimated inorganic and organic fertiliser use in 2000 (million tonnes N)	3.26

Germany: In Germany two main areas have been identified where policies could lead to reductions in emissions, adipic and nitric acid manufacture, and agriculture.

In the case of adipic acid manufacture, one of the two producers in Germany has already installed a 7M DM (4M ECU) facility to practically eliminate N_2O emissions, through a process in which N_2O is broken down thermally into oxygen and nitrogen. The second producer plans to begin using a facility for catalytic destruction by 1999 or earlier . Additional measures could also be put in place to reduce emissions from nitric acid production.

In the agricultural sector, it is believed that reductions in emissions will result from programmes already in place, including:

- regional policies to support environmentally friendly farming practices;
- EU agri-environment measures;
- Fertiliser Ordinance (in force since July 1996), which introduced regulations on fertiliser use and implements the EC Nitrate Directive
- CAP reform including introduction of set aside and reductions in livestock numbers;

Additional measures which are identified as potentially leading to further reductions are mainly aimed at ensuring best practice is followed in fertiliser use and include:

- integrated methods of cultivation;
- matching nitrogen fertilisation levels to plant requirements;
- reduction of nutrient losses through optimal soil preparation, crop rotation and irrigation;
- improving fertiliser efficiency by improving fertiliser dosage;
- improving expert advice on fertiliser use;
- selecting suitable fertiliser types;
- specifying best practice for fertiliser use (e.g. prescribing soil testing determination of fertiliser requirements, limiting applications of liquid manure and requiring fertiliser use to be documented).

The other non-energy area in which it is suggested reductions might be made is in wastewater treatment plants, by enclosing the tanks and installing waste gas scrubbing.

The emissions predicted in 2010 in scenarios ‘with’ and ‘without measures’ in place are shown in Table 4.3. The reductions in the main source sectors are partially offset by an increase in the energy related emissions due to an increase in road traffic emissions as the proportion of cars equipped with catalytic converters increases.

Two areas for improvement identified in the energy sector are options for reducing N_2O emissions in fluidised bed combustion, and improving catalytic converter technology to reduce or eliminate N_2O formation.

Table 4.3 Predicted Emissions In Germany In 2010 (kt)

Source	1990	2010 (without measures scenario)	2010 (with measures scenario)	Reduction from measures
Transport	11	21	210	
Other energy	26	22	22	
Industrial processes	83	106	23	83
Agriculture (direct)	64	58	54	4
Waste	4	4	4	
Other	6	6	6	
Groundwater/surface water (agriculture)	32	30	27	3
Total[a]	**226**	**247**	**157**	**90**

[a] Totals may not equal sum of above due to rounding errors

Greece: While there are no specific policies in place to reduce agricultural emissions, these are expected to fall in the future due to:

- a decrease in fertiliser consumption due to price increases following the deregulation of the fertiliser market;
- publication in 1994 of a "Code of Good Agricultural Practice" which sets out guidelines on the rational use of fertilisers;
- support for organic farming under the EU Agri-Environment programme.

These predicted reductions are however, expected to be more than offset by an increase in transport emissions due to the increased use of catalytic converters.

Ireland: No specific policies relating to N_2O emissions.

Italy: While no specific policies are in place emissions from agriculture are expected to fall by 20% due to the reduction in fertiliser use resulting from implementation of the Nitrate Directive and from set aside. Overall, this reduction will be partially offset by an increase in traffic related emissions.

Luxembourg: No specific policies are in place.

Netherlands: As it is expected that N_2O emissions will remain at the same level as 1990 with falling emissions from agriculture compensating increasing emissions from transport, no specific policies have been considered necessary (1997). The following measures are however in place:

- research into options for reducing emissions from nitric acid production
- existing policies on nutrients (nitrate) and ammonia emissions, and a decrease in animal manure production will lead to reductions; the development of practices to reduce NH_3 emissions by injecting manure directly into the soil has however led to an increase in emissions.

- Increased catalytic converter use in passenger vehicles and a possible increase in energy use in transport could increase emissions by almost 100% between 1990 and 2000.

Portugal: The extensification of farming encouraged through the recent reform of CAP, including "set-aside" and other agri-environmental measures such as the extension and /or maintenance of traditional agricultural systems, is identified as reducing the use of fertilisers and number of head of cattle so leading to a reduction in emissions of N_2O and CH_4. There are no plans to introduce specific measures to reduce emissions.

Spain: Three types of measures are being implemented to rationalise the use of fertilisers and hence reduce N_2O emissions:

- implementation of automated methods to obtain the fertiliser application recommended for specific soil, climate and crop conditions;
- wider use of non-traditional methods for applying fertilisers;
- limit for applying organic nitrogenous fertilisers to 179 kg of nitrogen per ha per year.

Sweden: No specific policies have been put in place but it is thought that measures already in place under an action programme to reduce the leaching of plant nutrients from agriculture should also help to reduce N_2O emissions. Measures adopted under the programme include:

- limitations on the number of animals per ha;
- increased storage capacity for manure;
- increased proportion of autumn and winter-planted land;
- ban on fertiliser spreading at unsuitable times.

UK: Within the UK the manufacturer of adipic acid is committed to reducing emissions of N_2O by 2000. In the agricultural sector, the CAP reforms of set-aside, and a reduction in cereal prices, are identified as leading to a decrease in fertiliser use and hence emissions; a decline in livestock numbers should result in a reduction in livestock wastes used as fertiliser.

4.2 EU INITIATIVES

CAP: at the EU level, it is noted that environmental requirements need to be integrated into the Common Agricultural Policy (CAP) and that measures included in the last CAP reform in 1992, such as the change in the price support system, can help to reduce emissions of greenhouse gases. For example, the reduction in agricultural prices makes the use of inputs such as fertiliser less profitable, and following the CAP reform, inorganic fertiliser use fell by about a third, leading to a fall in associated N_2O emissions. Application rates for inorganic fertiliser are likely to continue to fall, as better use is made of nitrogen from organic manure and due to changes in crop areas.

Agri-environmental scheme: set up to promote farming activities that benefit the environment has now approved 117 programmes, setting out 2500 measures in regions throughout the EU. While the measures are not specifically aimed at reducing greenhouse gas emissions, some of them may have a beneficial impact and the EC is seeking to ensure that monitoring of the programmes will take into account effect on greenhouse gas emissions.

Research: the EC has a research programmes on agricultural and forest research, and while only a few are aimed directly at the reduction of greenhouse gases, many are indirectly related (e.g. looking at reduction of fertiliser use).

4.3 SUMMARY OF PROPOSED POLICIES BY SECTOR

In summary, proposed policies relate to the agricultural and industrial emissions only. In the **agricultural** sector, very few countries have initiated policies specifically designed to reduce N_2O emissions. A number of existing trends in agriculture, principally brought about by the reform of the Common Agricultural Policy in 1992, and existing programmes to prevent nitrate leaching and water pollution are identified as helping to reduce inorganic fertiliser use, and/or reduce applications of organic fertiliser.

The reform of CAP in 1992 led to a switch from yield based payments to area based payments and a requirement for farmers to take a certain proportion of their land out of production ('set-aside'). These changes are identified by several countries as potentially leading to reductions in fertiliser use. The reforms are also likely to lead to a reduction in livestock numbers and were hence assumed by some countries to lead to a reduction in applications of organic fertiliser (manure). Another result of the CAP reforms was the introduction of the Agri-environment Regulation which requires Member States to introduce a range of schemes in which farmers receive payments in return for a range of environmentally friendly management practices including reducing the polluting effects of agriculture, encouraging environmentally favourable extensification of crops and livestock, and setting-up environmentally beneficial long-term set aside. These schemes are generally funded jointly by the EU and Member States. Several countries identify schemes introduced under this regulation as potentially leading to reductions in emissions.

In addition many countries identify measures introduced to help implement the EU Nitrates Directive (91/676/EEC), or to generally help to reduce pollution from agriculture, as leading to reductions in fertiliser use. Such measures include the introduction of Codes of Good Agricultural Practice, programmes to provide expert advice, standard methods for calculating the nitrogen need of crops and hence determining fertiliser application, and rules for the application of manure.

Reductions in agricultural N_2O emissions which were estimated quantitatively were:

France	-14%
Italy	-20%
Netherlands	-20%

In the **industrial processes** sector, adipic acid manufacturers in Germany, France and the UK are all to implement abatement technology to reduce emissions by 95% to 99%. No plans are indicated for the Italian manufacturer.

5. Options for Reducing Emissions from Agriculture

5.1 APPROACH TAKEN

The agricultural sector is the largest source of N_2O emissions accounting for 46% of anthropogenic emissions. However, due to the nature of the emission sources it is also a difficult sector to assess. There are large uncertainties over emission factors, on how various parameters affect emissions and scant data on the efficacy of options to reduce emissions. Due to these uncertainties, to the complex nature and interactions which occur in the agricultural sector and also to the strong influence of background trends, other influences and policy considerations (e.g. the Common Agricultural Policy), it was not possible to consider a large number of options discretely, as is being done in the majority of the study. Instead, a more ‘broad brush’, top down approach was taken looking at the factors which influence agricultural emissions, and how these factors might be influenced by management and policy options. An emissions model of the agricultural sector, was constructed and used to examine, how a significant reduction in emissions could be achieved. A detailed discussion of the options, the modelling work and results are given in Appendix 3, and are summarised below in Sections 5.4 and 5.5.

In addition to this ‘broad brush’ approach, work was also carried out to look in more detail and to cost in a ‘bottom-up’ type of approach the reductions achievable from some of the nearer term options. This work is reported in full in Appendix 4 and is summarised in Section 5.6 below. Costs calculated for both the top-down and bottom-up approaches are discussed in Section 8.

5.2 EMISSION MECHANISMS

Agricultural N_2O emissions derive from three principal sources (IPCC, 1996):

- direct emissions from soil nitrogen e.g. applied fertilisers (both manures and artificial), the mineralisation of organic soils and crop residues;
- emissions from livestock wastes in store;
- indirect emissions from nitrogen lost to the agricultural system e.g. through leaching, runoff or atmospheric deposition.

Nitrous oxide is produced by the processes of denitrification and nitrification. Denitrification is the microbial reduction of nitrate or nitrite to dinitrogen or N-oxides. The main bacterial genera responsible for denitrification are *Pseudomonas*, *Bacillus*, *Paracoccus* and *Rhizobium*. These bacteria are facultative aerobes (*i.e.* they are able to exist in both aerobic and anaerobic conditions), but can use nitrate as an electron acceptor in the absence of oxygen. Denitrification occurs in anaerobic, flooded soils, and in anaerobic microsites in otherwise aerated soils. The general pathway for denitrification is (Bouwman, 1990):

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2 + H_2O$$

Nitrous oxide is readily soluble, and surface water draining from agricultural fields contains dissolved N_2O, which is later denitrified or lost to the atmosphere (Fowler, *pers. comm.*). Leached nitrate can be denitrified in ground or surface waters to provide a source of N_2O as large as direct emissions from soils (Bouwman, 1990). Chemodenitrification, resulting from chemical processes in the soil without microbial activity, may also contribute to N_2O losses (Vinten and Smith, 1993).

Nitrification is the oxidation of ammonium to nitrite or nitrate. The main bacteria genera are *Nitrosomonas*, *Nitrosococcus*, *Nitrospira*, *Nitrosolobus* (ammonium to nitrite) and *Nitrobacter* (nitrite to nitrate). *Nitrosomonas* and *Nitrobacter* are the most common. The main nitrification reactions are (Batjes and Bridges, 1992):

$$\begin{tikzcd} NH_4^+ \arrow[r] & NH_2OH \arrow[r] & \lbrack HNO \rbrack \arrow[r] \arrow[d, shift right] & NO \arrow[r] & NO_2^- \\ & & N_2O \arrow[u, shift right] & & \end{tikzcd}$$

(*Nitrosomonas*)

$$2NO_2^- + O_2 \rightarrow 2NO_3^-$$

(*Nitrobacter)*

5.3 INFLUENCES ON EMISSIONS

The principal environmental parameters affecting N_2O emissions are the availability of a nitrogen source, moisture and temperature, with nitrogen availability being the most important (Colbourn, 1993). Agricultural management has a major influence on nitrogen availability and environmental conditions, through, for example, fertiliser applications, livestock waste handling, residue management or operations affecting the structure, aeration and pH of soils. The use of farm management to reduce nitrogen losses from the agricultural system through improved fertiliser efficiency has been evident for some time. However, the principal objective of these efforts has been to maximise crop productivity and the profitability of farm enterprises. More recently, recognition of the greenhouse forcing effect of N_2O and NO_x, as well as the contribution of NH_3 to acidifying deposition, has led to an interest in reducing trace gas emissions on the grounds of environmental protection. The manipulation and use of appropriate management techniques provides an important opportunity for N_2O mitigation from agriculture.

Farmers adopt management practices based on a desire to maximise the profitability of their farm enterprise, at the same time as minimising risk, and following local traditions and cultures. The use of management techniques by the farming community to mitigate N_2O emissions can be encouraged by the implementation of policy. Policy influences farm management through:

- financial incentives and intervention;
- the imposition of regulations;
- education and extension.

Within the European Union, agricultural policy is driven by the CAP (Common Agricultural Policy), which is in a constant state of reform and at various stages of implementation. It is likely that current and proposed future reforms to the CAP will significantly affect N_2O emissions from agriculture. For example, the introduction of the Agri-environment Regulation is likely to lead to measures which reduce emissions. Similarly, measures being introduced to help implement the EU Nitrates Directive will affect N_2O emissions.

5.4 OPTIONS TO REDUCE EMISSIONS

5.4.1 Potential options

Based on the influences discussed above, it is possible to identify a number of management options which might have an impact on the factors influencing emissions. These are summarised in Table 5.1. In addition it is possible that changes in farming systems, such as organic farming might have also an influence on emissions.

Table 5.1 Agricultural Management Options Influencing Emissions

Type of option	Management Option
1. Crop management	(a) change in fertiliser application rates (b) precision farming (c) crop selection (i.e. with different nitrogen requirements) (d) breeding nitrogen fixing crops (e) breeding crops to improve nitrogen use efficiency (e.g. lower requirements, more efficient uptake) (f) cultivation of unmanaged land (i.e. histosols) (g) irrigation management (h) soil pH management (i) crop residue burning (j) reduce soil compaction
2. Fertiliser efficiency management	(a) nitrification inhibitors; (b) release rates (e.g. slow or timed release, coatings to limit or retard water solubility); (c) improved fertiliser placement and timing (e.g. band placement, foliar applications).
3. Manure management	(a) storage times and conditions (e.g. slurry treatment to change viscosity); (b) application placement (e.g. slurry injection); (c) application timing; (d) application amounts (e.g. controlled rate systems); (e) export of manure (from the agricultural system).
4. Reducing the amount of manure nitrogen	(a) dietary manipulation; (b) breeding nitrogen efficient livestock; (c) livestock selection (e.g. livestock types, herd sizes).

Implementation of these management options could be brought about by a number of policy mechanisms, as listed in Table 5.2.

Table 5.2 Potential Policy Instruments to Implement Management Options

Type of Policy Option	Option
1. Market based instruments	(a) fertiliser tax; (b) intervention (area payments, set-aside, quotas); (c) move toward free markets (removing subsidy); (d) incentives for agri-environment management (ESAs, NSAs, extensification etc.)
2. Regulation (restrictions on nitrogen and crop management)	(a) nitrate vulnerable zones (NVZs); (b) top limits on nitrogen/ha applications; (c) closed season on applications (d) straw burning restrictions.
3. Enhancing the knowledge-base	(a) funding of scientific research; (b) technology transfer (advice, dissemination, codes of good practice, etc.); (c) consumer awareness.

5.4.2 Feasibility of Options

Although there is an extensive literature on aspects of soil processes, fertiliser and manure management, and N_2O emissions, availability of reliable generic data concerning changes in emissions in response to management decisions is still poor. This is because most results are site-specific, and as the emission mechanism is potentially influenced by a large number of factors, extrapolating these site results to a larger scale is inappropriate without further work to help reduce uncertainties. It is therefore not currently possible to quantify the impact of some management options. In other cases, previous experience shows that some policy and management options are unlikely to be effective.

The approach taken in this study was therefore to identify options which on the basis of experimental evidence and/or previous experience were considered most likely to deliver real reductions in emissions in practice. It was assumed that this ‘package of options’ must not only deliver significant reductions in N_2O emissions, but also:

- minimise costs, as far as possible;
- allow for the social dimensions of the CAP that provide, for example, for disadvantaged (*i.e.* marginal) agricultural systems.

Analysis of piece-meal changes in a wide range of policy options suggested that substantial reductions in emissions[3] could not be satisfied easily in this way, and that more powerful changes were required. Given the criteria above, the best mitigation approach appears to be to implement policy that:

(a) limits top rates of inorganic nitrogen fertiliser applications by the introduction of nitrogen use quotas;
(b) limits the timing of fertiliser and manure applications;
(c) reduces price support
(d) provides direct subsidies for marginal (extensive) land.

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[3] The study was initiated pre-Kyoto, and the EU negotiating position of a 15% reduction on 1990 levels by 2010 was taken as a guide to the magnitude of the emission reduction a package of options would be required to deliver.

The price related approaches are in line with the proposed changes to CAP under Agenda 2000 which proposes further reductions in market support prices and an increase in direct payments to farmers. These latter may be made conditional on environmental requirements. Regulating applications of nitrogen is consistent with the aims of the Nitrates Directive.

These options and the way in which the emission reduction they might bring about are considered is described in Section 5.5, and the impact of a number of individual, more near term measures in Section 5.6. Those options which are not considered further in this study are discussed below, together with an explanation of the reasons for their exclusion from the present study.

5.4.3 Options not Considered Further in this Study

5.4.3.1 Management Options

Soil pH Management

N_2O emissions increase with increasing pH up to about pH 8. The influence of pH on N_2O emissions is especially great when soil nitrate levels are high. The literature reports widely varying emission increases, between 3 and 10-fold when pH is raised (in Granli & Bockman, 1994). However, liming also increases yield and the nitrogen uptake rate of crops, so less nitrogen is available in soil to be emitted as N_2O (Bailey, 1995). As pH management is already practised on most farms with significant nitrogen applications, this was not considered a useful mitigation option.

Irrigation Management

Irrigation management is another potential way of controlling emissions. If a soil is wetted to produce anoxic microsites, and then dries within 24-72 hours, insufficient time will have elapsed for N_2O reductase to be generated, preventing N_2O reduction to N_2. Maximum N_2O emissions are reported shortly after irrigation or rainfall (in Granli & Bockman, 1994). However, manipulating irrigation to control emissions would be likely to have adverse effects on crop growth and labour requirements, and the scarcity of reliable data mean that realistic assessments are not possible.

Fertiliser efficiency management

Developments in fertilisers have already improved crop nitrogen recovery, with subsequent diminished losses to leaching and volatilisation. Slow release fertilisers can increase nitrogen recovery from 22% to 79%, with cost savings of 65% (Shoji & Kanno, 1994). Much attention has been focused on this topic, and it was felt that most farms are employing new fertiliser techniques as they develop. Any policy option which encourages farmers to manage nitrogen more efficiently would be likely to increase the use of better fertilisers.

5.4.3.2 Policy Options

Fertiliser taxes

Fertiliser taxes are already in use in some EU15 countries, (*e.g.* Denmark). However, there is some doubt that they are an effective instrument for reducing nitrogen over-application, as farmers will continue to pay higher prices for the same amount of fertiliser as a risk aversion response. Vatn et al. (1996) report that taxes do not motivate farmers to modify nitrogen-fertiliser practices or adopt a better use of manure unless the taxation level is very high. Their results suggest a 50% tax rate is required for a 5% reduction in nitrogen per hectare (N/ha) applied to grain crops, and a 20% reduction in N/ha on grass. A tax rate of 100% could induce a 10% reduction in N/ha applied to grain crops, and a 40% reduction in N/ha to grass.

Other authors come to similar conclusions, summarised by Herlihy & Hegarty (1994), who concluded that extreme price increases (taxes) were required to decrease nitrogen applications: For example, a 200% tax is required for a 25% decrease in N/ha, except where nitrogen is applied in great excess. Fertiliser taxes are normally 20-30%, and have little effect. Direct restriction of applications is more effective, and therefore more efficient both economically and environmentally. For these reasons, taxes are not considered further here. The feasibility of fertiliser taxes is however currently the subject of new research by DGXII of the EC.

Other market based policy instruments

The EU agricultural policy of area payments and price support has encouraged cultivation of marginal lands in Spain and elsewhere, which could be abandoned if payments stopped (Faulkner, 1995). Various models exist for predicting land use conversions in response to policy changes, for example, reduced price support for milk causes conversions to forest (Plantinga, 1996). Agricultural systems that remain in practice are still likely to include input/output adjustments to increase efficiency. Vatn et al. (1996) predict that a 33% price reduction would result in a 5% reduction in nitrogen applications to grain crops, and a 20% reduction to grass.

Various researchers have modelled shifts within cropping sequences, depending on relative gross margins as affected by CAP payments. For example, if there is a shift from crop specific to homogenous payments, oilseed rape growing decreases and is replaced by cereals; if set-aside requirements are removed, industrial oilseed rape is also replaced by cereals. In Germany, the cereal area is predicted to increase by 6% with high set-aside requirements, by 11% with low set-aside, and by 14% with no set-aside (Kleinhanss, 1996). Reduced price support leads to activity moderation on marginal Greek farms, with unconventional crop choices and agricultural product processes leading to higher debts, and dependence on seasonal labour and rented land (Damianos & Skuras, 1996). Crop selection trends can be influenced or accelerated with economic instruments, *e.g.* slow conversions to woodland could be overcome by changing regulations which counteract financial incentives (Lloyd et al., 1995).

Even if policy instruments are successful in motivating farmers to consider reducing nitrogen inputs and to adopt more efficient techniques, the potential negative impact resulting from compromising crop yields may prevent such instruments being employed. It is necessary to be sure that crops can perform at lower nitrogen levels before such a policy is recommended. Some cultivars of major crops already perform well under low nitrogen conditions, with yields at 89% optimum nitrogen; others suffer larger yield losses at 61% (Legouis & Pluchard, 1996). Current research is developing new ways to improve crop nitrogen dynamics. Nitrogen-fixing bacteria can be inoculated into the rhyzosphere of triticale, resulting in high yields and a self-supporting nitrogen balance which is inhibited by fertiliser-nitrogen (Umarov et al., 1994). Wheat can be infected with endophytic nitrogen-fixers (Sabry et al., 1997); as can rape (Glagoleva et al., 1996). Nitrogen uptake in barley can be increased by inoculating the rhyzoplane with nitrogen-fixers (Belimov et al., 1995). Legumes can be inoculated with improved nitrogen-fixers, increasing nitrogen uptake (Shaheen & Rahmatullah, 1994). It seems likely that when the results of these current research programmes are available for commercial use, there will be considerable scope for fertiliser-nitrogen reductions.

5.5 A PACKAGE OF OPTIONS TO REDUCE EMISSIONS

5.5.1 Methodology

In order to estimate the reduction in emissions which might be achieved by the 'package of options', a model of EU agricultural emissions was set up, using the IPCC methodology (IPCC, 1997) for estimating emissions (the model is described in more detail in Appendix 3). Assumptions were made on future fertiliser use, livestock numbers, cultivated areas etc. to develop background trends (full details are given in Appendix 3). A number of additional assumptions were then made to develop a 'business as usual' scenario:

- The set-aside requirement was reduced in line with current policy statements from 15% in 1994 to 0% by 2005 (*i.e.*: an increase of 17.6% from the 1994 fertilised arable area, which effectively accounted for 85% of the total area available).
- The agri-environment schemes that have already been implemented between 1994 and 1997 were included, but no new uptake was assumed after 1997.
- In the absence of reliable published information, restrictions on fertiliser use were based on expert judgement. The amount of N used per crop type was considered to decrease by 2% (for each projection year), and sheep and beef herd sizes were considered to decrease by 1% (for each projection year).
- The implementation of NVZs were considered to reduce N use and leaching losses by 5%.
- The effects of research and development, and of continuing technology transfer and consumer influences were expected to continue to increase, leading to reductions in N use (of 10% by 2020) and in the quantity of N_2O released from a given application of fertiliser (by 4% by 2020).
- Improvements in manure and livestock management were considered to reduce N use in grassland systems by between 5 and 10% (for 2010 and 1020), reduce N volatilisation from manures by between 2 and 5%, reduce leaching losses by between 5 and 10% and reduce manure production in pig and dairy systems by between 2 and 5%. Once again, due to the absence of published sources of information, quantification of these effects was based on expert judgement. The greater potential for N savings from manure management (as opposed to fertiliser N which is already used relatively efficiently) is reflected in these figures.

More detail about the way in which the scenario was developed is given in Appendix 3, and the projection of emissions is discussed in more detail in Section 9.

The model was used to assess the impact of the 'package of options' described in 5.4.2, that is measures which:

(a) limit top rates of inorganic nitrogen fertiliser applications by the introduction of nitrogen use quotas;
(b) limit the timing of fertiliser and manure applications;
(c) reduce price support
(d) provide direct subsidies for marginal (extensive) land.

In addition to these measures which are described in more detail below in Section 5.5.2, the impact of two existing trends were included in the scenario:

- Agri-environment scheme were considered to have an increasing impact, as schemes are developed and extended, leading to a reduction in fertiliser N use by 5% by 2020.

- The European Fertiliser Manufacturers Association projections for fertiliser use until 2005 were adopted and extended to 202 (EFMA, 1996). These projections are based on the widely proposed movement towards a free market as well as improvements in manure use, projected development of southern European agricultural systems, and world market dynamics.

5.5.2 Description of Options

5.5.2.1 Nitrogen Application Limits

The rationale behind the nitrogen application limits is to reduce the total amount of nitrogen in the system by replacing inorganic nitrogen fertiliser with organic nitrogen from manure. Most nitrogen pollution (nitrate leaching, ammonia, nitrous oxide and NO_x emissions) is lost from the surplus nitrogen in the system, i.e. that which is not taken up by the crop. The same processes occur in non-agricultural systems, although the quantities of nitrogen lost are generally much lower. This is because the total amount of nitrogen is lower and the system is less leaky, and more of the available nitrogen is taken up by the biomass. In agricultural systems, nitrogen quantities are boosted by the addition of nitrogen to the system (manure is not regarded as an nitrogen addition, as it represents nitrogen that is already within the agricultural system[4]). Crop uptake of nitrogen is increased, but does not balance the additional nitrogen input, and there is a greater pool of surplus nitrogen available to leaching and denitrification processes, so acting as a potential pollutant.

In the scenario considered, it is envisaged that nitrogen application limits would be introduced for inorganic fertilisers, with no limits imposed on the use of organic sources of nitrogen. This would encourage farmers to substitute their inorganic fertiliser usage with manures. A target application rate of 50 kg/ha was selected for grassland and arable areas, with reductions in the application rate being phased in over time: 80 kg/ha in 2000, 70 kg/ha in 2005, 60 kg/ha in 2010 and 50 kg/ha in 2020. The nitrogen limits would target arable and grassland systems only because these sectors are the largest nitrogen users, and their application rates (according to EFMA, 1996) are forecast to increase in the future (see Figure 5.1). An analysis based on targeting cereal production only was found not to satisfy the emission reduction criteria specified for this scenario. The 50 kg N/ha application rate was selected after an analysis of the effect of a range of alternative application limits (from 100 to 50 kg N/ha) found that only the 50 kg N/ha achieved an emission reduction target of 15%[5]. An alternative approach to nitrogen limits, of limiting fertiliser applications to 80% of the optimum nitrogen requirements of the crop, was also found to be ineffective. The linear phase-in rates (between 2000 and 2020) were introduced to allow for the evolution of appropriate commercial activities (e.g. manure distribution networks), management practices (e.g. on-farm) and technological development (e.g. manure processing). The substitution of inorganic fertilisers with manures would constitute a more efficient use of manures, which are currently disposed of as waste products.

The need for a fundamental reassessment of the way the EU uses nitrogen before nitrogen-related pollution problems can be solved is raised by many authors, for example Vandervoet et al. (1996), who state that measures to control nitrate leaching and nitrogen deposition '*do not satisfactorily solve the problems, mainly because the ultimate origins of the problems are not sufficiently influenced and measures therefore inevitably result in a shifting of problems*'.

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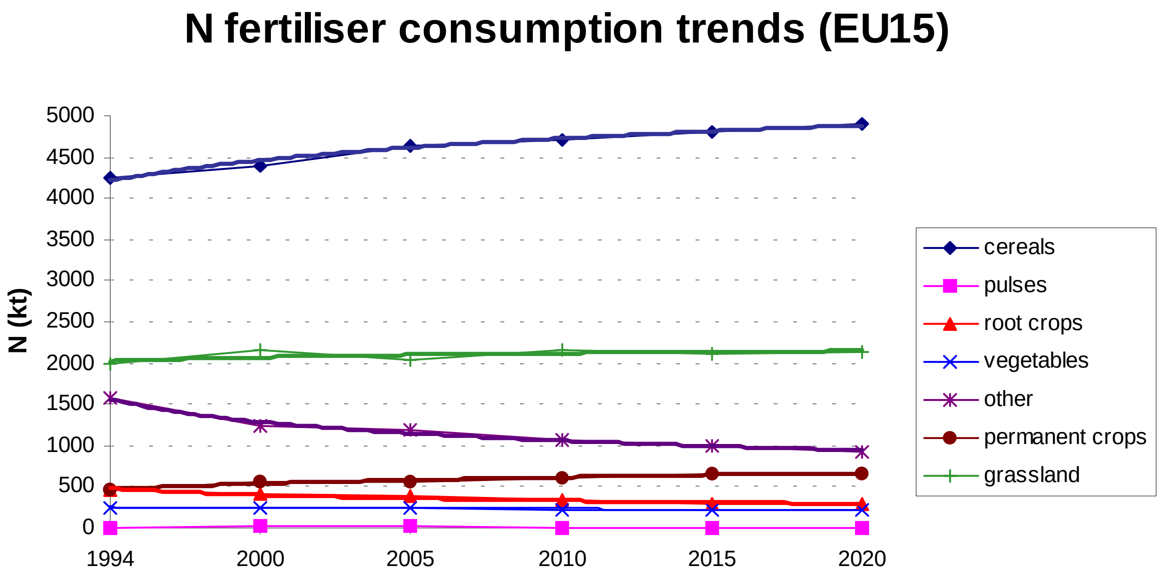
[4] Although manure will indirectly contain nitrogen which has been imported into the system, e.g. fertilisers applied to animal feed. For the scenario considered animal numbers are considered to be influenced by factors not considered in the model, and hence the nitrogen in manure is not considered as a nitrogen addition.

[5] The study was initiated pre-Kyoto, and the EU negotiating position of a 15% reduction on 1990 levels by 2010 was taken as a guide to the magnitude of the emission reduction a package of options would be required to deliver.

5.5.2.2 Timing of applications

Restrictions on the timing of fertiliser and manure applications would be introduced in order to minimise N_2O emissions from the indirect sources resulting from leaching, as well as direct emissions from denitrification processes in wetter winter soils with anaerobic sites. Such an effect would benefit water quality as well as N_2O emissions. Restrictions on the timing of applications would require longer manure storage times and greater capacities. This would be associated with additional costs and emissions from the stored manure, which would probably be balanced out by reduced emissions elsewhere.

Figure 5.1 Projected Fertiliser Use For Major Crop Types In EU15



Source: EFMA, 1996 for 1994 to 2005/6; remaining data is extrapolated.

Under the seasonal restrictions, applications of slurry, poultry manure and inorganic fertiliser would be banned from September to February, with applications of other types of manure permitted until October. These dates are based on leaching risk assessments (Chambers and Smith, 1996) which demonstrated that most leaching occurs when quickly-available nitrogen sources (slurry, poultry manure and inorganic nitrogen) are applied over a time period beginning immediately after harvest until early spring, when crops begin to take up nitrogen and soil through-flow decreases. Relatively less available nitrogen-sources, such as farmyard manure, caused relatively little leaching if applied during September and October, when winter or cover crops could absorb the smaller amounts of nitrogen produced. The ban on applications of inorganic fertilisers from September to February is in line with the requirements of the Nitrate Directive, which bans applications between 1 September and 1 February in Nitrate Vulnerable Zones (NVZs). In the scenario, however the ban has a blanket coverage and is not restricted to NVZs.

5.5.2.3 Removal of price support

The removal of price support is in line with the indicated direction of CAP reform, and would encourage farmers to carefully re-examine their inputs in order to maximise profitability through improved fertiliser use efficiency. This would drive increases in efficiency at all levels of nutrient management, and so contribute to reducing nitrogen surpluses.

5.5.2.4 Subsidies for Marginal Land

However, removal of price support would also mean that farming in some marginal areas would no longer be viable. Meester (1994) estimated that about 40% of land in EU12 would be too marginal to continue to compete with more productive areas, under a scenario of technological improvements and the removal of the social support aspects of CAP. Using the simplistic assumption that the proportion of relatively marginal land is the same throughout the EU15, and (based on Meester's conclusion above) that half of the area of marginal land would be abandoned if price support was removed, about 20% of the current agricultural area could be at risk.

The abandonment of 20% of EU15 agricultural area represents a politically undesirable impact. The situation is complicated by the fact that in many instances, inappropriate farming of marginal lands causes substantial environmental damage, and so their abandonment could, under some circumstances, be an environmental benefit. For this scenario to be acceptable politically, some provision would have to be made for the protection of farmers and environment in marginal areas. Savings from the removal of price support would be used to compensate marginal land use systems, in a Marginal Land Subsidy. This would pay for appropriate non-agricultural or very extensive agricultural management, helping to preserve the rural community while returning the area to a sustainable land use.

5.5.3 Impact of Measures

The projected emissions under the 'business as usual' scenario and the 'package of options' scenario is shown in Table 5.3. Overall the 'package of options' scenario achieves a 21% reduction in emissions by 2010 compared to the 'business as usual' scenario. The greatest reduction is achieved as would be expected from the restrictions on fertiliser applications; timing limits also produced substantial reductions, mainly from soils, although there was a slight increase in emissions from the livestock sector.

Table 5.3 Reductions in Emissions under the Package of Options Scenario

	2000	2005	2010	2020
B-a-U	564	572	554	538
Package of Options	495	472	440	418
Reduction	**69**	**100**	**114**	**120**

5.5.4 Implications for Methane Emissions

Agriculture is also a significant source of methane emissions, principally from enteric fermentation and from animal waste products. Waterlogged soils can also generate methane, but quantifying these emissions is very uncertain because biological methane formation depends on a range of environmental variables (Lelieveld and Crutzen, 1993), such as temperature, moisture status, pH, *etc*. Methane can also be oxidised in the aerobic soil layer overlying the methanogenic anoxic layer, and all aerobic mineral soils can act as methane sinks. Furthermore, there is evidence to suggest that ammonium ions act as an inhibitor to methane oxidation in soils, to the extent that the methane sink capacity of aerobic soils may be reduced by as much as 75% following the addition of fertiliser (Mosier *et al.*, 1991).

Some of the possible implications for methane fluxes resulting form the measures considered are:

- removal of set-aside will increase the area of fertilised crops and reduce the soil methane sink capacity;
- uptake of the agri-environment schemes will reduce fertiliser application rates and increase the soil methane sink capacity;
- uptake of the agri-environment schemes will decrease sheep and beef herd sizes and reduce methane emissions from enteric fermentation and animal wastes;
- the proposed regulations on fertiliser limits and timing of applications will reduce overall fertiliser use and enhance the soil methane sink capacity;
- the requirement for longer storage times for livestock wastes will increase methane emissions, but this could be off-set by improvements in manure management technology.

5.6 POTENTIAL OF INDIVIDUAL MEASURES

The ‘scenario based’ approach taken above gives a broad indication of the reductions which can be achieved through a package of fairly stringent measures, some of which would require substantial changes to agricultural systems and practices. In order to assess the scale of reductions which could be achieved by individual measures requiring less wholescale changes to farming practices, four measures which could be implemented in the short to mid term were identified and investigated in more detail.

The options which were examined were

- ensuring application of fertiliser N at recommended economic levels by taking full account of nitrogen applied as animal manures and residual nitrogen fertiliser from break crops;
- switching from winter to spring cultivars;
- applying fertiliser nitrogen applications below the economic levels;
- use of slow release type fertilisers

Each of the options is discussed in more detail in Sections 5.6.1 to 5.6.4 below. Estimates were made of the potential reduction which could be achieved from each measure, focusing on the UK, with an extrapolation to other parts of the EU wherever possible. Potential barriers to the implementation of options due to the nature of the agricultural sector and farmer behaviour were also identified, and the need for increasing farmer awareness considered. As previously estimates of the quantities of N_2O abated by each measure were made using standard IPCC methods for estimating N_2O emissions (IPCC, 1997) i.e. N_2O-N emissions will be reduced by 0.0125 kg N for every 1 kg reduction in fertiliser-N use. This is an over-simplification of the situation, as N_2O emissions are likely to be influenced to a greater extent by differences in soil type and conditions and season than allowed in the current methodology. A summary of potential reductions from each measure is given in Section 5.6.5.

5.6.1 Ensuring Application of Fertiliser Nitrogen (N) at Recommended Economic Optimum Levels.

Levels of fertiliser application to two crops were considered: winter wheat and main crop potatoes. The British survey of fertiliser practice provided reliable estimates of actual fertiliser-N applications to these crops over recent years (Table 5.4), and a comparison with the recommended nitrogen application levels (Tables 5.5 and 5.6), suggests that excess application of fertiliser-N is a feature of “normal” farming practice at the present time. In broad terms, it appears that little or no account is being taken for the residual N from previous crop, or from the nitrogen available from organic fertiliser applications

It should be noted however, that it is impossible to assess the extent to which these levels of N application exceed the economic optimum recommendations with absolute accuracy, as at field level, the optimum N application rate depends on a wide range of factors such as the soil type, previous cropping, soil mineral N levels, the yield potential of the crop, the extent to which organic manures are used on the farm, and so on.

5.6.1.1 Potential for reducing fertiliser-N applications by taking better account of the N applied as manures.

A study on fertiliser applications to wheat crops which received animal manures, indicated an average reduction in fertiliser-N applications of 22 kg per hectare. The N available from the manures was however estimated to be equal to about 40 kg per hectare, so that an additional potential saving of 18 kg of fertiliser-N could have been made. The area of wheat land in England and Wales benefiting from animal manures is about 220000 ha (Smith and Chambers, 1995), so that the estimated reduction of N_2O-N emissions is 49.5 tonnes or 77.8 tonnes of N_2O.

Table 5.4 Fertiliser-N applications to Winter Wheat and Main Crop Potatoes

Year	Winter Wheat kg/ha	Main Crop Potatoes kg/ha
1992	188	181
1993	186	191
1994	187	197
1995	194	182
1996	188	180
5 year average	189	186

Source: The British Survey of Fertiliser Practice 1996

For main crop potatoes grown on land to which animal manures were applied, the average reduction in fertiliser-N is only 3 kg per hectare, compared to a potential saving of about 40 kg per hectare (Smith and Chambers, 1995). In such circumstances a further 37 kg reduction in fertiliser could be made without detriment to crop yield. Estimates indicate about 35%, or 29000 hectares of the main crop potatoes receive applications of animal manures, and a reduction in fertiliser-N of 1073 tonnes could be made leading to savings of 21 tonnes of N_2O.

Table 5.5 Nitrogen Recommendations for Winter Wheat

Soil Type	Application (kg/ha) Nitrogen Index[6]		
	0	1	2
Sandy	175	140	80
Shallow	225	190	130
Deep Silty	180	90	0
Clays	190	110	0
Other Minerals	210	150	70
Organic	120	60	0
Peaty	80	20	0

Table 5.6 Nitrogen Recommendations for Main Crop Potatoes

Soil Type	Application (kg/ha) Nitrogen Index[6]		
	0	1	2
Sandy and shallow	240	200	130
Other minerals	220	160	100
Organic	180	130	80
Peaty	130	90	50

It is not possible to extrapolate this data to the EU level as no data is available on overall manure applications. It is possible that similar potential savings could be achieved across most parts of northern and western European countries and less likely in southern Europe, but the topic is too speculative to reach any firm conclusions at this stage. Controls on total nutrient inputs in the Netherlands suggest there may be less scope for saving in that country.

5.6.1.2 Potential for reducing fertiliser N applications by taking better account of residual nitrogen from previous crops

Assuming that the majority of break crops are followed by wheat in the arable rotation, then up to 50% of the (UK) winter wheat crop could benefit from residual nitrogen leading to fertiliser-N savings. On the basis that a potential saving of up to 60 kg per hectare of N, (depending on soil type and the specific previous crop), could be made in such a situation, it is assumed that a saving of at least 25 kg per hectare could be made on all the winter wheat grown. Surveys suggest that typically farmers only make allowance for residues of 10 kg N after such break crops. Therefore the potential saving of 15 kg or more, could be achieved. This offers potential savings of about 14250 tonnes of fertiliser and an estimated emissions reduction of 280 tonnes of N_2O in the UK.

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[6] An assessment of available nitrogen in the soil, based on the expected residues of nitrogen from previous crop. The index range is 0 to 2, with index 0 for fields with small nitrogen reserves, e.g. following cereals, and index 2 for soils with the greatest soil nitrogen reserves, e.g. following grazed grass or intensive vegetable crops.

Similar data is available for winter barley crops following break crops. However in this case the allowance for residual N from the previous crops is a mere 1 kg, thus offering a potential reduction of 24 kg per hectare or more. Assuming an estimated 5% of the break crop area is followed by barley, the total excess of fertiliser-N is calculated to be 750 tonnes leading to a potential emission reduction of about 14 tonnes of N_2O in the UK.

5.6.1.3 European Perspective

Looking across the northern and western European countries, crop performance and management systems are similar to those found in the UK. Commodity prices are dominated by the impact of the Common Agricultural Policy (CAP) so farm gate prices are very similar in ECU terms. Currency fluctuations can however have significant impact on farm gate prices , as shown by the situation in the UK, where the relatively weak position of the £ in the 1992 to 1995 period contributed to price improvements, and the more recent strength of £ sterling have seen dramatic falls in price. Putting all this aside, economic optimum fertiliser-N levels across northern EU countries are very similar to those found in the UK

In very general terms, the management of arable crops across the northern and western EU countries is similar to that found in the UK. Break crops, particularly OSR have been encouraged due to the CAP support systems, and it seems reasonable therefore to assume that the estimated reduction in applications to winter wheat could be applied more widely. For example, if is assumed a reduction of fertiliser-N could be made on the wheat grown in France Germany and UK (66% of the total EU crop), then total fertiliser N applications would be reduced by about 70,000 tonnes, giving an N_2O reduction of about 1400 t of N_2O.

5.6.1.4 Implementation Issues

It is believed that current farmer awareness of N_2O emissions, and the links to agriculture, are very low, verging on zero. The issue of nitrate leaching has greater awareness due to Government Legislation together with the press and media activity in relation to Nitrate Sensitive Areas, Nitrate Vulnerable Zones, and the prospect of farmers having to reduce fertiliser-N applications in these areas. Promotion of the potential cost saving to farmers available from reduced fertiliser use by making full use of residual nitrogen and animal manures is likely to develop greater interest than promotion of the environmental impacts. Possible methods for increasing awareness include:

- a series of promotional meetings and press coverage targeted at principle arable areas in the country
- the production of literature for distribution to all farmers (although survey work suggests farmers are not particularly responsive to literature)
- a series of practical demonstration farms on which regular open days and conferences are held at which the savings are made and demonstrated in a very practical way to farmers. This method is likely to offer the greatest possible impact over the medium to long term, as these farms would demonstrate practical system changes with identifiable cost benefit to farmers.

A very significant factor in this area of work is the recent decline in the profits achieved by farms across all the major sectors of agriculture. Farmers are under severe pressure to improve profits wherever possible. This could be seen as a positive factor which will help reduce excess fertiliser-N applications. However, in the arable sector, crop yield is by far the most significant factor determining the business profitability. All farmers need to strive to maximise output in order to spread the overheads over a greater tonnage of product. Fertiliser-N has been, and continues to be, a relatively cheap and cost-effective input.

In Section 5.6.1.1 it is estimated that wheat crops to which animal manures had been applied could have had fertiliser-N reduced by about 18 kg per hectare. The cost saving is only worthwhile provided there is no yield penalty. At a wheat price of £80 per tonne, a yield loss of only 72 kg per hectare (1%) would result in reduced income equal to the savings in fertiliser price. Table 5.7 shows the sensitivity of this calculation to changes in the wheat price and fertiliser cost. While the cost of fertiliser, and the wheat price, could change significantly over time, the table shows that the break even yield loss is within the range 0.5% to 1.5%. The majority of farmers would consider the risk of reducing yields to be too great in the current climate, and are thus likely to continue to apply fertiliser-N in excess of the recommended requirement (which is based on field experiments) as an insurance against falling yields.

Table 5.7 Break-even Yield Loss from Reduced Fertiliser-N Applications (t/ha)

Fertiliser N p/kg	**Wheat price £ per tonne 60**	**70**	**80**	**90**	**100**
29	87	75	65	58	52
30	90	77	68	60	54
31	93	80	70	62	56
32	96	82	72	64	58
33	99	85	74	66	59
34	102	87	77	68	61
35	105	90	79	70	63

Note: assumes an average yield of 8 tonnes per hectare

5.6.2 Sub-optimal Fertiliser-N Applications

In an attempt to reduce N_2O emissions, fertiliser-N applications could be reduced below the economic optimum levels. The effect of 50 kg per hectare and 100 kg per hectare reductions for winter wheat (which is grown over a very large area) and winter oilseed rape (the most widely grown break crop) is evaluated in this section.

5.6.2.1 Impact of Sub-optimal Applications on Wheat Yields

The economic impact of reduced fertiliser-N applications on winter wheat crops is particularly sensitive to the effect on crop yield. This in turn will depend upon a whole range of factors such as soil type, crop rotation, season and so on. It is therefore difficult to be precise about the yield response when looking at wheat in the general sense.

Figure 5.2 below shows the yield response, averaged over 5 years, to different fertiliser-N applications on a clay soil with mineral N index of zero. The financial impact of changes in the system is also shown on the graph, based on an assumed wheat price of £80 per tonne and a fertiliser-N cost of 32 pence per kg of N. In this particular case the economic optimum fertiliser-N application was in the range 190 kg per hectare to 200 kg per hectare, and yield declines at application levels below this, leading to a reduction in margin[7]. The financial implications of reduced margin due to reduced yield are explored further in Section 8.5.1.2, but it is clear that the overall economic impact of reduced fertiliser-N applications is particularly sensitive to the yield response.

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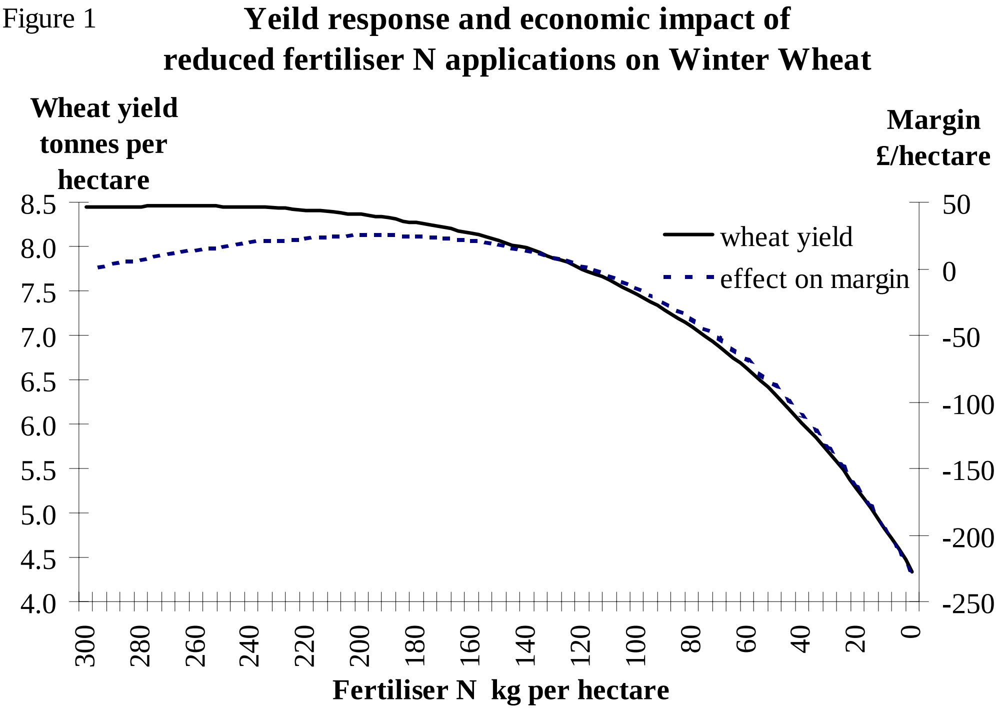
[7] Gross Margin is the margin of all income from crop sales and support payments less the direct growing costs such as seed, fertiliser and sprays.

Figure 5.2 Yield Response and Economic Impact of Reduced Fertiliser N Applications on Winter Wheat



5.6.2.2 Impact of Sub-optimal Fertiliser N Applications on Oilseed Rape Yields

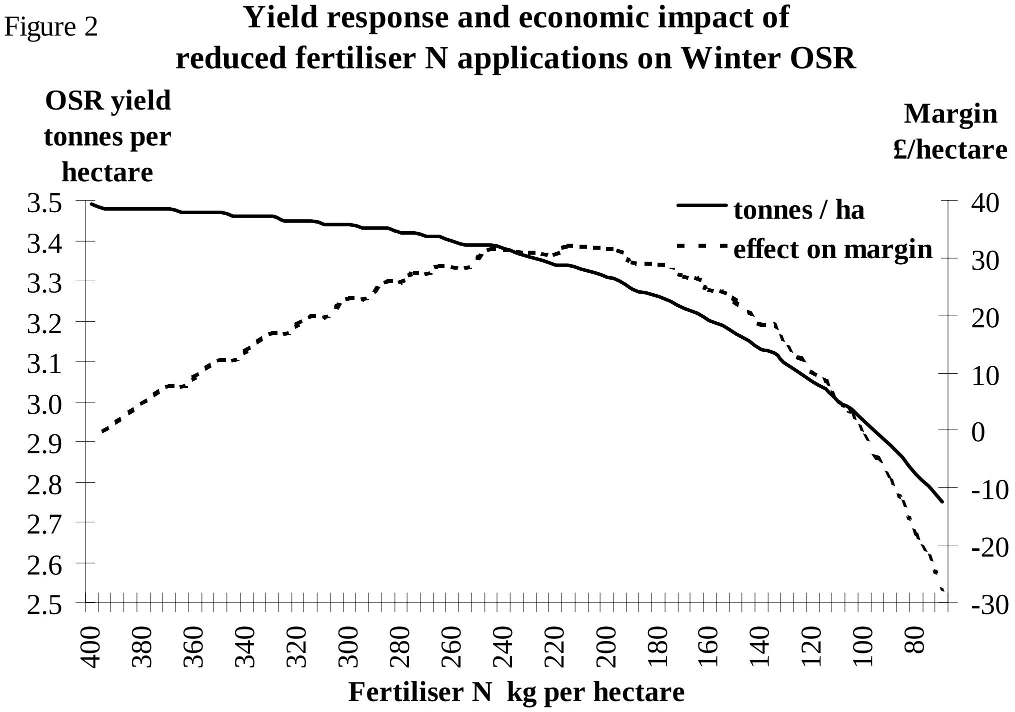
Assessing the impact of reduced nitrogen applications on oilseed rape (OSR) in general suffers all the problems already described for wheat. The actual yield response to reduced nitrogen will depend on a range of factors such as rotation, soil type, climatic conditions and so on. Specific trial data for a three year trial is shown in Figure 5.3 below, which also shows the economic consequence of cost savings and yield loss. It has been assumed that the average OSR price is £180 per tonne (forecast 1998 to 2000) and a fertiliser-N price of 32 pence per kg of N.
In this particular case the economic optimum fertiliser application is calculated to be 215 kg N per hectare at an OSR price of £180 per tonne. In this particular case the economic optimum fertiliser application is calculated to be 215 kg N per hectare at an OSR price of £180 per tonne. Again the financial implications of reduced margin due to reduced yield are explored further in Section 8.5.1.2, but it is clear that the overall economic impact of reduced fertiliser-N applications is particularly sensitive to the yield response.

Estimated reductions if sub-optimal applications of fertiliser N for winter wheat and oil seed rape were made in the UK are shown in Table 5.8

Table 5.8 Potential Emission Reductions in the UK from Sub-optimal Fertiliser N Applications

Reduction in N application kg/ha	Fertiliser N reductions (t of N)		Emissions reduction (t of N_2O)	
	Wheat	OSR	Wheat	OSR
50	96300	18800	1866	369
100	192600	37600	3732	739

Figure 5.3 Yield Response and Economic Impact of Reduced Fertiliser N Applications on Winter OSR



5.6.3 Changing to Spring Cultivars

Changing from winter to spring cultivars would reduce the quantities of nitrogen applied to the crop and therefore has some potential to reduce N_2O emissions. The spring-sown crops have lower nitrogen recommendations due to the shorter growing period and lower yield potential as compared to winter sown crops. Consideration is given to such a change in farming practice for two of the most widely grown winter crops, barley and oilseed rape crops. Similar estimates could be made in respect of winter wheat and oats, as there are spring-sown cultivars of those crops.

For winter barley, an average recommendations for fertiliser-N application to spring barley would be 30 kg/ha less than for winter barley; for oilseed rape the difference would be 40 kg/ha. The subsequent reduction in N_2O emissions which might be expected for switching from winter to spring cultivars of these two crops is shown in Table 5.9.

Table 5.9 Potential Reduction in UK N_2O Emissions from changing from Winter to Spring Cultivars of Barley and Oilseed rape

Spring cultivar	Fertiliser-N reductions kg/ha	tonnes	Emissions abated t of N_2O
Barley	30	25179	495
OSR	40	15048	296

Winter cropping dominates the farming of the cool temperate countries of the EU, and so there will be similar scope for conversion to spring cropping. However, this option will be less readily applicable to southern Europe, where the hot, dry summers are likely to give very poor yields of spring-sown crops. In the far north and east of Europe, where the winters are cold, and the ground snow-covered for several weeks, crops are already predominantly spring-sown.

In practice the potential benefits for N_2O emissions from spring cultivars may be considered outweighed by the potential environmental problems of bare land over the winter period, or land being used for livestock feeding, and likely increases in nitrate leaching over winter. Moreover, it should be borne in mind that N lost to waters by leaching or runoff also ultimately contributes to N_2O emissions. In the current IPCC methodology N_2O emissions from that source are estimated as 0.025 kg N_2O-N per kg N lost by leaching or runoff. This emission factor is greater than from fertiliser-N inputs or crop residue returns. Thus reducing nitrate leaching, as well as being of benefit in itself, may also help to reduce N_2O emissions, and may be a preferable option.

5.6.4 Alternative Fertiliser-N formulation

It has been suggested that slow release fertiliser products may lead to a reduction in N_2O emissions, although there is little substantive evidence as to the reduction in emissions which may be achieved in practice. At present slow release products are more commonly available and used within the horticultural sector, as the much greater value of some horticultural crops justifies the use of these more expensive products. It has proved particularly difficult to find reliable information on slow release fertilisers applicable to the arable situation, and discussions with representatives of fertiliser companies have not identified products readily available for the arable as opposed to horticultural usage. It is assumed that if slow release products were to be manufactured for widespread use across arable cropping, then the scale of manufacture would offer cost savings with the result that the product could be available to farmers at a cost up to 10% above current costs of fertiliser nitrogen.

The sensitivity of crop margins to different fertiliser-N prices is shown in Table 5.10. While fertiliser-N is a significant production cost, particularly in the combinable cropping situation, even 10% changes in product cost have minimal impact on overall gross margins achieved.

Table 5.10 Gross Margin Sensitivity to 10% Increase in Cost of Fertiliser Nitrogen

	Cost of Fertiliser N as % of all input costs	**Effect of 10% fertiliser N cost increase on gross margin**	
		£ /ha	**%**
Wheat	21%	-5.88	0.96%
Barley	22%	-5.32	1.02%
OSR	27%	-7.28	1.18%
Main crop potatoes	7%	-8.25	0.37%

While this could be considered positive, in that slow release fertilisers may have minimal effect on margins even at greater cost, farmers will always seek to use the cheapest source of fertiliser thus any additional costs could be a deterrent to wide spread usage. In the wider context, Table 5.10 also highlights the difficulties associated with proposed fertiliser taxes aimed at reducing agricultural usage for wider environmental reasons. Fertiliser costs would have to increase several fold before significant change to economic optimum applications rates could be seen.

6. Options to Reduce Emissions from the Chemicals Sector

In 1994 emissions from the chemical sector were 30% of anthropogenic emissions, the second most significant source. These arose mainly from adipic acid manufacture, but emissions from nitric acid production were also significant. Potential options for reducing emissions from these two processes fall into four main categories:

- use of ‘end-of-pipe technology to reduce emissions;
- modification/optimisation of the production process;
- alternative production processes;
- reduced demand;

These options are discussed below, together with an indication of the status of the technology, costs for the technology, an estimate of their applicability and effectiveness, and a discussion of possible implementation methods.

The cost effectiveness of options is given in Section 8 together with an estimate of the impact of the options on future emissions.

6.1 ADIPIC ACID MANUFACTURE

As discussed in Section 3.1.2, N_2O is produced when KA (a mixture of cyclohexanol and cyclohexane), is oxidised with nitric acid to produce adipic acid. Emissions are estimated at 300 g N_2O per kilogram of adipic acid produced (Thiemens and Trogler, 1991).

6.1.1 End-of-pipe technologies

6.1.1.1 Description of technologies

Two main techniques have been identified for reducing emissions of N_2O from the production process:

In *catalytic destruction*, a catalyst bed (of metal oxides such as CaP and MgO) is used to decompose the N_2O into N_2 and O_2. The reaction is strongly exothermic and the heat produced must thus be removed; if there is a suitable demand on the production site, then it may be recovered and used to produce steam. Potential problems with the process include the need to recharge poisoned catalyst twice a year, and the complex design needed to generate useful steam from the process. A simpler, once though version of this process is being piloted at a site in the USA.

Anther catalytic destruction technique involves the use of catalysts to decompose the N_2O to NO, which can then be oxidised and converted to nitric acid. The process has been tested, but was abandoned as the estimated capital cost of the process was very high.

An alternative process is *combustion* of the off-gases in the presence of methane. The N_2O acts as an oxygen source and is reduced to nitrogen, giving non-negligible quantities of NO and some residual N_2O. The combustion process can be used to raise steam, if a demand exists on site.

6.1.1.2 Applicability and Current Deployment

All of the major manufacturers in Europe have either installed or will be installing abatement plant, as summarised in Table 6.1.

In the UK, under the Environment Protection Act of 1990, nylon manufacture requires an authorisation to operate subject to regulation by the Environment Agency. Under this legislation, N_2O is a prescribed substance and emissions must be prevented or minimised subject to the use of Best Available Technique not Entailing Excessive Costs. In order to comply with this legislation, the UK manufacturer Du Pont are planning to install an abatement unit by October 1998 that will reduce emissions by at least 95% (UK, 1997).

In Germany, Bayer installed a unit for the thermal reduction of N_2O at their production plant in 1994. While currently operating at an 80% reduction rate, it is planned to improve this figure (Brück, 1997). The other German manufacturer BASF is planning to commission a catalytic system by the end of 1999 (at the latest). In France, regulation requires that emissions are reduced by 99%. The manufacturer Rhone Poulenc is a member of the collaborative group of nylon manufacturers set up in 1991 to share information on N_2O control (as are the other major European producers). As a member of the group it has a commitment to substantially reduce emissions by 1998.

Production in Italy is at a lower level than in the other European countries (Italian emissions are only 6% of the total for the EU) and at present there appear to be no plans to abate emissions.

Table 6.1 Planned Implementation of Reduction Measures at Adipic Acid Plant

Country	Manufacturer	Technique	Efficiency	Implementation
UK	Du Pont	Combustion	at least 95%	October 1998
France	Rhone-Poulenc	Not known	99%	
Germany	Bayer	Combustion	currently 80% - planned to improve	1994
Germany	BASF	Catalytic		by end of 1999

6.1.1.3 Effectiveness and Cost

The effectiveness of these end of pipe technologies ranges from 90 to 99%. Assuming an average reduction efficiency of 95%, implementation by the major producers (assuming 1990 production levels) would reduce emissions by 207 kt. If abatement equipment was also installed by the Italian producer, then emissions would be reduced by a further 14 kt.

Accurate cost data is difficult to obtain partly because the limited number of adipic acid manufacturers means that there is much commercial sensitivity surrounding the processes, and partly because the economics of the various methods are very site specific. For example, if a combustion process is used then heat can be recovered and used for steam generation; this may lead to a saving in other operating costs depending on the need for steam on the site and the cost of other on-site steam generation options. The capital cost of plant installed in Germany is reported to be 7 million DM for a combustion unit and 20 million DM for a catalytic unit. The cost of abatement has been estimated as below 160 ECU/t by Reimer (Reimer, 1996), although no details of the process of cost assumptions are known. Cost estimates are discussed further in Section 8.

6.1.1.4 Options for Implementation

Suitable technology is available and is already being implemented by the major manufacturers in response to national pollution control regulations or national strategies to reduce greenhouse gas emissions. The major manufacturers world-wide have also made a voluntary agreement to reduce emissions. As the chemical industry is covered by the Integrated Pollution and Control Directive (96/61/EC), emission limits based on BAT could be set in the Directive.

6.1.2 Alternative production processes

In the past, several manufacturers used air oxidation (rather than nitric acid oxidation) of KA to produce adipic acid. However this process produced low quality adipic acid and is not a commercial option. Research has been carried out by some manufacturers into a butadiene carbonylation process (which does not produce N_2O emissions), but was abandoned on the basis that it was too costly (ENDS, 1996); one manufacturer has commented that they do not expect this route to be exploited commercially “in the next 25 years if ever”.

In the longer term, a possible option is to use petroselenic acid as a substitute for adipic acid. Petroselenic acid can be obtained from corriander, so that the commercial cultivation of corriander could provide a source. Alternatively, there is ongoing research into using biotechnology to genetically modify oilseed rape to produce petroselenic acid.

6.2 NITRIC ACID PRODUCTION

Most commercial manufacture of nitric acid is based on the oxidation of ammonia. There are three main steps to the process:

i) catalytic oxidation of ammonia (NH_3) (in the presence of air) to nitrogen monoxide (NO);
ii) oxidation of nitrogen monoxide to the dioxide (NO_2);
iii) absorption of the nitrogen dioxide in water to produce medium concentration nitric acid (HNO_3).

It is the first of these stages which leads to emissions of N_2O. Using suitable catalysts, about 93-98% of the ammonia is converted to NO, but the rest of the ammonia is converted into nitrogen (mostly) and nitrous oxide in the following undesired side reactions:

$$4\ NH_3 + 3\ O_2 \Leftrightarrow 2\ N_2 + 6\ H_2O$$

$$4\ NH_3 + 4\ O_2 \Leftrightarrow 2\ N_2O + 6\ H_2O$$

The N_2O and N_2 pass through the other stages of the process and are released in the flue gas along with any unreacted NO and NO_2. The yield of NO from the process is dependent on temperature and pressure, the lower the temperature and pressure, the higher the yield. Optimum temperatures are in the range of 800-950°C, but, while reactors designed for operating at 1 bar gauge can achieve yields of 97-98%, modern plant designs tend to favour operation at “medium” pressure (3-5 bar gauge) where the yield is around 96%. Atmospheric pollution, catalyst poisoning and non-ideal gas-flow distribution though the catalyst gauze may progressively reduce the yield by a further 10% (HMIP, 1993).

Three options exist for reducing N_2O emissions:

- Optimising the nitric acid production process;
- Reducing N_2O emissions using end of pipe technologies;
- Reducing demand for nitric acid.

6.2.1 Optimising the production process

The production process may be optimised so that the yield of NO is maximised (and hence the emissions of N_2O minimised) in the first oxidation step. It is difficult to estimate the reduction in emissions which might result from improving the production process, although the range in emission factors for different sites indicates that some improvement should be possible. One study (de Jager et al, 1996) has estimated that in the short term a 10% reduction in emissions might be achievable with no significant additional costs, although these assumptions have not been validated. In the longer term, improved process design for new production plants could incorporate abatement of N_2O, which would typically achieve reductions of 60 to 70 %; no estimate of additional costs and benefits is available for this option (de Jager et al, 1996).

6.2.2 End of pipe technologies

6.2.2.1 Non-selective catalytic reduction

Nitric acid production plant are generally installed with abatement equipment or processes to reduce NO_X emissions in the tail gas. There are four main methods:

- *Neutralisation with sodium hydroxide solution*: NO and NO_2 are absorbed to form sodium nitrate;
- *Extended absorption*: the absorption tower in which stage three of the process occurs is extended so that more NO_X is recovered as nitric acid and hence less NO_X is emitted.
- *Non-selective catalytic reduction (NSCR):* hydrogen, natural gas or naptha react with the NO_X and the free oxygen in the tail gases over a platinum, rhodium or palladium catalyst, and the NO_X is reduced to N_2.
- *Selective catalytic reduction (SCR):* ammonia is reacted with NO_X and to a lesser extent oxygen over a catalyst (suitable catalysts include vanadium pentoxide, platinum, iron/chromium oxides and zeolites). Again the NO_X is reduced to N_2.

The only method which reduces N_2O as well as NO_x emissions is NSCR, where the N_2O is also reduced to N_2. Typical conversion efficiencies are about 90% for the NO_X gases and 70% for the N_2O, although under pilot plant trials, conversion efficiencies of 90% have been achieved for N_2O (HMIP, 1993). Currently SCR systems rather than NSCR systems are generally fitted, partly because SCR equipment usually has a lower capital cost than NSCR systems, and partly for other, technical reasons. For example, the ammonia used in SCR is always available on a nitric acid plant, whereas the availability of hydrogen or the other reducing agent required for NSCR is site-specific (however the reducing agents used in NSCR are likely to be more inexpensive than ammonia). If it is assumed that some form of NO_x abatement is always required at a nitric acid plant, then the cost of reducing N_2O emissions would be the additional cost of an NSCR plant over an SCR plant.

6.2.2.2 Catalytic reduction of N_2O

Nobel metals on zeolite catalysts (e.g. CU-ZSM-5) have been shown to reduce N_2O emissions by over 80%. They have been shown to be effective in a process demonstration unit under conditions that occur in the off-gases of nitric acid plants (Choe et al, 1993), but no performance data is yet available for pilot or full scale plants, and more development and a demonstration scheme would be required to confirm the feasibility of this option. The catalyst requires a higher temperature than is typical for the off gases and heating of the offgases would be required. It may be possible to draw this heat from the process (e.g. from a heat recovery unit), if not this will be an additional running cost, and will potentially lead to CO_2 emissions from heat production.

6.2.2.3 Future options

Potential further options identified by Oonk (1995) are the biofiltration of off-gases using denitrifying bacteria and photo-catalytic conversion. The applicability of the options to nitric acid production offgases and the reduction potential and costs of these options are not yet known.

6.2.2.4 Reduced Demand for Nitric Acid

The majority of nitric acid is used in fertiliser production. Reducing the use of inorganic fertilisers e.g. by increasing the efficiency with which fertilisers are used, or by increasing the use of organic fertilisers, would thus lead to a reduction in N_2O emissions. As the use of nitrogenous fertilisers is a major source of N_2O emissions in the agricultural sector, these options are considered in the agricultural options.

6.2.3 Status and Effectiveness of Options

The status and effectiveness of the options discussed above is summarised in Table 6.2. Estimating the overall impact of options on emissions is difficult due to the uncertainty in estimating emissions from uncontrolled plant. Estimates vary, e.g.:

- 2 to 9 g N_2O per kg nitric acid (Kroeze, 1994)
- 9 to 25 g N_2O per kg nitric acid (Oonk, 1995)
- 300 to 3500 ppmv equivalent to 2 to 22 g N_2O per kg nitric acid (EFMA, 1995)

The French limit for new plant, based on use of best available technology is set at 7 g per kg of acid. In summary, more work is need to firstly clarify emissions production from current plant and secondly to confirm the reduction which is possible from these techniques.

Under the EC Directive on the Prevention of air pollution from stationary sources (84/360/EEC), Member States must have a system in place requiring authorisation for operation of nitric acid plants, and the use of Best Available Technology. Member States thus have legislation/procedures in place controlling emissions from nitric acid plants, although to date this has focused on NO_x emissions. These national level procedures could be extended to set limits based on the use of BAT for N_2O emissions as well. Indeed, France is already beginning to apply limits for emissions from production plants and Germany is also considering introducing legislation. Alternatively or in addition, as the chemical sector falls under the new IPPC directive, it is feasible that emissions from nitric acid production could be covered under a description of BAT under the Directive.

Table 6.2 Status and Effectiveness of Options to Reduce Emissions from Nitric Acid Production

Option	Reduction potential	Market Status	Comments
Optimisation of production process	10%	conceivable	possibly available by 2000; applicable for new plants
NSCR	70 to 90 %	may need demonstration to confirm applicability	applicable for new plants; available in mid term
Catalytic destruction	>80%	development and demonstration required	mid to long term option
Future end-of pipe options	not known	R&D	
Reduced demand	depends on trends in main demand sector fertiliser production and hence on developments in agriculture		

7. Options to Reduce Emissions from Combustion

As discussed in Section 3, emissions from stationary combustion accounted for just over 12% of N_2O emissions in 1994. Emissions from the combustion of fossil fuels in stationary sources, (power plant, boilers etc.) are generally low, typically 1 to 2 ppmv (Takeshita et al, 1993) for coal fired plant and 1 ppmv or below for oil and gas fired plant. Typical emission factors per unit of fuel are shown in Table 7.1, but it should be noted that measurement data is still fairly limited, and uncertainty over emissions factors still relatively high. Indeed, recent measurements in the UK indicate that emissions from large combined cycle gas turbines may be considerably higher than shown in Table 7.1 (Salway, 1997).

Table 7.1 Emissions Factors for Stationary Combustion by Fuel Type

Fuel	**g N_2O/GJ**
Coal (non fluidised bed)	1.4
Oil	0.6
Gas	0.1
Wood, other biomass and wastes	4

Source IPCC, 1996.

Combustion sources where emissions may not be low are:
- fluidised bed combustion where the lower bed temperature leads to higher emissions;
- possibly where NSCR is used to control NO_x emissions;
- combustion of wood, waste and other biomass.

Options to reduce N_2O from stationary combustion thus fall into three main categories:

- reduced emissions from fluidised bed combustion;
- use of other NO_x abatement techniques in preference to NSCR;
- reductions in fossil fuel consumption through e.g. energy efficiency and energy saving measures. Fuel switching from coal to gas may also offer reductions for boiler plant, but in view of the possibility that emissions from large gas turbines used for power generation may be relatively high, fuel switching in electricity generation is not considered a viable option.

These options are discussed further below.

The other source of combustion emission is road transport, which accounted for 5% of emissions in 1994. Emissions from this sector are expected to increase significantly due to the increasing penetration of catalytic converters, which increase N_2O emissions, into the fleet. Options to reduce N_2O emissions from transport fall into four broad categories:

- reducing transport demand

- increasing transport efficiency
- introduction of other transport modes with lower N_2O emissions
- improving catalyst design to reduce N_2O emissions

Again these are discussed in more detail below.

7.1 OPTIONS TO REDUCE EMISSIONS FROM FLUIDISED BED COMBUSTION

Fluidised bed combustion (FBC) is a ‘clean coal technology’ with a higher efficiency than conventional pulverised fuel combustion, lower emissions of NO_X due to a lower combustion temperature, and low emissions of SO_2 due to the addition of limestone to the bed. However the lower combustion temperature in the bed leads to higher N_2O emissions; emissions from FBC with hard coal are typically in the range of 50 to 100 ppmv (about 35 to 70 g/GJ). Lower rank coals (brown coals and lignites, peat wood and oil shales) have typically been found to produce less N_2O than bituminous coal and emissions from FBC of brown coal are estimated to be in the range of 10-40 ppmv (about 10 to 45 g/GJ). Circulating fluidised beds (CFBC) have been found to have higher emissions than bubbling fluidised beds, possibly due to the longer residence time in the former.

Emissions decrease with increasing bed temperature, and increase to a certain degree with increasing oxygen concentration, but optimising these conditions to reduce N_2O emissions can lead to increased NO_x emissions and reduce the efficiency with which $CaCO_3$ added to the bed reduces SO_2 emissions. Options considered for reducing N_2O emissions from FBC are discussed below.

7.1.1 Optimise FBC Operating Conditions and Use SCR to Reduce NO_x

As indicated above, optimising conditions within a FBC, e.g. by keeping the bed at a higher temperature (of about 900°C) can reduce N_2O emissions, but also increases NO_x emissions. Tests on a 72 MWt and a 105 MWe CFBC indicated that while N_2O emissions were reduced by about 33% and 60% respectively by increasing the bed temperature, NO_x emissions were doubled (Boemer et al, 1993). Increased NO_x emissions can be reduced by the use of NO_x abatement technologies such as selective catalytic reduction (SCR) or selective non-catalytic reduction (SNCR), although due to the possible role of SNCR in increasing N_2O emissions (see below), the use of SCR is preferable. SCR, which can reduce NO_x emissions by up to 90% has been fitted to FBC plant in Japan and Sweden, so is technically feasible (Takeshita et al, 1993).

7.1.2 Use of Gas Afterburner

Under this option, FBC operating parameters are optimised to minimise NO_x and SO_2 emissions. The N_2O in the flue gas is then decomposed by injecting gas into the flue gas downstream of the boiler, which raises the temperature. This method has been tried on a 12 MWt circulating fluidised bed and N_2O concentrations were reduced by about 90% (Lyngfelt et al, 1996). There was no significant increase in NO_x emissions. It appears that this approach might offer the potential to reduce N_2O emissions without any concomitant increases in emissions of other pollutants, but further work is required on large scale commercial plants to confirm this and allow the estimation of capital and operating costs (Takeshita et al, 1993). On the 12 MWt bed, an amount of gas corresponding to 10% of the total energy input was required.

7.1.3 Catalytic decomposition of N_2O

The concentration of N_2O in the flue gas is suitable for reduction using a catalyst, i.e. a catalyst reactor would be installed downstream of the boiler. Research in Japan did not find a catalyst which could operate at the temperatures available in FBC after heat recovery (350 °C) (Kimura, 1992), and although it is possible that catalysts will become available in the future, further work would be required to verify the efficiency of catalysts, and its lifetime. The investment cost for such a plant could be high, and a potential disadvantage for boilers where this is retrofitted is the large space required to install a catalyst reactor downstream of the boiler (Takeshita et al, 1993).

7.1.4 Reversed Air Staging

Research in Sweden has examined the possibility of using reversed air staging in fluidised bed combustion to reduce N_2O emissions. A lowered air ratio or lowered fraction of primary air (i.e. an increase in air staging) both decrease N_2O emissions by reducing the efficiency with which sulphur is captured in the bed (and thus increasing SO_2 emissions). However it is possible to reduce N_2O emissions without affecting SO_2 emissions by ensuring a good supply of oxygen in the bottom part of the chamber (where it is more important for sulphur capture) and less oxygen in the upper part. This was done by introducing primary air only though the bottom zone of the combustion chamber, and introducing secondary air for final combustion after the cyclone (Lyngfelt et al, 1995). The results show that for the test plant (a 12 MWt circulating FBC), reversed air staging can reduce N_2O emissions by about 75% (from about 100 ppmv to 25 ppmv at 6% O_2) without any effect on emissions of other pollutants (NO, SO_2, and CO). Similar results were also obtained using peat: N_2O emissions were reduced by about 70% from 63 ppm to about 20 ppmv. More work is needed to establish whether the results would be valid in plant of other sizes, and to examine the trade-off between increased power consumption and reduction in emissions. In greenhouse gas terms, an increase of 10 to 20% in auxiliary power consumption would still lead to a large net reduction in greenhouse gas emissions, due to the very high GWP of N_2O.

7.1.5 Pressurised FBC

The options above refer to fluidised bed combustion plant which operates at atmospheric pressure. An emerging technology is pressurised FBC. Four demonstration plants (ranging from 70 to 135 MWe are in operation in Europe and emissions range from about 10 to about 40 ppmv (depending on boiler load). Emissions from a small test plant using circulating PFBC technology were found to be below 20 ppmv. Emissions are thus still higher than from conventional fossil fuel fired plant, but lower than from atmospheric FBC plant.

7.1.6 Use of Conventional Coal Technologies or IGCC

An alternative to the use of FBC is to use conventional pulverised fuel type coal plant, or other new coal technologies such as integrated gasification combined cycle (IGCC) technology. IGCC technology also reduces emissions of other pollutants (SO_2 and NO_x) and its higher efficiency helps to reduce CO_2 emissions per unit of electricity produced compared to conventional technology.

7.2 OPTIONS TO REDUCE EMISSIONS ASSOCIATED WITH SNCR

A number of combustion modifications and end of pipe technologies, of which the most common are selective catalytic conversion (SCR) and selective non catalytic conversion (SNCR) are the most common, can be used to abate NO_x emissions from power plant; these are discussed in more detail in the report on NO_x emissions. It appears that combustion modifications do not lead to any increase in N_2O emissions.

In the case of SCR, ammonia is injected into the flue gas immediately upstream of a noble metal or vanadium catalyst. The NO_x and ammonia react to form nitrogen and water, leading to a reduction efficiency of 80 to 90%. While laboratory studies have indicated that some N_2O may be formed in SCR studies (Kramlich and Linak, 1994), measurements on commercial plants suggested that in commercial applications, SCR does not lead to an increase in N_2O emissions (Takeshita et al, 1993).

SNCR systems do not use a catalyst, and as a result the reactions require a higher temperature, typically 900-1200°C. To achieve these temperatures, gaseous ammonia (or liquid caustic ammonia or urea) is injected directly into the upper section of the boiler, achieving a 30 - 50% NO_x reduction. The evidence regarding the impact on N_2O emissions is somewhat conflicting (Tashekita et al, 1993; Kramlich and Linak, 1994), but it appears that when urea in used in SNCR systems, some of the NO_x which is reduced can be converted to N_2O, leading to increased emission levels. The situation regarding ammonia is less clear, but it appears that while emission levels are not as high as when urea is used, they are higher than the levels associated with uncontrolled plant (Takeshita, 1995).

While more work is required to clarify emission factors from NSCR systems, it would appear that systems using ammonia are preferable. If further work was to verify that emissions are higher from SNCR compared to SCR then this might become a consideration in the choice of abatement systems. Both the capital and operating costs of SNCR are lower than for SCR, and even though SCR can achieve much higher reductions in emissions, the cost per tonne of NO_x abated using SCR systems is about twice that of NSCR systems (Soud and Fukasawa, 1996). Until more information is available on N_2O emissions from SNCR systems however, it is not possible to calculate the cost of using SCR in preference to NSCR.

7.3 OPTIONS TO REDUCE EMISSIONS ASSOCIATED WITH STATIONARY FOSSIL FUEL COMBUSTION

Emissions associated with stationary combustion may be reduced by a number of measures which are primarily aimed at reducing CO_2 emissions. These fall into four main types of measures:

- Energy efficiency/saving in demand sectors;
- Fuel switching from coal or oil to gas in the electricity supply industry and other sectors such as industry;
- Increased use of renewables;
- Improving supply side efficiency e.g. through increased use of cogeneration.

The potential impact of these types of measures on N_2O emissions has been estimated using the methodology described in Appendix 5 for a number of generic type measures:

- energy saving in industry;
- energy saving in the residential and commercial sector;
- introduction of gas fired CCGT for electricity generation;
- use of 'zero emission' renewables such as wind, PV, small scale hydro;
- use of biomass renewables e.g. energy crops, waste;
- use of CCGT based cogeneration in industry.

Table 7.2 and Figure 7.1 show the reduction in N_2O emissions which might be achieved for each million tonnes of CO_2 saved in Member States though implementing these measures. The methodology is based on using national estimates of N_2O and CO_2 emissions and due to the level of uncertainty in estimating N_2O emissions from combustion should be regarded as indicative only. As discussed above revisions to emission factors for CCGT plant in the light of new measurement data indicate that savings relating to the use of gas for electricity generation are unlikely to be achieved.

Table 7.2 Effect of CO_2 Reduction Measures on N_2O Emissions

	Reduction* in N_2O emissions (t) from saving 1 Mt of CO_2 through:					
Country	Industrial energy saving	Res/com energy saving	Grid connected CCGT	Zero emission renewables	Biomass based renewables	CCGT cogeneration
Austria	29	30	ns	69	11	ns
Belgium	75	94	ns	63	37	372
Denmark	42	52	69	34	22	63
Finland	65	18	ns	51	16	ns
France	53	33	ns	30	-57	ns
Germany	28	32	99	34	18	67
Greece	17	70	36	22	12	30
Ireland	96	109	419	127	111	247
Italy	122	122	800	141	122	350
Luxembourg	4	6	4	3	-1	4
Netherlands	18	17	702	20	-3	89
Portugal	190	166	701	155	136	512
Spain	118	118	ns	136	111	516
Sweden	154	77	ns	166	-50	ns
UK	8	8	44	13	-4	23

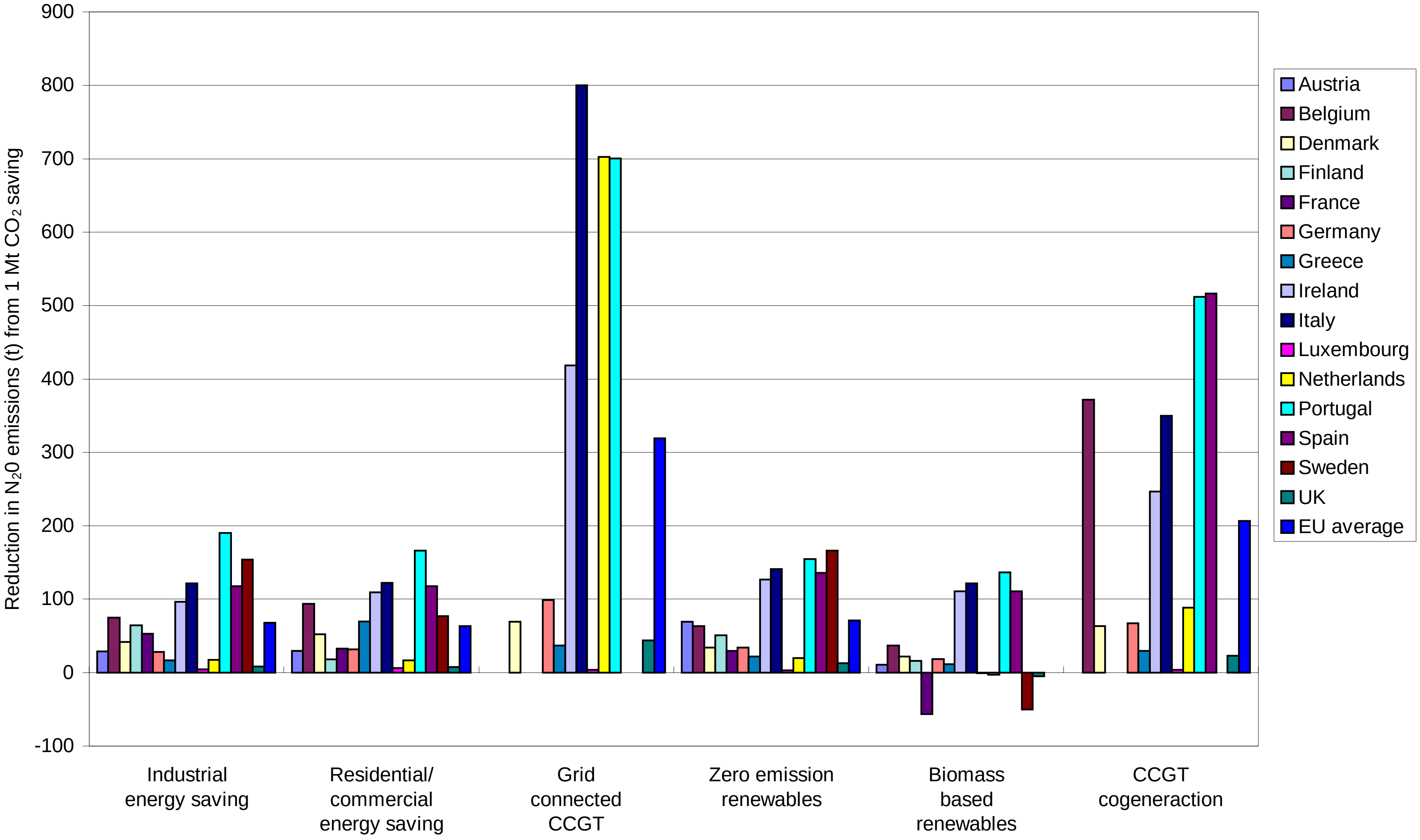
ns - assuming displacement of the average generating mix, this measure would not achieve a net saving in CO_2, emissions, and so the effect on N_2O has not been considered.

* A minus sign indicates that an increase in N_2O emissions is associated with a decrease in CO_2 emissions.

Both national and EU wide studies have indicated a large theoretical potential for CO_2 savings in the EU. Furthermore, it is estimated that substantial CO_2 savings might be achieved through demand side measures which have a negative or zero cost.

An estimate of the overall potential for CO_2 measures to reduce N_2O emissions has been made based on the recent Commission paper 'Climate Change - The EU Approach for Kyoto' (COM(97)481) which estimates the potential CO_2 emission reductions which might be

Figure 7.1 Impact of Measures to Reduce CO_2 Emissions from Stationary Sources on N_2O Emissions



achieved from various sectors. Due to the doubt over savings arising from the use of CCGT generation and also the use of gas turbines for CHP, savings from these sectors are not taken into account. Savings from the use of renewables for heat production have yet to be calculated and it is assumed that renewables used for electricity generation are 'zero emission renewables'. Furthermore it has been assumed that the emissions reductions are spread evenly over the EU i.e. in proportion to their 1990 CO_2 emissions. In total it is estimated that the CO_2 measures related to stationary combustion might reduce N_2O emissions by about 16 kt (Table 7.3). A more detailed calculation requires further information on the allocation of CO_2 reductions between countries and more detail on the assumptions made.

Table 7.3 Reductions in N_2O associated with CO_2 Reductions

Measure	Reduction Mt of CO_2	Reduction kt N_2O
Industrial energy saving	100	5.2
Residential/ commercial energy saving	100	5.1
Renewables for electricity generation	100	5.6
Total	**300**	**15.9**

7.4 OPTIONS TO REDUCE EMISSIONS FROM TRANSPORT

Emissions from fuel combustion in transport are very low, apart from situations where overall reducing conditions occur e.g. in the case of three-way catalysts in petrol vehicles, and cases where overall oxidising conditions exist e.g. emission abatement of diesel engines and lean-burn spark ignition engines. For cars fitted with a new three way catalyst, emissions may be 4 to 5 times higher than cars with no catalyst; as the catalyst ages, emissions tend to increase and emission factors for cars with medium aged catalysts may be 10 to 16 times higher than cars with no catalysts (Olivier, 1993). Other parameters, including catalyst type, size and temperature, engine output, and power, may also affect emissions. As some if these are dependent on driving conditions, emissions also vary with driving conditions. Typical emission factors for petrol and diesel cars are shown in Table 7.4.

Table 7.4 Typical Emission Factors for Petrol and Diesel Cars

Type of vehicle	g N_2O/km
Petrol car with no catalytic converter	0.005
Petrol car with catalytic converter	0.05
Diesel car	0.01

7.4.1 Reducing Transport Demand and Increasing Transport Efficiency

In a similar way to stationary combustion, it is possible to reduce transport related N_2O emissions by reducing the volume of traffic demand i.e. vehicle kilometres, which will also have the advantage of reducing emissions of CO_2 and of other transport related emissions such as NMVOC and NO_x. A large number of policy options exist for reducing transport demand and these are being examined in detail in the work on the transport sector being carried out for NO_x and NMVOC abatement.

Improving the 'fuel efficiency' of vehicles, will also tend to reduce NO_x emissions from vehicles and hence N_2O emissions. Estimated improvements in the fuel economy of typical new light duty vehicles by 2005 are shown in Table 7.5. These arise mainly from:

- body and chassis developments such as reduction of aerodynamic drag, tyre rolling resistance and vehicle weight
- powertrain developments such as use of multivalve combustion systems, exhaust gas recirculation, reduction of friction in gasoline and diesel engines, direct injection diesel engines and multivalve gasoline engines.

Table 7.5 Estimated Improvements in Fuel Economy and Associated Costs (1992-2005)

	Gasoline vehicles		Diesel vehicles	
	Improvement in fuel economy	Increase in first cost of vehicle	Improvement in fuel economy	Increase in first cost of vehicle
Small cars	14%	5-8%	4%	2-5%
Medium cars	19%	6-10%	8%	2-4%
Large cars	19%	1-4%	24%	5-10%
Light commercial vehicles	13%	2-4%	18%	5-10%

Source: ETSU, 1994

Understanding of N_2O emissions from cars is not yet advanced enough to estimate with certainty the reduction in N_2O emission which might result from improvements such as those described above. It is however possible to estimate the reduction in N_2O emissions which will occur when measures primarily designed to reduce CO_2 emissions from transport by reducing transport demand (i.e. vehicle kilometres) are implemented. These estimates are shown in Table 7.6 and Figure 7.2. The estimates take account of the increasing penetration of catalytic converters in the fleet and also trends in the use of diesel vehicles.

An estimate of the overall potential for CO_2 measures to reduce transport N_2O emissions has been made based on the recent Commission paper 'Climate Change - The EU Approach for Kyoto' (COM(97)481) which estimates the potential CO_2 emission reductions which might be achieved from various sectors. In view of the points made above, reductions in N_2O emissions have only been estimated for the CO_2 savings arising from intermodal shift. For the 50 Mt CO_2 reduction identified, it is estimated that in 2010 this would lead to a reduction in N_2O emissions of 9.8 kt.

Figure 7.2 Impact of Measures to Reduce CO_2 Emissions from Transport on N_2O Emissions

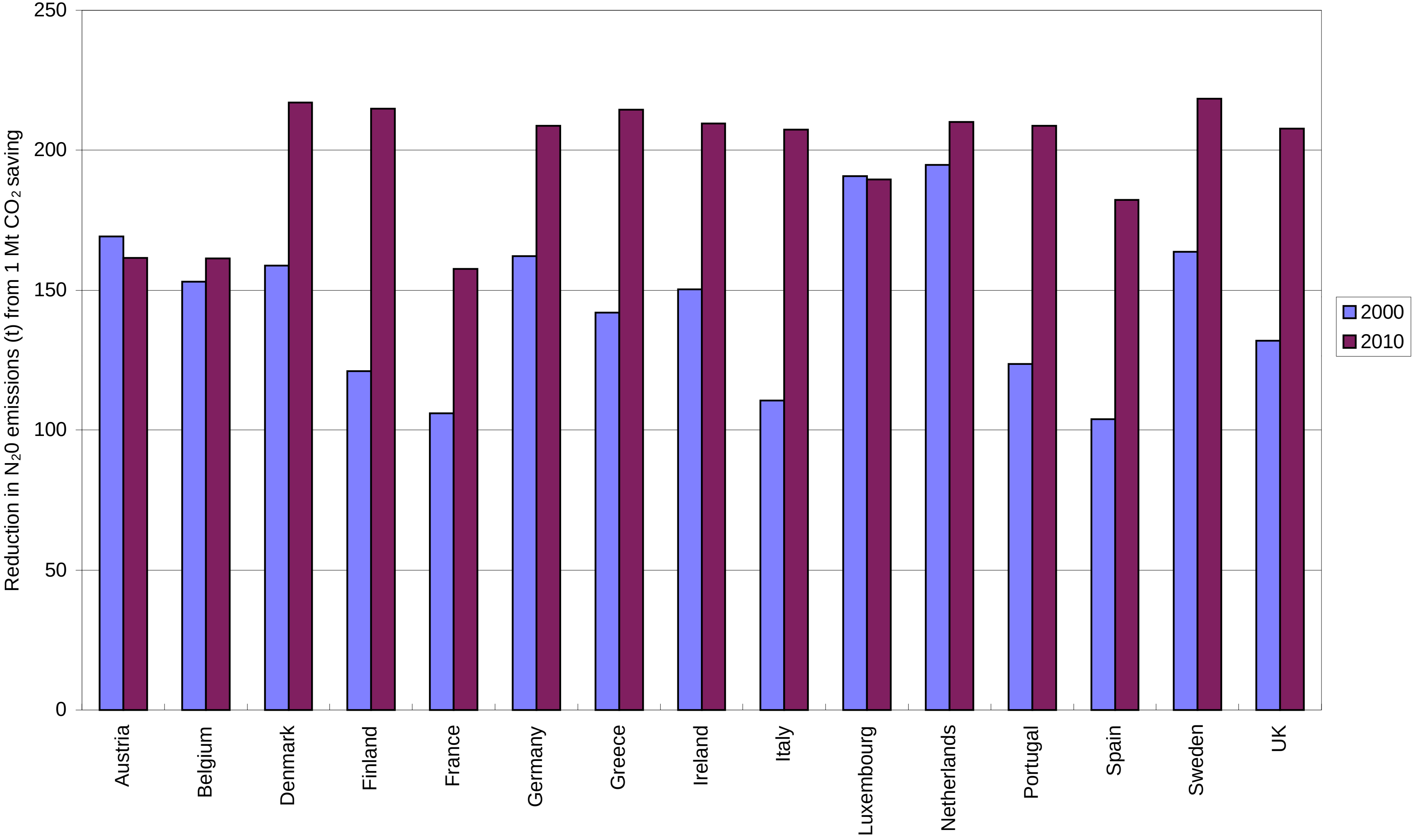


Table 7.6 Effect of CO_2 Reduction Measures on N_2O Emissions

	Reduction in N_2O emissions (t) from saving 1 Mt of CO_2 through:	
	Reduced transport (in 2000)	Reduced transport (in 2010)
Austria	169	162
Belgium	153	161
Denmark	159	217
Finland	121	215
France	106	158
Germany	162	209
Greece	142	215
Ireland	150	210
Italy	111	207
Luxembourg	191	190
Netherlands	195	210
Portugal	124	209
Spain	104	182
Sweden	164	218
UK	132	208

7.4.2 Improving Catalyst Performance

The current three way catalytic converters are designed to reduce emissions of NO_x, CO and VOCs, all of which are ozone precursors. N_2O is produced as a result of incomplete catalytic reduction of NO and NO_2 to N_2. It is possible that in the longer term it might be possible to develop a new catalytic converter which also prevented N_2O formation; it is likely that this would require a significant R&D effort.

As N_2O emissions increase with vehicle age, it is possible that emissions could be reduced by ensuring replacement of aged catalytic converters which showed increased emissions, but this may be difficult to detect. The measurement of N_2O requires laboratory equipment (e.g. a gas chromatograph) and is therefore is not easily carried out as part of a routine emissions test at a garage. The performance of the catalytic converter with regard to other pollutants is unlikely to be a suitable ‘proxy’ indicator as performance with regard to N_2O emissions is likely to degrade more quickly than with regard to other pollutants. This option is therefore not considered feasible.

Replacement of catalytic converters could be required on a periodic basis to ensure that performance does not degrade. The cost of replacing a catalytic converter ranges from about £200 to £1000 per vehicle and the estimated saving (assuming replacement every 3 years) is about 20 kg of N_2O, the cost of this option is thus extremely high.

8. Cost Effectiveness of Measures

8.1 INTRODUCTION

This section assesses the cost-effectiveness of measures designed to reduce emissions of N_2O from the chemical industry and the power sector. The assessment uses discounted cash flow techniques, to reduce the stream of non-recurring (capital) costs and recurring (annual) costs associated with each measure to a single present value in a given base year. Furthermore, to facilitate comparison between measures with different operating lives, the present value of the total costs stream of each measure is annualised over the forecast period of plant operating life. As with normal economic project appraisal, this involves calculating the equivalent annual cost of each measure. An indicator of the cost-effectiveness of each measure is then derived by normalising the equivalent annual cost to the resulting emission reduction to give an abatement cost in ECU per tonne of N_2O. Costs are presented in 1995 ECU and a discount rate of 8% has been used in annualising cost. The methodology is described in full in Appendix 1.

Due to the different way in which it was necessary to consider agricultural measures, it was not possible to assess their cost effectiveness using this methodology. However, a preliminary indicative estimate of the costs associated with the measures has been made and is presented in Section 8.5.

8.2 CHEMICAL INDUSTRY

With respect to the chemical industry, three options to reduce N_2O emissions have been identified for which some cost data is available:

- adipic acid production - end-of-pipe technology;
- nitric acid production - non-selective catalytic reduction (NSCR);
- nitric acid production - catalytic destruction.

8.2.1 Cost Assumptions

8.2.1.1 Adipic Acid Manufacture: end-of-pipe technology

Very little cost data is available for this option due to commercial sensitivity. An indicative calculation has been made, however, based on the reported capital costs for a German plant, and the following additional assumptions:

- The non-recurring capital cost is 27 million DM (in 1995 prices).
- Annual recurring costs are between 5 and 15% of the investment cost (best estimate 10%).
- The option has a lifetime of 15 years and requires 2 years to install.
- The plant treats 85,000 tonnes of N_2O per year, and is effective in removing 95 per cent of emissions.

8.2.1.2 Nitric Acid Production: non-selective catalytic reduction (NSCR)

As discussed previously, SCR plant is already commonly used to abate NO_x emissions. A survey of plant in Europe in 1990 found investment costs of between 1,200 and 3,900 ECU per tonne per day of nitric acid production for SCR plant. However, the EFMA (1995) suggested investment costs were as low as 500 ECU per tonne per day production. Operating costs in the 1990 survey were estimated at about 10% of capital costs. The 1990 survey reports similar costs of 3000 ECU per tonne capital costs and 10% operating costs for an NSCR plant operating on waste gas. The cost-effectiveness of NSCR plant has thus been estimated using the following assumptions.

The non-recurring cost of an SCR plant is 500 ECU per tonne per day of production.

- The non-recurring cost of an NSCR plant is 50% higher than an SCR plant.
- The output of the plant is 1,000 tonnes of nitric acid per day. Therefore, the non-recurring cost of an NSCR plant is equal to 500 ECU per tonne per day of production * 1.5 * 1,000 tonnes of nitric acid per day, i.e. 750,000 ECU.
- The annual recurring costs are 10% of capital costs.
- Unabated emissions are 15 g/kg of production (ranging between 2 g/kg and 25 g/kg). Therefore, for a 1,000 tonne per day plant, with 100 per cent availability, annual emissions of N_2O are equal to 5,475 tonnes (ranging between 729 and 9,123 tonnes per year).
- The NSCR plant reduces N_2O emissions by 70%.

8.2.1.3 Nitric Acid Production: catalytic destruction

The cost of this option is based on capital and operating costs suggested by de Jager et al (1996). The following assumptions were made:

- The non-recurring costs comprises two elements: 1 million Dfl for the catalyst, which needs to be replaced every three years, and 4 million Dfl for other equipment, (in 1995 prices). Assuming an operating life of 15 years, the total cost in year zero of the catalysts required by this option is thus 3,484,400 Dfl. Hence, the total non-recurring cost in year zero is 7,484,400 Dfl.
- Annual recurring costs are 4% of the total non-recurring cost. The non-recurring and recurring costs for this option are based on those reported in de Jager et al (1996).
- The option takes one year to install.
- The plant produces 1 million tonnes of acid per year and unabated emissions of N_2O are assumed to be 15 g/kg of acid produced (ranging between 2 g/kg and 25 g/kg).
- The technology is effective in removing 80 per cent of emissions.

8.2.2 Cost-effectiveness

The cost-effectiveness of the above measures is summarised in Table 8.1.

Table 8.1 Cost-effectiveness of Measures Designed to Reduce Emissions of N_2O from the Chemical Industry (best estimate)

Mitigation Measure	ECU per tonne of N_2O Abated
Adipic Acid: end-of-pipe technology	37
Nitric Acid: NSCR	42
Nitric Acid: catalytic destruction	43

The estimated cost of reducing emissions from adipic acid production is considerably lower than the cost estimate provided by Reimer (1996) of 160 ECU per tonne. As a cost breakdown is not provided by Reimer, it is not possible to identify the reason for this discrepancy. The cost-effectiveness of the measure is reduced to 29 ECU per tonne if annual recurring costs are assumed to be 5% of capital costs. Conversely, if annual operating costs are assumed to be 15% of capital costs, the cost-effectiveness of the measure increases to 46 ECU per tonne.

The cost-effectiveness of catalytic destruction is estimated to be 43 ECU per tonne N_2O abated. As indicated earlier there is considerable uncertainty over the level of unabated emissions associated with nitric acid production, and they may be considerably lower or higher than the 15 g/kg on which the above cost-effectiveness value is based. If unabated emissions are assumed to be 2 g/kg or 25 g/kg of production, then the cost-effectiveness of this measure is 325 or 26 ECU per tonne, respectively.

The costs of abatement from an NSCR plant reported in Table 8.1 (42 ECU per t N_2O) assume all the cost of the NSCR plant is ascribed to N_2O reduction. If, however, it is considered that NO_x abatement is required anyway for nitric acid production, and that the cost is the additional cost over that of an SCR system which is able to produce the required NO_x reduction more cheaply, then the cost is 14 ECU per tonne. If unabated emissions are assumed to be 2 g/kg or 25 g/kg of production, then the cost of reduction is 318 or 25 ECU per tonne, respectively. If estimates are based on the much higher capital costs indicated by the 1990 survey (of about 3,000 ECU per tonne per day of production), then the cost of abatement ranges between 153 and 1,909 ECU per tonne, depending on the assumption made regarding unabated emissions. These costs are all generally lower than those quoted by de Jager et al (1996) of 450 to 1,350 ECU/t for an NSCR plant. Again no cost breakdown is provided so that no comparison is possible.

8.3 THE POWER SECTOR

Within the power sector, enough cost and performance data is available to calculate the cost-effectiveness of three options:

- Fluidised bed combustion - use a gas afterburner.
- Fluidised bed combustion - reversed air staging.
- Fluidised bed combustion - optimise operating conditions to minimise N_2O production and use SCR to maintain low NO_x emissions.

8.3.1 Cost Assumptions

8.3.1.1 Fluidised Bed Combustion: gas afterburner

The following assumptions were made:

- The non-recurring cost is $US 30 per kWe (in 1993 prices), with a range of between $US 15 and $US 40 per kWe. These costs were taken from the afterburner cost for large conventional facilities (i.e. 300 MW). The load factor is 85 per cent, therefore, annual output is 24 * 365 * 0.85 = 7,446 kWhe per kWe. Consequently, non-recurring costs are equal to $US 30 per kWe divided by 7,446 kWhe per kWe, i.e. $US 0.00403 per kWhe.
- The recurring cost is 0.95 MJ per kWhe or 0.264 kWh per kWhe. This is the amount of fuel which has to be put in as gas rather than coal. The cost is therefore the price differential

between coal and gas. In 1993 the price of coal and gas purchased by the UK power sector was 0.61 pence per kWhe and 0.706 pence per kWhe, respectively. This equates to a price differential of £0.00095 per kWhe, or $US 0.00142 per kWhe. The recurring cost of this option is therefore equal to 0.264 kWh per kWhe * $US 0.00142 per kWhe, which is equal to $US 0.000376 per kWhe.
- The option has a lifetime of 30 years and requires one year to install.
- The reduction potential of the option is 0.6g N_2O per kWhe.

8.3.1.2 Fluidised Bed Combustion: reversed air staging

The following assumptions were made in estimating the cost-effectiveness of this measure:

- The non-recurring cost of the measure is zero.
- A preliminary estimate of the non-recurring cost of reversed air staging has been made assuming that it leads to an increase of 10% in auxiliary power consumption (which is itself assumed to be 10% of generated electricity); that is, 0.01 kWh per kWhe. The average price of electricity purchased by all consumers in 1995 was 4.007 pence per kWhe. The annual recurring cost of this option is thus equal to 0.01 kWhe per kWhe * £0.04007 per kWhe, i.e. £0.0004007 per kWhe.
- The option has a lifetime of 30 years and requires one year to implement.
- The reduction potential of the option is 0.5g N_2O per kWhe.

8.3.1.3 Fluidised Bed Combustion: optimised conditions and the use of SCR

In order to estimate the cost-effectiveness of this measure the following assumptions were made:

- The non-recurring cost of this option is $US 36 - 37 per kWe (in 1995 prices). The capital cost of an SCR plant is taken from Soud and Fukasawa (1996). The load factor is 85 per cent, annual output is thus 24 * 365 * 0.85 = 7,446 kWhe per kWe. Consequently, non-recurring costs are equal to $US 36 -37 per kWe divided by 7,446 kWhe per kWe, i.e. between $US 0.00484 and $US 0.00497 per kWhe.
- Annual recurring costs are 6% of the investment cost (taken from IIASA report).
- The option has a lifetime of 15 years and requires one year to implement.
- The reductions achieved by the plant are based on conventional plant with much higher uncontrolled levels of NO_x than those from CFBC (of about 250 ppm). It has been assumed that there will be no change in capital cost for a SCR plant treating the uncontrolled NO_x emissions from the CFBC plant (of 50 ppm). The reduction potential of a SCR plant costing $US 36 per kWe is 0.20g N_2O per kWhe, whereas, a SCR plant costing $US 37 per kWe reduces N_2O emissions by 0.22g per kWhe.
- A reduction of 1 g of N2O through an increase in bed temperature, leads to an increase of 0.7g in NOx emissions, which is reduced by SCR (based on Boemer et al 1993).

8.3.2 Cost-effectiveness

Table 8.2 summarises the cost-effectiveness of measures to reduce emissions of N_2O from fluidised bed combustion. The use of a gas afterburner or reversed air staging is significantly more cost-effective than the use of SCR.

Table 8.2 Cost-effectiveness of Measures Designed to Reduce Emissions of N_2O from the Power Sector (best estimate)

Mitigation Measure	N_2O Reduction (g/kWh_e)	ECU/t N_2O Abated
Gas afterburner	0.60	1,107
Reversed air staging	0.50	966
Minimise N_2O production and use SCR to reduce NO_x emissions	0.20 to 0.22	3,263 to 3,049

There is some uncertainty over the non-recurring cost of the gas afterburner, with a range of between $US 15 and $US 30 per kWe. The corresponding reduction costs are 837 and 1,287 ECU per tonne.

8.4 VARIATIONS IN COSTS ACROSS EUROPE

To gain an insight into how the cost-effectiveness of the various measures might vary across the EU15, each component of the base data has been adjusted to take into account known differences in relative factor prices between the base country, for which detailed cost data exists, and other members of the EU15, for which cost data needs to be estimated. Further details of the methodology and relative price indices used is given in Appendix 1.

Table 8.3 shows the highest and lowest costs of each measure designed to reduce emissions of N_2O from the chemical industry (based on best estimates). Similar information for measures to reduce emissions from fluidised bed combustion is shown in Table 8.4. It is important to understand that the cost ranges shown in these two tables are due, not to uncertainties in the cost or efficiency data, but to the variation in cost-effectiveness of each measure that might be expected across the members of the EU15, resulting from differences in relative factor prices.

In addition, the figures shown in Tables 8.3 and 8.4 should be interpreted with caution. They should be seen simply as an indication of the degree to which the cost-effectiveness of the various measures considered in this study, might be expected to differ from one Member State to another. The figures also allow those Member States to be identified in which the implementation of the various measures is likely to be relatively more, or less expensive. Large uncertainties exist in relation to the accuracy of the selected indices to reflect actual variations in relative factor prices, and in the assumption that costs are equally split between the different cost components, so that the use of a weighted average indice is appropriate. Only if one accepts these assumptions can the figures displayed in Tables 8.3 and 8.4 be interpreted as providing a reasonable indication of the cost-effectiveness of the various measures in each Member State.

Table 8.3 Variation in Costs Across the EU15 of Measures Designed to Reduce Emissions of N_2O from the Chemical Industry

Mitigation Measure	ECU per t N_2O Abated (high)	ECU per t N_2O Abated (low)
Adipic Acid: end-of-pipe technology	37 (D)	26 (UK)
Nitric Acid: NSCR	69 (DK)	41 (GR)
Nitric Acid: catalytic destruction	52 (DK)	31 (GR, P)

Table 8.4 Variations in Costs Across the EU15 of Measures Designed to Reduce Emissions of N_2O from Fluidised Bed Combustion

Mitigation Measure	ECU/t N_2O (high)	ECU/t N_2O (low)
Gas afterburner	2,382 (DK)	1,265 (UK)
Reversed air staging	1,719 (P)	550 (S)
Minimise N_2O production and use SCR to reduce NO_x emissions	5,015 (DK)	3,022 (GR)

8.5 THE AGRICULTURAL SECTOR

Costs are estimated here for the individual measures which were discussed in Section 5.6. Indicative costs have also been estimated for the ‘package of options’ discussed in Section 5.5. However, it has not been possible to model the macro-economic changes in the agricultural sector which would accompany the wide sweeping policy changes which form some of these measures (e.g. removal of price support). The estimates are therefore very approximate and first order only.

8.5.1 Costs Associated with Individual Measures

The financial consequences of system changes in agriculture are dependent upon the costs and prices associated with the change. UK agriculture is experiencing dramatic fluctuations in costs and particularly product prices. For example, the wheat price has fallen from highs of £120 and more in the 1995 harvest to between £70 to £80 for the 1997 harvest. At the same time the cost of fertiliser nitrogen to UK farms is very variable depending on the type and source of fertiliser, the quantity purchased and the world market situation, and nitrogen fertiliser costs have fluctuated from over 43 pence to under 25 pence per kg of N. The main factors driving these changes are currency exchange rates and the common agriculture policy (CAP). For the purpose of this assessment of cost-effectiveness of measures, costs and product prices are best estimates for the period to 2000, based on proposed policy reforms and forecast currency changes. A cost of 32 pence (1997) per kg of N is assumed for the British situation. This equates to ammonium nitrate (34.5 N) delivered at £110.40 per tonne, which is considered a reasonable annual average for fertiliser N in the UK over the next one to two years. This is equivalent to 0.43 ECU (1995) per kg. The average costs of fertiliser N in France and Germany is considerably higher (123% and 170% respectively than in the UK) indicating that measures involving fertiliser savings may be more cost-effective in those countries than the UK.

8.5.1.1 Making better use of N from manures applied and residual N from previous crops

There are no additional costs associated with these measures, but there is a saving from reduced application of inorganic fertiliser N. For each 1 kg reduction in fertiliser, N emissions are reduced by 0.0125 kg N_2O-N; as the cost of fertiliser N is 32 p/kg this gives a cost of -£16,291 per t N_2O (1997), i.e. there is a saving attached to the reduction. This is equivalent to -21,668 ECU/t N_2O for the UK (in 1995 ECU) and given the higher cost of fertiliser N in France and Germany, -26,652 and -36, 836 ECU/t N_2O (1995 ECU) in those countries.

This is an over-simplification of the situation, as:

- N_2O emissions are likely to be influenced to a greater extent by differences in soil type and conditions and season, but the current methodology does not allow a more accurate estimate.
- Farmers awareness of the possibility of taking account of this additional N from other sources will need to be raised, and this will have a cost attached to it. This is discussed in more detail below.

Some estimates of the cost of farmer awareness programmes are available for the UK:

- A series of promotional meetings and press coverage could be relatively inexpensive, but the level of uptake is likely to be modest. Depending on the number of meetings the cost of this type of activity would be £5,000 to £10,000, for meetings covering the principle arable regions of the country, for example 2 or 3 in the Eastern Counties, similar numbers in the Midlands, 2 meetings in the South and a further 2 in the North. This number of meetings should help raise the issue of N_2O emissions, but would not be sufficient to communicate to all farmers. This would require significantly more meetings held at local levels to smaller farmer groups.
- An alternative method would be the production of literature for distribution to all farmers. The cost of this method of communication would be about £20,000. The target audience would be greater as the booklet could be sent to all farmers. There is however survey work which suggests farmers are not particularly responsive to literature.
- A third method would be to have a series of practical demonstration farms on which regular open days and conferences are held at which the savings are made and demonstrated in a very practical way to farmers. The minimum cost of this type of promotion is likely to be in the order of £20,000 to £30,000 per demonstration farm per year. The cost may be more if the farm needs to be set up but this is likely to offer the greatest possible impact over the medium to long term, as these farms would demonstrate practical system changes with identifiable cost benefit to farmers.

It was estimated (Section 5.6) that the total reduction achieved through this type of measure in the UK was 92 t of N_2O per year. If the third (and most expensive) option for raising farmer awareness was taken, i.e. setting up of demonstration farms and 10 farms were needed to give a good coverage of the principal arable areas, then the cost would be £200,000 to £300,000 per year. This is equivalent to a cost of about £3,270 per t of N_2O reduction, and is about 20% of the savings achieved for this option from the reduction of fertiliser use of -£16, 291 per t of N_2O.

8.5.1.2 Sub-optimal Applications of N to Winter Wheat and OSR

Winter Wheat

Table 8.5 below shows the effect on yield and net margin for fertiliser-N levels 50 kg and 100 kg per hectare below an optimum of 190 kg per hectare. The assumptions used in this calculation are a wheat price of £80 per tonne and a fertiliser-N cost of 32 pence per kg of N.

Table 8.5 Effect of Reduced Fertiliser-N on Winter Wheat.

Fertiliser N reductions kg/ha	Wheat yield response kg/ha	Net effect on margin £/ha
50	-340	- 11.20
100	-1030	- 66.40

The overall economic impact of reduced fertiliser-N applications is particularly sensitive to the yield response. Table 8.6 shows the effect on margin for a range of yield changes resulting from the application of 50 kg and 100 kg fertiliser-N below optimum levels.

Table 8.6 Sensitivity Assessment of Effect of Reduced Fertiliser-N Applications on Margin of Winter Wheat

Yield loss	Fertiliser N reduction	
	- 50 kg	-100 kg
kg/ha	£/ha	£/ha
0	16	32
200	**0**	16
400	**-16**	0
600	-32	-16
800	-48	-32
1000	-64	**-48**
1200	-80	**-64**

It is reasonable to assume that a 50 kg per hectare reduction on N would reduce yields by between 200 to 400 kg per hectare and a 100 kg per hectare of N would result in a yield loss in the order of 1000 to 1200 kg. The shaded areas in Table 8.6 show the probable impact on income of expected yield loss due to reduced fertiliser-N application.

The implications of the restriction of fertiliser-N on the UK winter wheat crop are shown in Table 8.7.

Table 8.7 Cost Of Abatement of N_2O Emissions by Sub-optimal Application of Nitrogen to Winter Wheat in UK

Fertiliser N reductions		Emissions Reduction	Lost Margin	Cost-effectiveness	
kg/ha	tonnes	t N_2O	£M (1997)	£(1997)/t N_2O	ECU(1995)/t N_2O
50	96300	1866	21.6	11404	15168
100	192600	3732	127.9	33804	44961

Oilseed Rape

In this particular case the economic optimum fertiliser application is calculated to be 215 kg N per hectare at an OSR price of £180 per tonne. Reducing fertiliser-N applications by 50 and 100 kg per hectare would have resulted in lost margin of £5.60 and £23.80 respectively.

Table 8.8 below shows the overall sensitivity to different yield changes. The normal expectation is a yield loss in the region of 100 to 200 kg per hectare from a 50 kg per hectare N reduction and a 300 to 400 kg per hectare yield penalty from the 100 kg N reduction.

Table 8.8 Sensitivity Assessment of Effect of Reduced Fertiliser-N Applications on Margin of Winter Oilseed Rape

yield loss	Fertiliser N reduction	
	- 50 kg	-100 kg
kg / ha	£ /ha	£ /ha
0	16	32
100	**-2**	14
200	**-20**	-4
300	-38	**-22**
400	-56	**-40**
500	-74	-58

The costs of this approach to the reduction of N_2O emissions are summarised in Table 8.9.

Table 8.9 Cost Of Abatement of N_2O Emissions by Sub-optimal Application of Nitrogen to Oilseed Rape in UK

Fertiliser N reductions		Emissions Reduction	Lost Margin	Cost-effectiveness	
kg/ha	tonnes	t N_2O	£M (1997)	£(1997)/t N_2O	ECU(1995)/t N_2O
50	18800	369	2.1	5702	7584
100	37600	739	8.9	12116	16115

8.5.1.3 Changing from Winter to Spring Cultivars

The economic consequence of such a change is difficult to calculate at a global as opposed to farm level. The reason being that individual farmers may have the opportunity to change their overall farming system to reduce the impact of the lower gross margins anticipated from the spring sown crops. For example, there may be an opportunity to reduce power and machinery costs by operating equipment with smaller capacity as field operations are spread over the autumn and spring period. On other farms with livestock, the farmers may take the opportunity to establish a crop such as stubble turnips to be grazed in the field by sheep over the winter period.

On the other hand, in wet seasons, farmers with heavy land risk not being able to establish a crop at all due to delays in cultivation and establishment.

For the purpose of this report the economic consequence of the change to spring cultivars is limited to the effect at the crop gross margins level, ignoring the other potential benefits from farming system changes and the risk of crop failure.

Winter Barley to Spring Barley

The change to spring cultivars offers potential savings in all input costs not just nitrogen fertiliser. There is however likely to be a yield penalty associated with spring crops over winter crops due to the shorter growing season. The calculations below assume no change in product price, that is to say both the winter and spring barley will be feed value. In some situations the move to spring cultivars would offer an opportunity to produce a malting sample in some years which would have a price premium over feed barley.

The cost implications of the change from winter to spring cultivars of barley is summarised in Table 8.10 below. Average yield data indicate a 1 tonne per hectare yield loss in the change from winter to spring barley. For the purposes of the report, it has been assumed that 30% of the cropped area produces straw with a value, either used on the farm or sold to other farmers.

In all the variable costs of growing the spring barley are £41 per hectare less than winter barley, however only £12.80 of this difference relates to the lower fertiliser nitrogen applications.

Table 8.10 Economic effect of changing from winter to spring cultivars of barley

Output	Winter £/ha	Spring £/ha	difference £/ha
Barley	450	375	
Straw	15	13	
IACS	248	248	
	713	636	77
Variable Costs	192	151	41
Net Margin	**521**	**485**	**36**

In the UK the winter barley cropped area varies year to year. Based on the 1997 harvest data, the total potential cost to the industry from the winter to spring cultivars would be in the order of £30 million. Assuming an average recommendation for fertiliser-N application to spring barley of 30 kg/ha less than for winter barley, total nitrogen applications would be reduced by about 25000 tonnes. The reduction in N_2O emissions is calculated to be 495 t and the cost per tonne of N_2O abated is £60,720 (1997 £) or 80,755 ECU (1995 ECU).

Winter OSR to Spring OSR

The change from winter to spring cultivars of OSR will have a significant impact on crop yield. In absolute terms the yield loss of at least 1.0 tonne per hectare could be anticipated, which equates to a 30% reduction.

The change to spring OSR will reduce the fertiliser-N applications by about 100 kg per hectare, thus saving about £32 per hectare in costs. The remaining cost reductions come from the other variable cost savings which would be achieved.

Table 8.11 below shows the cost of changing from winter to spring cultivars of oilseed rape. The calculation is particularly sensitive to market price change and yield changes. Table 8.12 shows the sensitivity of the cost difference in Table 8.11 to changes from the assumed 1 tonne yield loss and £180 per tonne market price. Based on the £82 per hectare costs shown below, the total cost of a complete change to spring cultivars would be about £30.8 million.

Table 8.11 Economic Effect of Changing from Winter to Spring OSR Cultivars

Output	**Winter £/ha**	**Spring £/ha**	**difference £/ha**
Oilseeds	594	414	180
IACS	314	314	0
	908	728	180
Variable Costs	280	182	98
Net Margin	628	546	82

Table 8.12 Sensitivity of Cost of Replacing Winter OSR with Spring OSR to Yield Loss and Oilseed Market Price

yield	**OSR Market Price**		**£ per tonne**	
reduction	**140**	**160**	**180**	**200**
kg/ha	**£/ha**	**£/ha**	**£/ha**	**£/ha**
750	7	22	37	52
1000	42	62	82	200
1250	77	102	127	152
1500	112	142	172	202

The cost of reducing the N_2O-N emissions by changing from winter to spring cultivars of OSR is calculated to be £104,360 (1997 £) per tonne of N_2O abated, which is equivalent to 138,810 ECU/t N_2O (1995 ECU).

8.5.2 Summary of Cost-Effectiveness and Reductions

A summary of the cost-effectiveness of the options considered is given in Table 8.13. The most cost-effective measures are those ensuring that application of fertiliser does not rise above the economic optimum by taking full account of nitrogen from animal manures and break crops. The least cost-effective measures are those involving a switch from winter to spring cultivars; these were also the options identified as least desirable environmentally due to potential environmental problems with bare land over the winter.

Table 8.13 Cost-Effectivenss of Measures to Reduce Agricultural N_2O Emissions in the UK

Measure	Cost-effectiveness	
	£ (1997)/t N_20	ECU(1995)/t N_20
Ensuring application at economic optimum	-16,290	-21668
As above, but including cost of farmer awareness programmes	-13,021	-17320
Sub-optimal fertiliser applications		
- Winter Wheat (-50 kg/ha)	11,404	15168
- Winter Wheat (-100 kg/ha)	53,120	70652
- OSR (-50 kg/ha)	5,702	7584
- OSR (-100 kg/ha)	12,116	16115
Change from winter to spring cultivar - barley	60,716	80755
Change from winter to spring cultivar - OSR	104,364	138810

8.5.3 Costs Associated with 'Package of Options'

The broad brush modelling work described in Section 5.5 described a 'package of options' scenario, under which it was possible to reduce emissions by 21% by 2010 compared to a business as usual scenario. The three main measures in this package of options which contributed the majority of the emissions reductions were:

- limiting inorganic fertiliser applications (and allowing for substitution by organic N from manures)
- seasonal ban on nitrogen applications
- the removal of price support and a phasing in of a marginal land subsidy

Estimates of costs for the first two options are made below in Sections 8.5.3.1 and 8.5.3.2, focusing on costs incurred by the farmer. It has not been possible within this study to estimate the costs of the last option, removal of price support, as the scale of the changes involved require that the agricultural sector is modelled at the macro-economic level, i.e. above the micro-economic level which is the approach taken in the rest of the study.

8.5.3.1 Cost of limiting inorganic fertiliser applications

Cost implications

It is likely that this would have a number of cost implications, including:

- manure would be traded as a commodity;
- costs would be incurred in transporting manure between farms;
- manure processing would be encouraged (*i.e.* in order to produce a less bulky and more easily handled product);
- arable farms may adopt a mixed land use policy in order to generate their own supply of manure N;
- fertiliser manufacturers may lose income (although this could be compensated by a switch to manure processing and distribution).

It is assumed that the fertiliser use restrictions will not cause a loss of productivity nor reduce farm profitability, because:

- manure N will be used as a substitute for fertilisers;
- the cost of purchasing manure would be off-set by the savings on fertiliser purchase (the price differential that is estimated later in the section confirms this);
- technological development and transfer over time will improve N use efficiency.

In addition, livestock farmers will have the benefit of manures becoming a new tradable commodity to supplement their incomes. However, this also represents an opportunity cost to the farmer which is equal to the value of the manure in its current use; this will not always be zero. The additional transport costs associated with the movement of manure between farms could be offset by the price received for manure. This needs to be considered in conjunction with the transport cost savings regarding fertiliser; besides the price paid for manure will more than likely include transport costs. Such costs would be further reduced by the incentive to develop manure processing to aid distribution, and the costs associated with the development of new processing technologies would be off-set by the tradable value of manure. The additional costs of developing new technologies would need to be recovered initially through higher manure prices; whether or not this off-sets the incremental transport costs of unprocessed manure is hard to say. It is likely that farmers would employ contractors for manure transport and application, where on-farm facilities do not exist. This may have implications for farm machinery and labour requirements. The encouragement of mixed farming would probably stimulate farm labour and thus, rural employment. These latter impacts represent second-order economic impacts, which are not included in this assessment, in line with the approach adopted in the power sector and chemical industry.

The cost is composed of two elements:

- the cost saving from reduced application of inorganic fertiliser
- the cost of replacing inorganic fertiliser N with manure N

Cost savings from reduced application of inorganic fertiliser

The cost of the fertiliser limits introduced under the ‘package of options’ scenario were calculated by estimating a value for a unit of fertiliser-N and applying this to the reduction in N applications as the limits on cereal and grass applications are phased in. The price of fertiliser-N was calculated using the 1994 prices for two example fertiliser formulae cited in EUROSTAT (1996). The average price across EU15 for ammonium nitrate fertiliser (25% N) was 44.38 ECU/100 kg, or 1.71 ECU/kg N. A compound fertiliser (17:17:17 NPK) cost on average 19.58 ECU/100 kg, or 1.15 ECU/kg N. It was assumed that the price of ammonium nitrate was representative of all straight N fertilisers, and the price of the 17:17:17 fertiliser was representative of all compound fertilisers.

The consumption profiles of straight and compound fertilisers across EU15 were calculated using FAO consumption data (FAO, 1995). Only three EU15 countries, France, Spain and Sweden, provide a breakdown of fertiliser consumption, and these were assumed to represent the rest of the study group. In these three countries, 29% of the fertiliser N consumed was in compound fertilisers, with the remaining 71% consumed as straight N fertilisers. Given the above assumptions, the price of 1 kg fertiliser-N was calculated to be 1.54 ECU, in EU15 in 1994.

The reductions in fertiliser applications arising from the imposition of a 50 kg/ha limit on inorganic fertiliser applications on cereals and grassland are shown in Table 8.14.

Table 8.14 Fertiliser Reductions And Cost Savings Arising From Fertiliser Limits

	2000	2005	2010	2020
Reduction in fertiliser applications	**kt N**	**kt N**	**kt N**	**kt N**
Cereals	1,395	2,339	2,877	3,161
Grass	426	543	829	830
Total	1,821	2,882	3,706	3,991
Value of fertiliser reduction	**M ECU**	**M ECU**	**M ECU**	**M ECU**
Cereal	2,148	3,602	4,431	4,868
Grass	656	836	1,277	1,278
Total	2,804	4,438	5,707	6,146

Cost of replacing fertilisers with manure-N

The fertiliser limits were introduced with the aim of stimulating farmers to replace fertiliser N, which represents an addition of N to the agricultural sector, with manure N, which is already within the agricultural sector, in an effort to reduce N surpluses and increase the overall efficiency of the system. Replacing inorganic fertilisers with manures will involve transporting the manures from the point of production (livestock farms) to the point of application (livestock and arable farms).

The price of transporting a tonne of slurry has been calculated at £0.12 - £0.16 /km (ETSU, 1996). Taking the median figure, this is equivalent to 0.17 ECU /t /km.

Given a slurry N content of 2.75 kg/t (median of range 1.5 kg/t to 4 kg/t; MAFF, 1987), the cost of transporting unprocessed slurry is 0.06 ECU/kg N/km. Cattle manure, with a N content around 1.5 kg/t, costs 0.11 ECU/kg N/km, and poultry litter, with a median N content of 19.75 kg/t, is the cheapest to transport at 0.009 ECU/kg N/km. Given a hypothetical distance of 100 km from source to point of application, the costs of transporting the manure would be 12 ECU/kg N (slurry), 22 ECU/kg N (manures) and 1.8 ECU/kg N (poultry litter). The travelling costs shown in Table 8.15 are calculated to include an empty return journey by the transport vehicle, and so costs per km must be multiplied by 200 for a 100 km journey. Further analysis could establish a more detailed understanding of regional transport requirements.

However, it is unlikely that a sustainable system could be built around transporting unprocessed manure and slurry over long distances. Their high water contents increase their weight out of proportion to the value of the nutrients they contain, and removing part of the water would represent a way of significantly reducing transport costs, particularly for slurry. Slurry is usually assumed to have a water content of 90%. Manures and poultry litters are so variable that there is no commonly accepted standard, so for the purposes of this exercise they will be assumed to have a water content of around 50%. Travelling costs for two processing options are shown in Table 8.15.

- Halving the water content of animal wastes, so that manures become a lighter, more solid cake with 25% water content, and slurries become a denser sludge with 45% water.

- Reducing water content to 4%. This is taken as the minimum feasible, because it is the standard water content for a similar product: commercially distributed sewage sludge cake.

Table 8.15 Transport Costs Of Livestock Wastes

	transport costs (ECU/kg N/km)			200 km journey (ECU/ kg N)		
	slurry N	**manure N**	**poultry litter N**	**slurry N**	**manure N**	**poultry litter N**
Unprocessed	0.06	0.11	0.009	12	22	1.8
Water content halved	0.03	0.08	0.007	7	17	1.4
Dried to 4% water	0.008	0.06	0.005	2	12	1
Saving on drying to 4%	0.052	0.05	0.004	10	10	0.8

The industrial costs of processing the livestock waste are impossible to report accurately, given the scarcity of data. However, it is likely that fertiliser manufacturers would be able to adopt technology developed in the sewage sludge or food processing sectors, and would gradually take over the processing and distribution of livestock wastes. In order to provide rough cost estimates for manure processing and distribution, a simple scenario for manure handling was developed. Raw livestock waste is collected from the farm and transported 50 km to a processing plant. The waste is stored, dried, and then transported 100 km to the point of application.

The amount of processed manure will be driven by the demand for N to replace the inorganic N no longer applied, shown in Table 8.14. Thus, in 2000 there will be a demand for 1,821 kt manure-N, 2,882 kt manure-N will be needed by 2005, 3,706 kt by 2010, and 3,991 kt by 2020.

The 1994 baseline figures for the EU15 livestock herd, and the IPCC default values for the proportion of manure from each livestock category handled in particular waste handling systems were used to characterise the amounts of manure-N produced and handled as slurry, farmyard manure and poultry litter. IPCC daily spread systems and solid storage and drylot were treated as manure. IPCC ‘other handling system’ was assumed to be poultry litter, as over 80% of poultry N is handled in this category. Manure-N deposited in the pasture, range or paddock was discounted from this calculation, as it is not available for transport and application elsewhere.

In 1994, EU15 livestock produced 11730 kt manure-N, of which 8131 kt was handled and available for transport (excluding pasture range & paddock). Of the available manure-N, 5311 kt was produced as slurry, 1686 kt was manure, and 1134 kt was poultry litter. The relative ratio between the manure systems of 65%, 21% and 14% is assumed to remain constant over the time period considered.

The estimated cost of processing the manure was based on a Dutch study of the costs of treating pig slurry (van de Kamp & Smart, 1993). The researchers estimated that treating pig slurry costs 30-45 Dutch guilders/t. Taking the median figure of 37 NLG, this is equivalent to 17 ECU/t. This figure is based on processing costs alone (the most important factor being energy costs) and so does not include the annualised capital cost of the equipment. Hence, it represents an underestimate of the total processing costs. The figure is assumed to include a reasonable overhead for the processor.

Storage costs were based on an estimated cost of slurry storage at £2.24/t/yr (ETSU, 1996). This is equivalent to 2.71 ECU/t/yr. No estimate of the costs of solid stores or 'other' (presumably mostly poultry litter or deep pit systems) was available, and so costs were assumed to be half those of slurry systems (1.36 ECU/t/yr), as slurry requires specialist robust tanks, and solid systems were thought to be less demanding. Storage capacity was assumed to be 25% of the total volume of raw manure handled.

Table 8.16 shows the associated costs for transporting, storing, and processing the manure according to the assumptions above. Processing is clearly the most expensive part of the system, accounting for 97% of the costs. Total costs for transporting, storing, processing and delivering all the manure needed in EU15 were estimated as 12, 273 M ECU in the year 2000, 19,043 M ECU by 2005, 24, 368 M ECU by 2010, and 26, 115 M ECU by 2020

The cost of manure-N under this pricing system is 6.7 ECU/kg manure-N in 2000, falling slightly to 6.5 ECU/kg in 2020. (The price decreases because less has to be spent annually on additional storage facilities, after the capital investments in the first years.) This means that on average manure is relatively much more expensive than fertiliser-N, which is estimated at 1.54 ECU/kg. If the price of fertiliser N is made of the same elements, i.e. transport, storage and processing, then the price differential between the two times the quantity of manure N used instead of fertile N, can be interpreted as the cost of the measure to farmers. The net savings on fertiliser limits would also need to be considered.

The relative costs of the particular manure types used in this analysis are determined by their N contents. Poultry manure, with it's very high untreated N content (19.75 kg N/t) is very economical to use, with a price of 0.88 ECU/kg N in 2000, falling to 0.86 ECU/kg N in 2020. Conversely, manure, with a low starting N content of 1.5 kg N/t, works out the most expensive option, with an estimated price of 11.6 ECU/kg N in 2000, falling to 11.4 ECU/kg N in 2020. Slurry is intermediate between the two, costing 6.4 ECU/kg in 2000 and 6.2 in 2020. This is the most relevant costing for farmers, as most manure-N is produced as slurry, and this would be the largest source of processed manure-N.

Processing costs are assumed to remain stable during the time period used in this study. However, in reality, costs are expected to decrease significantly as the industry evolves. Harvesting of valuable manure components, such as acetic acid and steroids, is also expected to be developed (van de Kamp & Smart, 1993). This may improve the gross margins for the processor, reducing the level of costs borne by the farmer. These points mean that future prices for manure-N are likely to be lower than those estimated here.

Table 8.16 Transport, Storage And Processing Costs Arising From Substituting Manure-N For Fertiliser-N

Manure	N requirement		Transport (raw, 50 km)		Storage			Processing		Transport (processed;		Total	Cost of manure	
	kt N	Total manure kt	ECU/kt N/km	k ECU total	ECU/t/yr	Capacity increase kt	k ECU total	ECU/t	k ECU total	ECU/kt N/km	k ECU total	k ECU	ECU/t manure	ECU/kg N
2000														
slurry	1184	430545	60	7104	2.75	107636	296000	17	7319273	8	1894	7624271	17.71	6.44
manure	382	254667	110	4202	1.36	63667	86587	17	4329333	60	4584	4424706	17.37	11.58
poultry	255	12911	9	230	1.36	3228	4390	17	219494	5	255	224368	17.38	0.88
total	1821	698124		11536		174531	386977		11868100		6733	12273345	17.58	6.74
2005														
slurry	1874	681455	60	11244	2.75	62727	172500	17	11584727	8	2998	11771470	17.27	6.28
manure	605	403333	110	6655	1.36	37167	50547	17	6856667	60	7260	6921128	17.16	11.44
poultry	403	20405	9	363	1.36	1873	2548	17	346886	5	403	350200	17.16	0.87
total	2882	1105193		18262		101767	225595		18788280		10661	19042798	17.23	6.61
2010														
slurry	2409	876000	60	14454	2.75	48636	133750	17	14892000	8	3854	15044058	17.17	6.24
manure	778	518667	110	8558	1.36	28833	39213	17	8817333	60	9336	8874441	17.11	11.41
poultry	519	26278	9	467	1.36	1468	1997	17	446734	5	519	449717	17.11	0.87
total	3706	1420945		23479		78938	174960		24156068		13709	24368216	17.15	6.58
2020														
slurry	2594	943273	60	15564	2.75	16818	46250	17	16035636	8	4150	16101601	17.07	6.21
manure	838	558667	110	9218	1.36	10000	13600	17	9497333	60	10056	9530207	17.06	11.37
poultry	559	28304	9	503	1.36	506	689	17	481165	5	559	482915	17.06	0.86
total	3991	1530243		25285		27325	60539		26014134		14765	26114723	17.07	6.54

Total Net Cost of Measure to Farmer

The net cost to the farmer and the cost-effectiveness of the measure is shown in Table 8.17.

Table 8.17 Cost-effectiveness of Limiting Inorganic Fertiliser N Applications

Year	**2000**	**2010**	**2020**
N requirement (kt N)	1,821	3,706	3,991
Saving from reduction in inorganic fertiliser application (M ECU)	-2,804	-5,707	-6,146
Cost of transport, storage and processing of manure (M ECU)	12,273	24,368	26,115
Net cost	9,469	18,661	19,969
Reduction in emissions	68.45	126.1	158
Cost-effectiveness of option ECU/t	138,330	148,020	126,550

8.5.3.2 Cost of seasonal ban on N applications

Imposed restrictions on the timing of fertiliser and manure applications would require greater waste storage capacities, with the additional costs associated with this. It is possible that the capital costs faced by farmers in establishing such facilities will be covered by the EU as a one-off payment ‘set-up’ grant. However, this would be repaid in full after an appropriate period of time, and thus still represents a cost to the farmer.

The seasonal restriction on N applications will have few cost implications for inorganic fertiliser, but may have an impact on manure storage times. Livestock farmers will need to be able to store livestock wastes throughout the closed application season. The scenario construction assumes that farmers in EU15 have on average five month’ manure storage capacity, and that this will have to be increased by one month to six month’s capacity. This will only apply to the animal waste management systems that involve storage, which in the IPCC terminology are liquid systems, solid stores, and others.

Table 8.18 shows the additional amounts of manure to be stored and the associated costs for each system. The main contributors for slurry systems are cattle and pigs; solid system manure is mostly dairy, and ‘other’ derives from poultry, beef cattle and pigs. The N contents of the manure are as assumed above. The quantities of manure produced are the figures for 2000 in the *Package of Options* scenario. The costs of increased storage are only incurred once, for the year the closed application season is introduced. Slurry storage is estimated to cost £2.24/t/yr, equivalent to 2.71 ECU, with costs for solid storage systems assumed to be half those of slurry systems (1.36 ECU/t/yr).

Table 8.18 Additional Manure Storage Capacity And Associated Costs Resulting From The Seasonal Ban On N Applications

	Manure produced (kt N)	Weight of manure (kt)	Starting storage capacity 5 mths (kt)	Increase in storage capacity 1 mth (kt)	Cost of storage (ECU /t/yr)	Cost of increased storage requirement (M ECU)
Slurry store	5,036	1,831,444	763,101	152,620	2.7	414
Farmyard Manure	499	332,620	138,591	27,718	1.4	38
Other store	1,169	59,167	24,651	4,931	1.4	7
Total						**459**

The reduction in N_2O emissions in 2020 associated with the application of seasonal bans on fertiliser applications was estimated to be 67.9 kt of N_2O. The cost effectiveness of this measure is therefore 6,750 ECU/t N_2O.

9. Projections of Future Emissions

Two sets of projections of N_2O emissions to 2020 are made. The first, a Business-as-Usual Scenario is based on existing trends but takes account wherever possible of measures, reported in Member States' National Communications, which Member States are proposing to implement. This is set out in Section 9.1. Reductions offered by the measures described in Sections 5 to 7, and their cost-effectiveness are summarised and discussed in Section 9.2. Section 9.3 sets out two 'with measures' scenarios, which show the impact of the measures in reducing emissions.

9.1 'BUSINESS AS USUAL' SCENARIO

The 'business as usual' scenario, takes account of existing legislation and policies which are already being implemented by Member States as described in their national communications. The assumptions made for each sector in developing the business as usual scenario are outlined below. The starting point for emissions from each sector is taken from submissions made by Member States and the EU to the FCCC, as set out in Section 3.

9.1.1 Agriculture

Emissions from agriculture were estimated using the model described in Section 5 and Appendix 3.

Background trends in crop areas and livestock numbers were based on projections developed by the European Commission (European Commission, 1997). EC trends estimated up to 2005 were projected forwards to 2020, using a power trendline which calculated the least squares fit through the points. The projections are quantified in Table 9.1. The figures represent percentage changes relative to the baseline year 1994. These projections are based on long-term market and production fluctuations and supply/demand trends, and are assumed to underlie the effects of policy decisions taken at the CAP level.

Table 9.1 Estimated Background Trends (Relative to 1994)

	2000	2005	2010	2020
Cereals (yield)	+8.6%	+15.7%	+22.4%	+36.4%
Other crops (yield)	+10.7%	+12.2%	+17.6%	+28.6%
Non-dairy cattle	-6.5%	-1.9%	+0.1%	+4.1%
Dairy cattle	-10%	-18.5%	-27.2%	-44.2%
Poultry	+15%	+27%	+30.4%	+49.4%
Sheep	-3.9%	-4.0%	-2.0%	0%
Pigs	+5.4%	+9.0%	+12.8%	+20.8%
Other livestock	+5.5%	+10.9%	+13.7%	+23.4%

On top of these background trends, the following assumptions were made about future agricultural practices:

- The principal change concerns the set-aside requirement which is reduced in line with current policy statements from 15% in 1994 to 0% by 2005.
- The agri-environment schemes that have already been implemented between 1994 and 1997 are included, but no new uptake is assumed after 1997.
- In the absence of reliable published information, restrictions on fertiliser use are based on expert judgement. The amount of N used per crop type is considered to decrease by 2% (for each projection year), and sheep and beef herd sizes are considered to decrease by 1% (for each projection year). Furthermore, the implementation of NVZs are considered to reduce nitrogen use and leaching losses by 5%.
- The effects of research and development, of technology transfer and of consumer influences are expected to continue to increase, as there is a lag time between the development of new approaches and their uptake at the farm level. Subsequent changes in fertiliser management were considered (based on expert judgement) to reduce nitrogen use by between 1 and 10% (over the projection years) and the N_2O emission factor by between 1 and 4%.
- Improvements in manure and livestock management are considered to reduce nitrogen use in grassland systems by between 5 and 10% (for 2010 and 2020), reduce nitrogen volatilisation from manures by between 2 and 5%, reduce leaching losses by between 5 and 10% and reduce manure production in pig and dairy systems by between 2 and 5%. Once again, due to the absence of published sources of information, quantification of these effects is based on expert judgement. The greater potential for nitrogen savings from manure management (as opposed to fertiliser nitrogen which is already used relatively efficiently) is reflected in these figures.

The emissions predicted by the agricultural model for 1994 (the start year for the model) are 20% higher than those reported by Member States (Section 3). This may be due to the fact that not all Member Sates had used the revised IPCC methodology (which uses a higher emission factor for N_2O produced from nitrogen applications) to estimate emissions.. In order to have a consistent time trend the emissions predicted by the agricultural model have been used for 1994 and all years onwards. 1990 emissions for each Member State were produced by scaling the 1994 model prediction by the ratio between the reported 1990 and 1994 emissions.

The emissions estimated by the agricultural model which are included in the Business as Usual Projection are shown in Table 9.2. The fall in emissions with time is caused by several factors; the most important of which are, a reduction in fertiliser use between 1990 and 1994, and measures to reduce leaching and the agri-environmental schemes. More details on assumptions made in the model are given in Appendix 3.

Table 9.2 Projected Agricultural N_2O Emissions in EU15

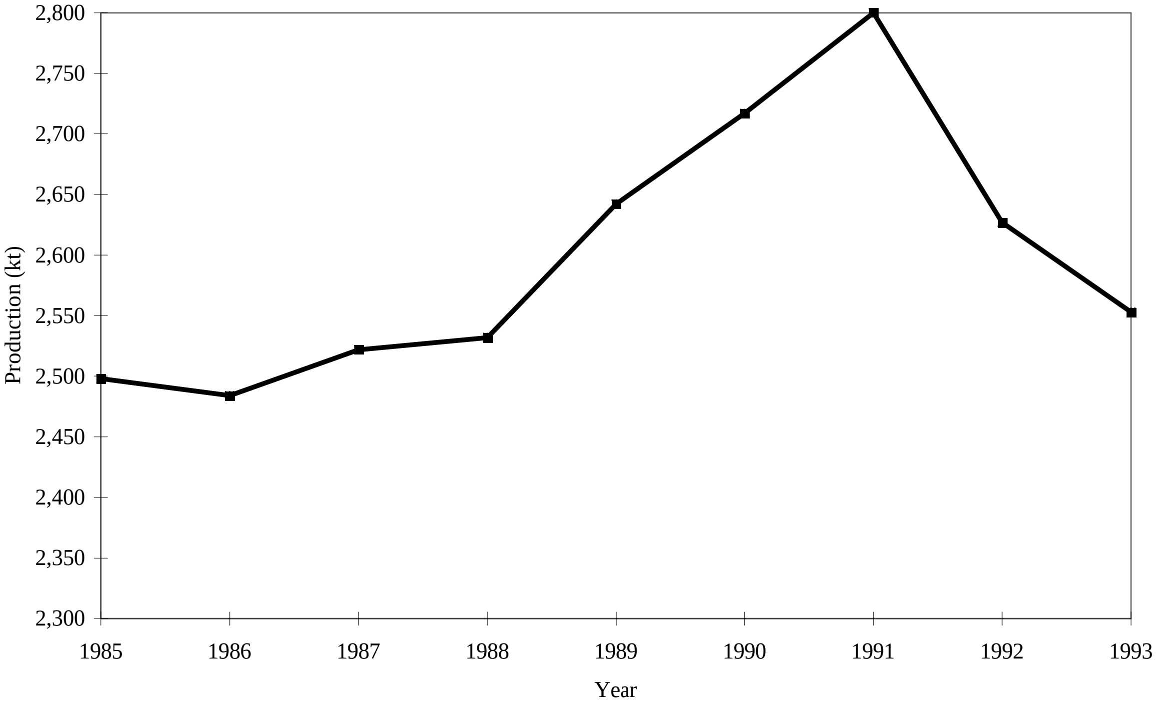
Year	kt of N_2O	Change from 1990
1990	612	
1994	581	-5%
2000	564	-8%
2005	573	-6%
2010	554	-9%
2020	538	-12%

9.1.2 Adipic and Nitric Acid Manufacture.

In the case of **adipic acid** manufacture, the plans of the major manufacturers to abate emissions by installing end-of pipe technology have been included in the business as usual scenario; i.e. it is assumed that these are all firm plans. The smallest manufacturer is assumed to have no plans to reduce emissions under this scenario.

The principal use of adipic acid is for the production of the synthetic fibre nylon 6,6, which is mainly used in carpet production. As no estimates of future adipic acid production were available, estimates were based on projected trends in the synthetic fibres market. EU production of synthetic fibres (excluding cellulosic fibres) from 1986 to 1993 is shown in Figure 9.1; production rose by an annual average of 2.3% between 1984 and 1991, but then fell by an average of 4.5% p.a. between 1991 and 1993 due to a downturn in the textiles and clothing and automotive industries, which were hit by a combination of recession and structural change. The EU fibres industry is expected to perform slightly better in the 1995-97 period, with nylon production overall increasing by about 5% yearly. Demand from the industry's main clients is expected to improve in the second half of the decade, with prospects for carpets looking healthy (EC/EUROSTAT, 1995). However set against this is the fact that companies face increasing competition from other parts of the world particularly the newly industrialised countries in Southeast Asia (imports of fibres increased by 5.9% p.a. on average between 1984 and 1993, and exports declined). Overall, it has been assumed that the production of adipic acid regains 1990 levels by 2000, and that from 2000 onwards, production increases by 1% per annum - this is about half the rate of increase in GDP forecast under the Conventional Wisdom scenario in the DGXVII projections of future energy use "European Energy to 2020" (European Commission DGXVII, 1996). Emissions from this process thus fall substantially by 2000 due to the introduction of abatement techniques, and then rise slightly as production levels increase.

Figure 9.1 Synthetic Fibres Production in the EU, 1986-93



Source: EC/EUROSTAT, 1995

The main use for **nitric acid** is in fertiliser manufacture, and trends in acid production have therefore been based on the trends in the consumption of nitrogenous fertiliser which were determined by estimating agricultural emissions (shown in Table 9.3 below). This approach assumes that the proportion of the fertiliser market supplied by imports remains constant.

It is assumed that the reduction in nitric acid emissions planned in France and Germany is achieved.

Table 9.3 Projections of Nitrogenous Fertiliser Use in the EU

Year	Projected inorganic fertiliser use (kt N)	Use relative to 1994
1994	10980	100%
1995	11045	101%
2000	11080	101%
2005	11142	101%
2010	11120	101%
2020	11184	102%

9.1.3 Transport

As discussed earlier, emissions from road transport are expected to grow significantly due to the introduction of catalytic converters. In order to estimate the penetration of catalytic converters into the vehicle fleet in Europe, a vehicle stock model was developed, based on data on new registrations of petrol and diesel cars, and stock size. For each Member State, the model was used to predict the number of petrol cars without a catalytic converter, petrol cars with a catalytic converter and diesel cars, for each year up to 2020. The differing vehicle stock turnover rates and differing average age of vehicles in each country were taken account of, as was the earlier dates of introduction of catalytic converters into some Member States. Increases in vehicle mileage were based on the annual rate of increase in transport fuel use predicted in the Conventional Wisdom Scenario in DGXVII's study European Energy to 2020. Four assumptions were made; firstly that the increase in transport energy use was evenly spread across all transport sectors, secondly that the increase in vehicle kilometres was directly proportional to increases in transport energy use (i.e. there were no gains in the fuel efficiency of cars), thirdly that the annual mileage for a car was not affected by its age, and fourthly that emissions of N_2O were not affected by the age of the catalyst. Emissions from the remainder of the vehicle fleet were forecast using country -specific GDP factors derived from the Energy in Europe study, the main assumption being that freight vehicle movements will be directly related to GDP. More details of the transport model used to derive emissions are given in Appendix 6.

Overall emissions from the road transport sector rise significantly between 1990 and 2000, as the proportion of petrol cars equipped with catalytic converters almost triples. By 2010 petrol cars without catalytic converter are forecast to form less than 1% of the vehicle fleet and subsequent rises in emissions are due to increases in vehicle mileage.

Emissions from mobile sources and machinery (off-road vehicles, railways, inland and coastal shipping etc.) were less than 1% of total emissions in 1994, the simple assumption was made that N_2O emissions were proportional to vehicle kilometres for these modes of transport, and that vehicle kilometres would rise in line with GDP.

9.1.4 Other energy related emissions

Forecasts of emissions from the energy industry, combustion in industry and combustion in the commercial and residential sectors were taken from the pre-Kyoto Scenario of DGXVII's projections of energy use in Europe, and adjusted to be consistent with reported emissions from these sectors in 1990 and 1994. The pre-Kyoto scenario envisages a steady increase in electricity demand, which requires an increase in generating capacity. This increase in generating capacity is largely met by gas, which has lower N_2O emissions than coal or oil fired plants. Of the new coal fired plants which are introduced, these are assumed to be either conventional type stations, or in the case of new thermal technologies, predominantly Integrated Gasification Combined Cycle Plants. A large build of fluidised bed combustion plants, which have significantly higher emissions is not forecast. Emissions per unit of electricity production over the period thus fall, largely offsetting the increase in electricity production until 2010, when emissions begin to rise. In the two other combustion sectors, a similar switch away from coal (and to some extent oil) to gas compensates for increasing demand and keeps emissions fairly steady.

9.1.5 Emissions from other sectors

The four remaining sources, land use change and forestry, solvent use, waste treatment and disposal, and 'other' emissions together accounted for 6% of total emissions in 1994. In the case of land use change and forestry, reported emissions occur from 'other land use change activities' in France and Italy. Due to a lack of information on the precise nature of its source, emissions have been assumed to remain constant in the future. The predominant source of emissions from solvent use is N_2O used for medical purposes (for pain relief and anaesthesia) reported by Germany. It was assumed these would increase in direct proportion to population growth. Emissions in the waste treatment and disposal sector arise mainly from waste water treatment; and to a lesser degree from waste incineration. Again future emissions from these sources were assumed to vary with population growth. Due to a lack of information on the source of 'other' emissions, these were assumed to remain constant in the future.

9.1.6 Total Emissions

The results of the forecast made for the Business-As-Usual scenario are shown in Table 9.4 and Figure 9.2. Changes from 1990 are shown in Table 9.5.

By 2000, emissions are projected to fall by 18% (221 kt) from 1990. This is mainly due to a significant fall (of 221 kt) in emissions from production processes resulting from the installation of abatement equipment at the main adipic acid manufacturing plants. There is also a fall (of 49 kt) in agricultural emissions, and a small fall (of 10 kt) in emissions from the energy industry due to fuel switching from coal to gas. These falls are partially offset by an increase in emissions (of 59 kt) from road transport, due to the increased penetration of catalytic converters.

After 2000, emissions begin to rise again, due mainly to an increase in emissions from transport; emissions from agriculture increase to 2005 as set aside is reduced and the cultivated area is increased, but fall again after this as yield improvements etc. lead to a reduction in fertiliser application rates. By 2010, emissions overall are still 15% below 1990 levels. Between 2010 and 2020, small increases in several sectors (production processes, energy industry and road transport) due to increased production and demand contribute to an overall increase in emissions. By 2020 however, emissions are still projected to be 12% below 1990 levels, due mainly to the large reductions achieved from the installation of abatement equipment on adipic acid plants.

Figure 9.2 Future N_2O Emissions in the EU15 under the Business as Usual Scenario (kt)

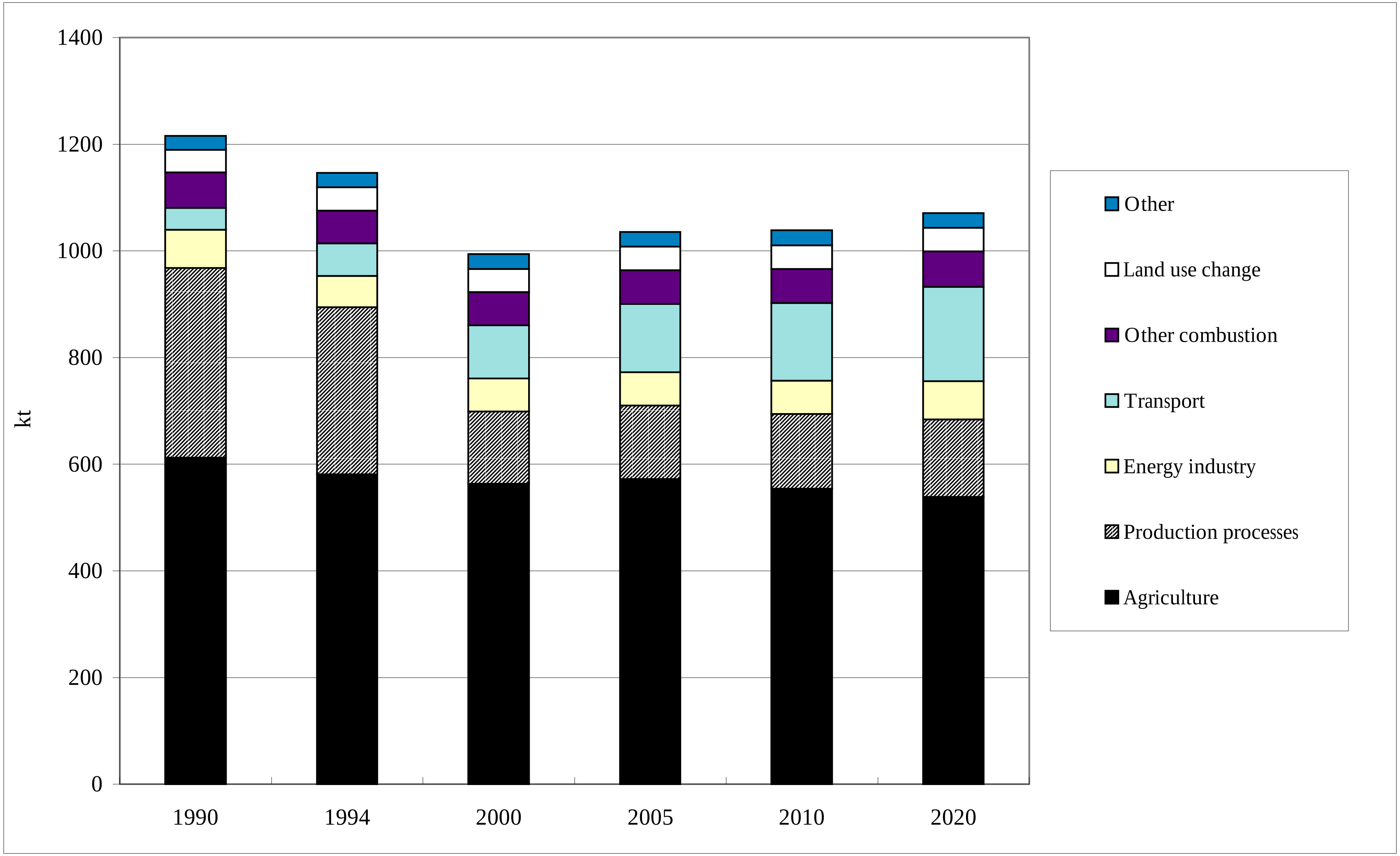


Table 9.4 Future N_2O Emissions under the 'Business as Usual' Scenario (kt)

Source	1990	1994	2000	2005	2010	2020
Agriculture	612	581	564	573	554	538
Production processes	356	313	135	137	140	145
Energy industry	72	59	62	62	62	72
Transport	41	61	100	128	146	176
Industrial combustion	30	28	29	30	30	31
Other combustion	36	33	33	34	34	36
Land use change and forestry	42	44	44	44	44	44
Solvent use	9	9	10	10	10	10
Waste treatment and disposal	12	13	13	13	13	13
Other	4	5	5	5	5	5
Total	1215	1147	994	1035	1039	1071
Percentage change from 1990		-6%	-18%	-15%	-15%	-12%

Table 9.5 Changes in N_2O Emissions under the 'Business as Usual' Scenario (kt)

Source	**1994**	**2000**	**2005**	**2010**	**2020**
Agriculture	-32	-49	-40	-58	-74
Production processes	-42	-221	-218	-216	-210
Energy industry	-13	-10	-9	-10	0
Transport	20	59	87	105	136
Industrial combustion	-2	-2	-1	-1	0
Other combustion	-3	-3	-3	-2	0
Land use change and forestry	2	2	2	2	2
Solvent use	0	0	0	1	0
Waste treatment and disposal	1	1	1	1	1
Other	1	1	1	1	1
Total	-69	-221	-180	-177	-144
Percentage change from 1990	-6%	-18%	-13%	-13%	-9%

9.2 COST-EFFECTIVENESS AND APPLICABILITY OF MEASURES

The main measures which were identified are summarised briefly below, together with a description of how the reductions they might achieve has been estimated. The cost effectiveness of the measures and the reductions which might be achieved (compared to the Business as Usual Scenario) is shown in Table 9.6. For comparison, modelling work carried out previously for the European Commission has indicated that the marginal cost of measures to achieve a 15% CO_2 reductions is 55 to 165 ECU/t CO_2 (1990 ECU) (Klassen, 1997). This is equivalent to a cost of about 62 to 185 ECU/t CO2 (1995 ECU) or 19 200 to 57 500 ECU/t N_2O (1995 ECU).

Table 9.6 Reductions achieved by Measures compared to Business as Usual Scenario

Sector	**Measure**	**Cost Effectiveness**		**Reduction (kt of N_2O)**	
		ECU/t N_2O	**ECU/t CO_2-equiv**	**2010**	**2020**
Adipic acid production	End of pipe technology	37 (29-46)	0.1 (0.1 to 0.1)	23	26
Nitric acid production	Use of NSCR	43 (25-318)	0.1 (0.1 to 1)	16	32
Nitric acid production	Catalytic destruction	42 (26-325)	0.1 (0.1 to 1)		*included above*
Fluidised bed combustion	Gas afterburner	1107 (837 to 1287)	4 (3 to 4)	*See text*	
	Reversed air staging	996	3	*See text*	
CO_2 Reduction Measures					
Industry	Energy efficiency	*See text*		5	5
Domestic/commercial	Energy efficiency	*See text*		5	5
Energy Industry	Renewables	*See text*		6	6
Road transport	Inter-modal shift	*See text*		10	10
Agriculture	‘Package of Options’	*See text*		114	120
Total				**179**	**204**

The following assumptions were made regarding the applicability of the measures identified;

- ***Adipic acid manufacture***; end of pipe technology is already being installed by the three main manufacturers; it is assumed that the remaining manufacturer installs abatement technology (either thermal or catalytic destruction) by 2005.
- ***Nitric acid manufacture***: data was not available to assess accurately the applicability of the measures identified for this sector (use of NSCR in preference to SCR and catalytic destruction). A preliminary assumption is made that an 80% reduction in emissions can be achieved and that this is achieved on 30% of production by 2010 and 60% of production by 2020.
- ***Fluidised bed combustion:*** the pre-Kyoto energy scenario which is used as the basis of the energy related emissions in business-as-usual scenario does not predict an uptake of this clean coal technology, so this mitigation option would not be implemented.
- ***CO_2 Reduction Measures***: these measures implemented to reduce CO_2 emissions (introduction of renewable energy, energy efficiency in the industrial and tertiary sectors and intermodal shift in the transport sector) will also have a beneficial effect on N_2O emissions. They are all assumed to be implemented between 2000 and 2010. Reductions in N_2O emissions based on the estimated CO_2 reductions available from these measures are estimated as described in Section 7. In total it has been estimated that these measures can reduce CO_2 emissions by 350 Mt; the total reduction in N_2O emissions achieved by these measures is estimated as 25.7 kt of N_2O which is equivalent to 8 Mt of CO_2, i.e. the effectiveness of these measures is increased by about 2% if the reduction in N_2O emissions is taken into account. The cost effectiveness of these CO_2 reduction measures is not reported, so a calculation of their cost-effectiveness in terms of reducing N_2O emissions is not possible. However if the cost of the measure is spread across both N_2O and CO_2 reductions (weighted by their GWPs) then the marginal cost per tonne of the N_2O (and CO_2) would be slightly less than the cost-effectiveness of the measure calculated in terms of its CO_2 reduction only. The marginal costs estimated for a 15% CO_2 reduction (of 62 to 185 ECU/t CO_2) would therefore be an upper limit for the cost of these reductions, although it is likely that a significant proportion of the reductions would be achieved at lower costs.
- ***Agricultural sector:*** it is assumed that the measures identified under the ‘package of options’ described in Section 5 are implemented and achieve the reductions estimated in Section 5. The package of options contained a number of wide sweeping changes in policy and farming practice, as the modelling work carried out showed that such wide sweeping changes were likely to be necessary if agricultural N_2O emissions were to be significantly reduced. The main measures considered were the reduction of price support and provision of direct subsidies for marginal land, limits on the top rates of inorganic fertiliser application, (with substitution of manures for inorganic fertilisers) and limits on the timing of fertilisers and manure applications. As discussed in Section 8, the wide sweeping nature of the policy options means that it is not possible to estimate in the same way as for other technical options the costs of these measures, particularly those relating to changes in CAP (such as the removal of price support and phasing in of a marginal land subsidy) which are likely to have macro-economic impacts. Indicative costs to the farmer were estimated for limiting inorganic fertiliser N applications as 127,000 to 148,000 ECU/t N_2O (410 to 480 ECU/t CO_2-equivalent) and for a seasonal ban on N applications as 6,750 ECU/t N_2O (22 ECU/t of CO_2-equivalent). However these costs are very approximate and ignore (potentially significant) costs and benefits which might be incurred by other parties.

From Table 9.6, it can be seen that measures to reduce emissions from adipic and nitric acid production, and from fluidised bed combustion are all relatively cost-effective, and are well below the estimated marginal cost of a 15% reduction in CO_2 emissions. Combined with reductions gained from measures aimed principally at CO_2 reductions these offer a reduction of 42 kt of N_2O (equivalent to 13 Mt of CO_2) by 2010. The package of options developed for the agricultural sector potentially offers the greatest reductions, but as discussed above the measures include relatively radical changes in CAP and in farming practice. It has only been possible to calculate very approximate costs for some of the measures in the package of options.

A number of less radical measures were considered for the agricultural sector, but due to the detailed data needed to evaluate the options an estimate of their cost and applicability has only been possible for the UK. This is summarised in Table 9.7, together with comments on the transferability of the data to other parts of Europe.

These measures which are based on more minor changes in farming practice offer substantially lower reductions. Some are relatively cost-effective, and those measures based on ensuring that nitrogen applications do not rise above the economic optimum by taking manure and residual nitrogen fully into account offer cost savings (even when the cost of information programmes is taken into account.) Switching from winter to spring cultivars is the most expensive option, and might anyway be disregarded on account of potential problems from increased nitrate leaching. The total estimated reduction in the UK, for these measures based on a 50 kg sub-optimal application of fertiliser N and excluding switching from spring to winter cultivars is 2.7 kt which is about 3% of UK agricultural N_2O emissions. As discussed in Section 5.6 the country specific potential of these measures will vary depending on soil types, farming practices etc.; however if as a very rough approximation it is assumed that a similar percentage reduction might be achieved in other northern and western Member States, then an overall reduction might be about 12 kt in 2010 and 2020, or about 10% of the reductions identified in the ‘package of options’ scenario.

9.3 EMISSIONS UNDER ‘WITH MEASURES’ SCENARIOS

The ‘package of options’ identified for the agricultural sector offer the greatest savings, but are potentially the most difficult to implement. Two projections are thus made, one with non-agricultural measures only implemented (Figures 9.3 and Tables 9.8), and one with all measures implemented (Figure 9.4 and Table 9.9). The scenarios are compared with the business as usual scenario in Figure 9.5.

With only non-agricultural measures implemented, emissions are projected to have fallen by 20% from 1990 levels by 2010 and to be 65 kt below those in the business as usual scenario. If the individual agricultural measures identified were implemented then emissions might fall by a further 12 kt to 21% below 1990 levels. Implementing the ‘package-of-options’ in the agricultural sector, emission are projected to fall to 29% below 1990 levels by 2010, a drop of 179 kt from emissions under the business as usual scenario.

Table 9.7 Costs and Applicability of Individual Agricultural Options in the UK

Measure	Reduction	Comment	Cost -effectiveness	
			ECU/t	ECU/t
	t of N_2O		N_2O	CO_2-equiv
Better account of manure N (wheat)	78	Not possible to extrapolate to EU as no similar data available on manure applications. Similar savings may be possible in N+W Europe (with less scope in NLs), savings less likely in S Europe.	-17 320*	-56*
Better account of manure N (potatoes)	21	As above	-17 320*	-56*
Better account of residual N (winter wheat)	280	For wheat grown in France Germany and UK (66% of EU crop) reduction might be 1.4 kt	-17 320*	-56*
Better account of residual N (barley)	14		-17 320*	-56*
Sub-optimal application of N				
to winter wheat (-50 kg)	1866	Country specific but reductions possible in N and W Europe.	15 168	49
to winter wheat (-100 kg)	3732	As above	70 652	228
to OSR (-50 kg)	369	As above	7 584	24
to OSR (-100 kg)	739	As above	16 115	52
change from winter to spring barley	495	Reduction may be offset by increased nitrate leaching from bare land over winter leading to increased emissions	80 755	261
change from winter to spring OSR	296	As above	138 810	448
Total reduction (based on 50 kg sub optimal application)	**3419**	**3% of UK agricultural emissions in 1995**		
Total reduction (based on 100 kg sub-optimal applications)	**5655**	**6% of UK agricultural emissions in 1995**		

[*] Including cost of information/awareness programmes

Figure 9.3 Future N_2O Emissions in EU15 with Non-agricultural Measures Implemented (kt)

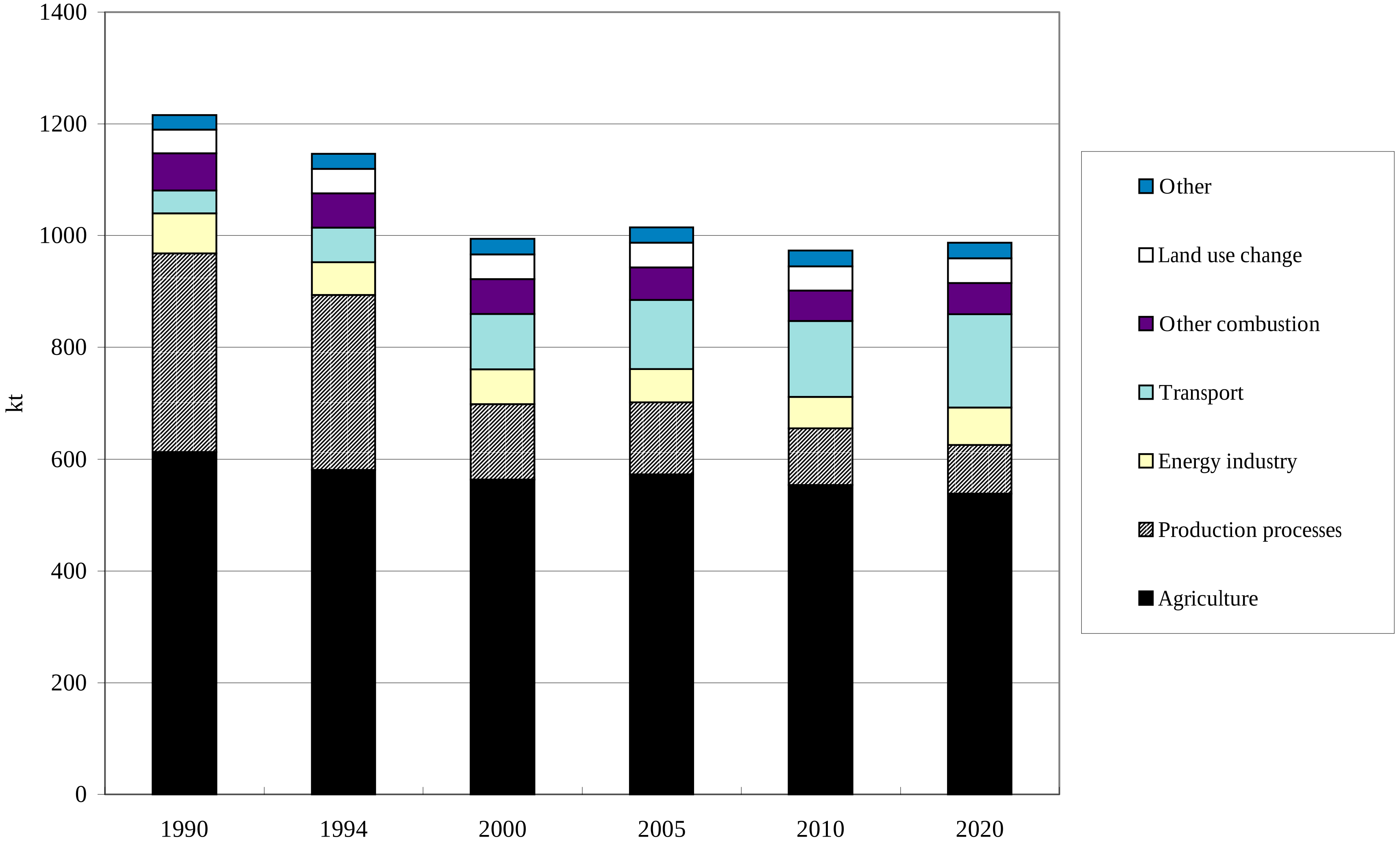


Figure 9.4 Future N_2O Emissions in EU15 with All Measures Implemented (kt)

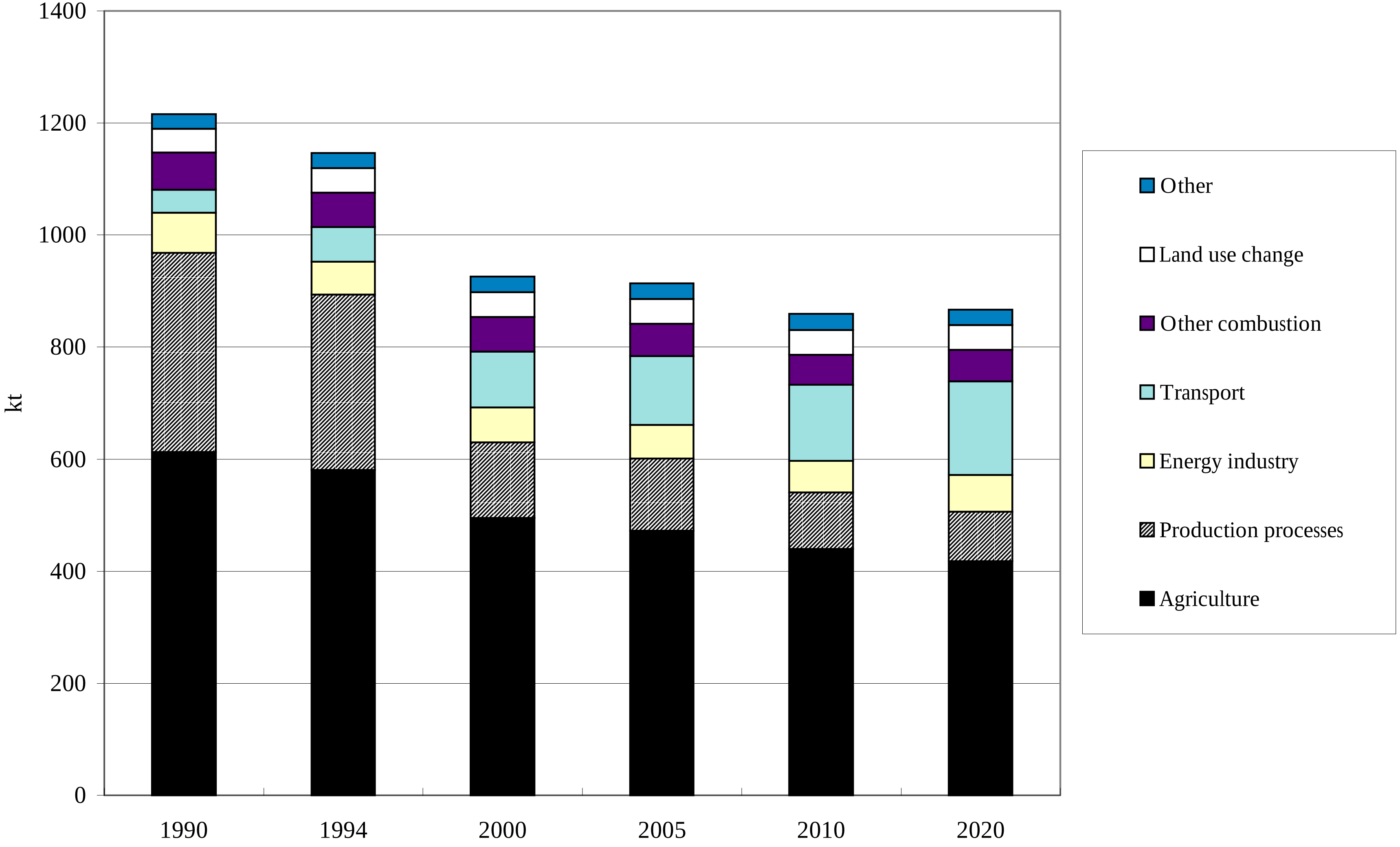


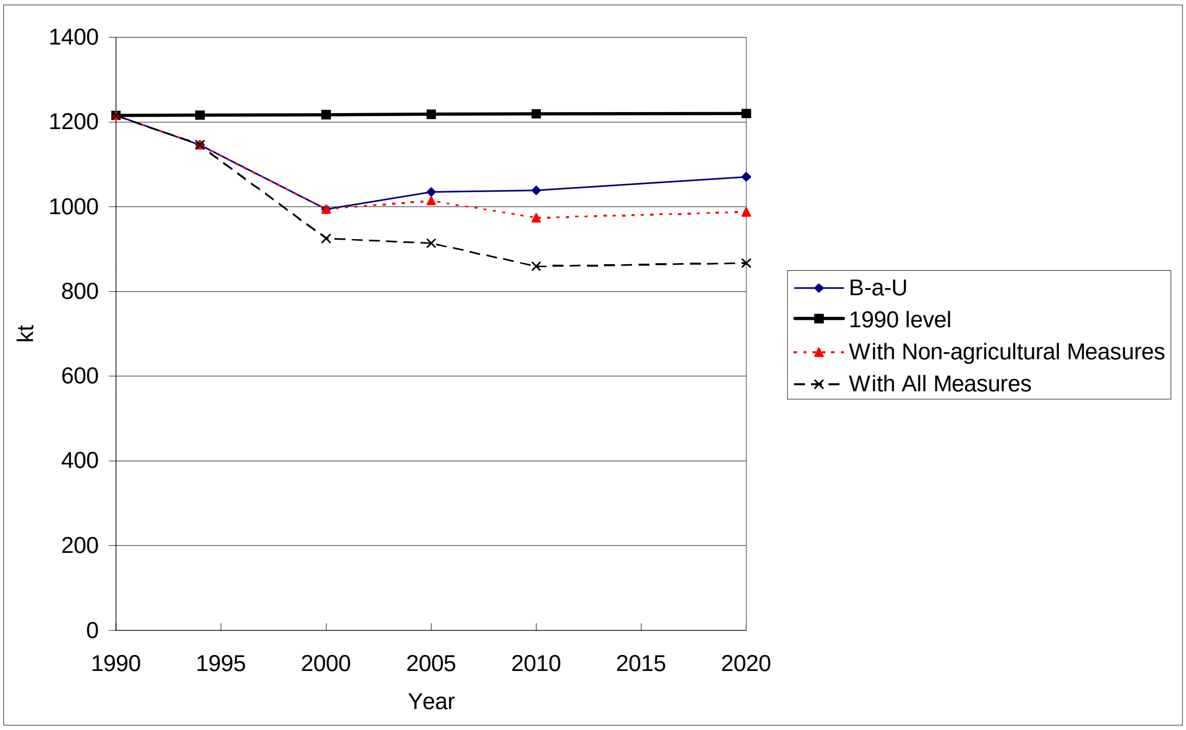
Table 9.8 Future N_2O Emissions with Non-agricultural Measures Implemented (kt)

Source	1990	1994	2000	2005	2010	2020
Agriculture	612	581	564	573	554	538
Production processes	356	313	135	129	101	87
Energy industry	72	59	62	60	57	67
Transport	41	61	100	123	136	167
Industrial combustion	30	28	29	27	25	26
Other combustion	36	33	33	31	29	31
Land use change and forestry	42	44	44	44	44	44
Solvent use	9	9	10	10	10	10
Waste treatment and disposal	12	13	13	13	13	13
Other	4	5	5	5	5	5
Total	1215	1147	994	1015	974	988
Percentage change from 1990		-6%	-18%	-17%	-20%	-19%

Table 9.9 Future N_2O Emissions with All Measures Implemented (kt)

Source	1990	1994	2000	2005	2010	2020
Agriculture	612	581	495	472	440	418
Production processes	356	313	135	129	101	87
Energy industry	72	59	62	60	57	67
Transport	41	61	100	123	136	167
Industrial combustion	30	28	29	27	25	26
Other combustion	36	33	33	31	29	31
Land use change and forestry	42	44	44	44	44	44
Solvent use	9	9	10	10	10	10
Waste treatment and disposal	12	13	13	13	13	13
Other	4	5	5	5	5	5
Total	1215	1147	925	914	859	867
Percentage change from 1990		-6%	-24%	-25%	-29%	-29%

Figure 9.5 Emissions under Business as Usual and With Measures Scenarios (kt)



10. Summary

10.1 BACKGROUND

Until recently, strategies for addressing climate change have principally been focused on reducing emissions of the main greenhouse gas carbon dioxide, but the importance of other greenhouse gases and opportunities for their abatement have been increasingly recognised in the last couple of years. This culminated in an agreement at the Conference of the Parties in Kyoto in December 1997 to set legally binding targets for reducing greenhouse gas emissions based on a ‘six gas basket’, that is targets apply to the emissions of the six greenhouse gases (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride) all weighted by their (100 year) global warming potential. The EU agreed to reduce emissions of the six gases by 8% of 1990 levels by 2010, and arrangements for sharing this reduction among Member States were agreed recently at the Environment Council in June 1998.

In February 1993, the EU in its Fifth Action Programme for the Environment “Towards Sustainability”, defined a series of actions for greenhouse gases, and in December 1994, the Environment Council asked the Commission to submit a strategy to reduce emissions of greenhouse gases other than CO_2, in particular methane and nitrous oxide.

This study for DGXI of the European Commission, considers nitrous oxide emissions within the EU and for each of the major source sectors (agriculture, adipic and nitric acid production, transport, and combustion) examines the technical feasibility of measures to reduce emissions. Wherever sufficient cost and performance data are available, the cost-effectiveness of the measures in terms of ECU (1995) per tonne of nitrous oxide abated is also estimated. The applicability of the measures is assessed to allow the calculation of achievable reductions compared to a ‘business-as-usual’ scenario to (2020), and to allow the projection of emissions under a ‘with measures’ scenario. The results for all sectors are summarised below and indicate that nitrous oxide emissions could be reduced to 20 to 29% below 1990 levels by 2010. A parallel study has been carried out on methane emissions (AEA Technology Environment, 1998) and has estimated that methane emissions could be reduced to 39% below 1990 levels by 2010.

10.2 CURRENT EMISSIONS

In 1994 it is estimated that the EU accounted for about 12% of global anthropogenic emissions of the direct greenhouse gas, nitrous oxide (N_2O). It is a potent greenhouse gas with a global warming potential (over 100 years) of 310 relative to the main greenhouse gas, carbon dioxide. EU nitrous oxide emissions of 1049 Mt in 1994, were equivalent to 10% of CO_2 emissions in that year and were thus a fairly significant contributor to total greenhouse gas emissions in the EU.

The main sources of emissions in 1994 are shown in Table 10.1. Estimates of N_2O emissions from many sources are relatively uncertain. Emissions estimates from agricultural soils have very high levels of uncertainty (perhaps two orders of magnitude), and emission factor data for combustion sources is scarce, so that emissions estimates are somewhat uncertain.

Between 1990 and 1994 emissions had already fallen by 6% due mainly to a significant decline in emissions from production processes and agriculture (12% and 5% respectively). The reduction in emissions from production processes (adipic and nitric acid production) is thought to be mainly due to a reduction in production levels. In agriculture, emissions fell mainly due to a reduction in the consumption of inorganic fertilisers. Emissions from fuel combustion also fell, due to fuel switching to gas.

Table 10.1 Sources of Nitrous Oxide Emissions in the EU (1994)

Sector	kt	%
Agriculture	484	46%
Production processes	313	30%
Transport	61	6%
Energy Industry	59	6%
Industrial combustion	28	3%
Other fuel combustion	33	3%
Land use change and forestry	44	4%
Waste	13	1%
Other	14	1%
Total	**1049**	**100%**

Source: Member States and EU Second Communications under the FCCC.

10.3 BUSINESS-AS-USUAL PROJECTIONS

Business-as-usual projections have been made for each of the main sectors as set out in Section 9. Emissions from the agricultural sector were modelled in some detail (Appendix 3) and for the EU were found to be 20% higher than those reported by Member States in their Second National Communications. This is believed to be due to the fact that not all Member States had yet adopted the revised IPCC methodology (IPCC, 1997), and in order to have a consistent timescale for agricultural emissions based on the revised methodology, the emissions calculated in the model were used for both current and future years leading to values for 1990 and 1994 which are higher than those in Table 10.1. In the case of production processes, the business as usual scenario takes account of the abatement measures Member States report will be implemented.

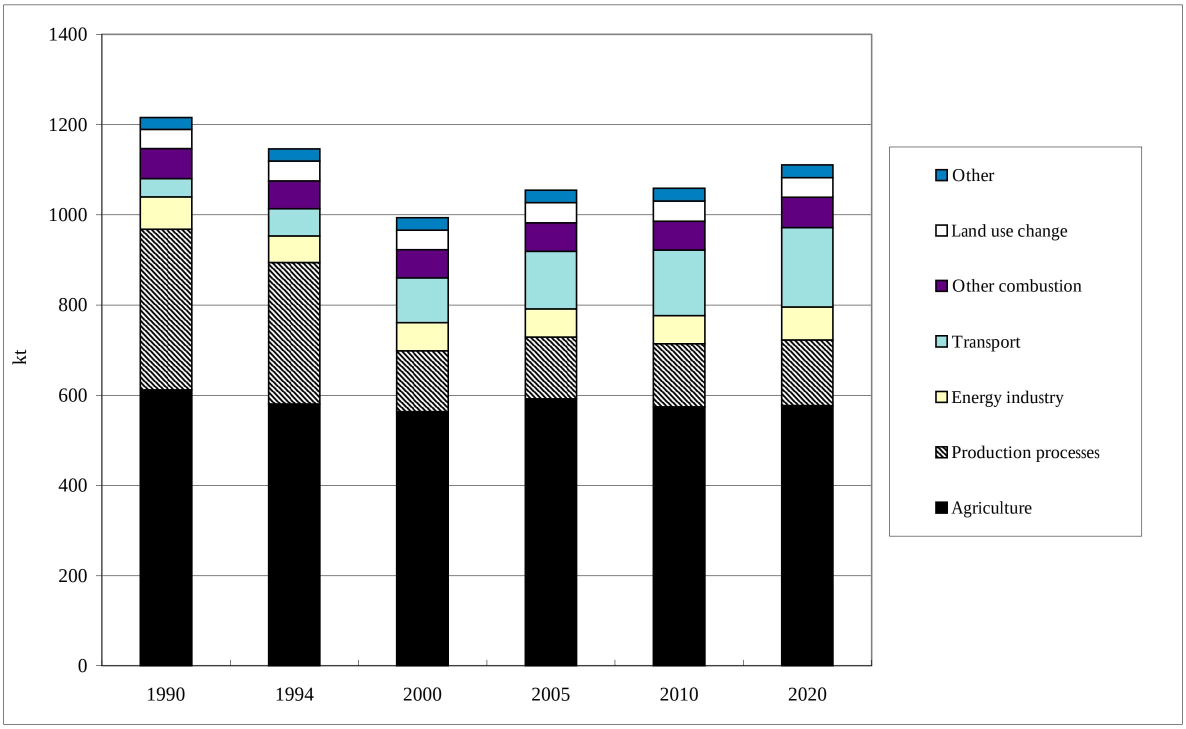
By 2000, emissions are projected to fall by 18% (221 kt) from 1990. This is mainly due to a significant fall (of 221 kt) in emissions from production processes resulting from the installation of abatement equipment at the main adipic acid manufacturing plants. There is also a fall (of 49 kt) in agricultural emissions, and a small fall (of 10 kt) in emissions from the energy industry due to fuel switching from coal to gas. These reductions are partially offset by an increase in emissions (of 59 kt) from road transport, due to the increased penetration of catalytic converters.

After 2000, emissions begin to rise again, due mainly to an increase in emissions from transport; emissions from agriculture increase to 2005 as set aside is reduced and the cultivated area is increased, but fall again after this as yield improvements etc. lead to a reduction in fertiliser application rates. By 2010, emissions overall are still 15% below 1990 levels. Between 2010 and 2020, small increases in several sectors (production processes, energy industry and road transport) due to increased production and demand contribute to an overall increase in emissions. By 2020 however, emissions are still projected to be 12% below 1990 levels, due mainly to the large reductions achieved from the installation of abatement equipment on adipic acid plants.

Table 10.2 N_2O Emissions under the Business as Usual Scenario (kt/year)

Source	1990	1994	2000	2005	2010	2020
Agriculture	612	581	564	573	554	538
Production processes	356	313	135	137	140	145
Energy industry	72	59	62	62	62	72
Transport	41	61	100	128	146	176
Industrial combustion	30	28	29	30	30	31
Other combustion	36	33	33	34	34	36
Land use change and forestry	42	44	44	44	44	44
Solvent use	9	9	10	10	10	10
Waste treatment and disposal	12	13	13	13	13	13
Other	4	5	5	5	5	5
Total	1215	1147	994	1035	1039	1071
Percentage change from 1990		-6%	-18%	-15%	-15%	-12%

Figure 10.1 N_2O Emissions under the Business as Usual Scenario (Mt/year)



10.4 MEASURES TO REDUCE EMISSIONS

Measures identified to reduce emissions are shown in Table 10.3 together with an estimate of the achievable reductions in 2010 and 2020 compared to the business-as-usual scenario. For comparison, modelling work carried out previously for the European Commission has indicated that the marginal cost of measures to achieve a 15% CO_2 reductions is 55 to 165 ECU/t CO_2 (1990 ECU) (Klassen, 1997). This is equivalent to a cost of about 62 to 185 ECU/t CO_2 (1995 ECU) or 19,200 to 57,500 ECU/t N_2O (1995 ECU).

10.4.1 Agricultural Sector

Agriculture is the largest source of N_2O emissions but the mechanisms causing release of N_2O are still relatively poorly understood, and there is a lack of knowledge on the specific effect that changes in cultivation techniques may have on emissions, which makes accurate estimation of the impact of measures difficult. This is an area where more research and development work is required to understand better the influence of a number of factors on emission rates, and to be able to extrapolate from field scale measurements to regional levels to be able to assess the impact of measures.

Given the current state of knowledge, the modelling work carried out for the study indicated that substantial changes in CAP policy and farming practice were likely to be necessary if a large reduction in emissions is to be achieved. The package of options believed to be most likely to deliver reductions was assessed. The main measures included in the package were:

- limit top rates of inorganic nitrogen fertiliser applications by the introduction of nitrogen use quotas;
- limit the timing of fertiliser and manure applications;
- reduce price support
- provide direct subsidies for marginal (extensive) land.

It should be noted that while these measures do require substantial changes in CAP and farming practice, the reduction of price support is in line with the revisions suggested under Agenda 2000 to move to a more market orientated approach, and a ban on applications of inorganic fertilisers from September to February is in line with the requirements of the Nitrate Directive for Nitrate Vulnerable Zones (NVZs) (although in the package of options the ban has a blanket coverage and is not restricted to NVZ).

The package of options is estimated to deliver reductions of 114 kt by 2010, which is 19% of agricultural emissions under the business as usual scenario. The wide sweeping nature of the policy options means that it is not possible to estimate in the same way as for other technical options the costs of these measures, particularly those relating to changes in CAP (such as the removal of price support and phasing in of a marginal land subsidy) which are likely to have macro-economic impacts. Indicative costs to the farmer were estimated for limiting inorganic fertiliser N as 127,000 to 148,000 ECU/t N_2O (410 to 480 ECU/t CO_2 equivalent) and for a seasonal ban on nitrogen applications as 6, 750 ECU/t N_2O (22 ECU/t of CO_2 equivalent). However these cost are very approximate and ignore (potentially significant) costs and benefits which might be incurred by other parties. A more accurate estimate of costs could be made using a detailed macro-economic model of the agricultural sector.

Table 10.3 Cost-effectiveness and Reductions Offered by N_2O Mitigation Options

Sector –Measure	**Cost Effectiveness**		**Reduction (kt)**	
	ECU/t N_2O	**ECU/t CO_2-eq**	**2010**	**2020**
Adipic acid production - End of pipe technology	37 (29-46)	0.1 (0.1 to 0.1)	23	26
Nitric acid production - Use of NSCR	43 (25-318)	0.1 (0.1 to 1)	16	32
Nitric acid production - Catalytic destruction	42 (26-325)	0.1 (0.1 to 1)	*included above*	
Fluidised bed combustion - Gas afterburner	1107 (837 to 1287)	4 (3 to 4)	*See text*	
Fluidised bed combustion - Reversed air staging	996	3	*See text*	
Industry - Energy efficiency	*See text*		5	5
Domestic/commercial - Energy efficiency	*See text*		5	5
Energy Industry - Renewables	*See text*		6	6
Road transport - Inter-modal shift	*See text*		10	10
Agriculture - 'Package of Options' (removal of price support, subsidies for marginal land, limits on inorganic fertiliser applications and limts on timing of fertiliser and manure applications)	See text		114	140
Total			**179**	**204**
Agriculture - Individual measures				
Take better account of manure N and residual N	-17 320*	-56*	*See text*	
Sub-optimal application of N				
to winter wheat (-50 kg)	15 168	49	*See text*	
to winter wheat (-100 kg)	70 652	228	*See text*	
to OSR (-50 kg)	7 584	24	*See text*	
to OSR (-100 kg)	16 115	52	*See text*	
change from winter to spring barley	80 755	261	*See text*	
change from winter to spring OSR	138 810	448	*See text*	

* Including cost of information/awareness programmes

A number of less radical measures were considered for the agricultural sector, and the costs of these measures are reported in Table 10.3. Some of these are relatively cost-effective, and those measures based on ensuring that nitrogen applications do not rise above the economic optimum by taking manure and residual nitrogen fully into account offer cost savings (even when the cost of information programmes to encourage this is taken into account). Switching from winter to spring cultivars is the most expensive option, and might anyway be disregarded on account of potential problems from increased nitrate leaching. Due to a lack of data it was only possible to estimate the reduction achievable from these measures for the UK; based on a 50 kg sub-optimal application of fertiliser N and excluding switching from spring to winter cultivars, the achievable reduction was about 3% of UK agricultural N_2O emissions. Using the very rough approximation that a similar percentage reduction might be achieved in other northern and western Member States, then an overall reduction might be about 12 kt in 2010 and 2020, or about 10% of the reductions identified in the ‘package of options’ scenario.

10.4.2 Production Processes

Measures to reduce emissions from adipic and nitric acid production are relatively cost-effective. Reductions of 237 kt (in 2010) are already included in the business as usual scenario as the main adipic acid manufacturers are already due to (or have) installed abatement plant. Further reductions of 39 kt are possible by abating emissions at the remaining adipic acid plant and at nitric acid plant.

10.4.3 Energy Sector

For stationary combustion sources, the main way in which emissions may be reduced is by reducing fossil fuels combustion through the introduction of energy efficiency measures and non-fossil fuel technologies such as renewables (apart from biomass combustion technologies where emissions may be higher). Based on Commission estimates of the reduction in CO_2 emissions which might be possible in these sectors (European Commission, 1997a), reductions of 16 kt in N_2O emissions in 2010 are forecast. The cost effectiveness of these CO_2 reduction measures is not reported, so a calculation of their cost-effectiveness in terms of reducing N_2O emissions is not possible. However if the cost of the measure is spread across both N_2O and CO_2 reductions (weighted by their GWPs) then the marginal cost per tonne of N_2O (and CO_2) would be slightly less than the cost-effectiveness of the measure calculated in terms of its CO_2 reduction only. The marginal costs estimated for a 15% CO_2 reduction (of 62 to 185 ECU/t CO_2) would therefore be an upper limit for the cost of these reductions, although it is likely that a significant proportion of the reductions would be achieved at lower costs.

A possible source of increased N_2O emissions in the energy sector is the use of fluidised bed combustion; however the analysis shows that it would be relatively cost effective to install abatement measures to reduce emissions from such plant.

In the transport sector, cars fitted with current three way catalytic converters produce higher N_2O emissions than those without, particularly as the catalyst ages. A priority should therefore be R&D to develop a new generation of catalytic converters which do not increase N_2O emissions. In the meantime, measures which aim to reduce passenger car mileage will also reduce N_2O emissions from transport, and the CO_2 reductions which the Commission estimate are possible from inter-modal shift in the transport sector are estimated to deliver reductions of 10 kt in N_2O emissions.

10.5 EMISSIONS UNDER A ‘WITH MEASURES’ SCENARIO

The ‘package of options’ identified for the agricultural sector offer the greatest savings, but these measures are potentially the most difficult to implement. Two projections are thus made, one with non-agricultural measures only implemented (Figure 10.2 and Table 10.4), and one with all measures implemented (Figure 10.3 and Table 10.5). With only non-agricultural measures implemented, emissions are projected to have fallen by 20% from 1990 levels by 2010 and to be 85 kt below those in the business as usual scenario. If the individual agricultural measures identified were implemented then emissions might fall by a further 12 kt to 21% below 1990 levels. Implementing the ‘package-of-options’ in the agricultural sector, emission are projected to fall to 29% below 1990 levels by 2010, a drop of 179 kt from emissions under the business as usual scenario.

Table 10.4 Future N_2O Emissions with Non-agricultural Measures Implemented (kt)

Source	1990	1994	2000	2005	2010	2020
Agriculture	612	581	564	573	554	538
Production processes	356	313	135	129	101	87
Energy industry	72	59	62	60	57	67
Transport	41	61	100	123	136	167
Industrial combustion	30	28	29	27	25	26
Other combustion	36	33	33	31	29	31
Land use change and forestry	42	44	44	44	44	44
Solvent use	9	9	10	10	10	10
Waste treatment and disposal	12	13	13	13	13	13
Other	4	5	5	5	5	5
Total	1215	1147	994	1015	974	988
Percentage change from 1990		-6%	-18%	-17%	-20%	-19%

Figure 10.3 Future N_2O Emissions with All Measures Implemented (kt)

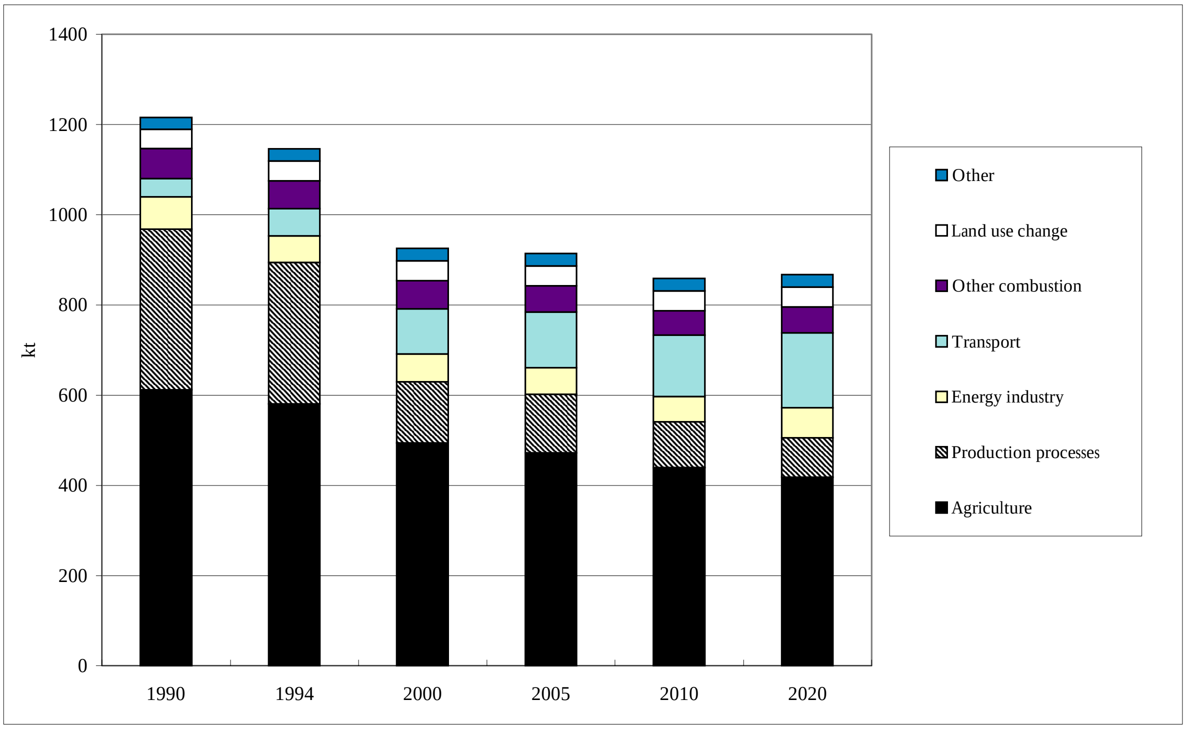


Figure 10.2 Future N_2O Emissions with Non-agricultural Measures Implemented

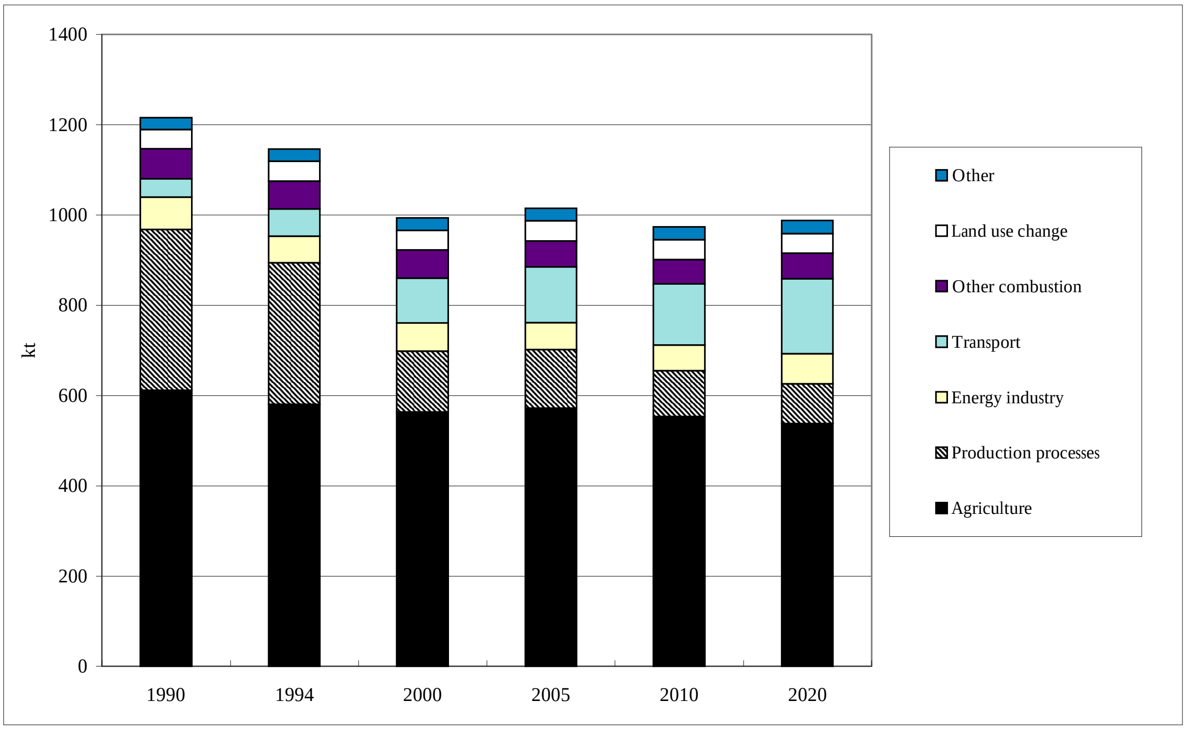


Table 10.5 Future N_2O Emissions with All Measures Implemented (kt)

Source	1990	1994	2000	2005	2010	2020
Agriculture	612	581	495	472	440	418
Production processes	356	313	135	129	101	87
Energy industry	72	59	62	60	57	67
Transport	41	61	100	123	136	167
Industrial combustion	30	28	29	27	25	26
Other combustion	36	33	33	31	29	31
Land use change and forestry	42	44	44	44	44	44
Solvent use	9	9	10	10	10	10
Waste treatment and disposal	12	13	13	13	13	13
Other	4	5	5	5	5	5
Total	1215	1147	925	914	859	867
Percentage change from 1990		-6%	-24%	-25%	-29%	-29%

10.6 COMPARISON WITH OTHER N_2O REDUCTION STUDIES

As part of an (ongoing) study for DGXI[8] led by Coherence on the economic evaluation of quantitative objectives for climate change, Ecofys have produced a report on the potential and costs of methane and nitrous oxide emissions reductions in the EU (Hendriks, de Jager and Blok, 1997). There is a significant difference in the business as usual forecasts in the two studies - the Ecofys study predicts a 9% increase in N_2O emissions by 2010, as compared to a 15% decrease in this study - but this is mainly due to the differing definitions of business as usual. The ongoing and planned instalment of abatement at the main adipic acid manufacturing plant is included in the business as usual scenario in this study and excluded in the business as usual scenario in the Ecofys study. The two studies predict broadly the same level of reduction under the with measures scenario - a 27% reduction in emissions by 2010 in the Ecofys study and a 29% reduction in this study. A paper written by Coherence identifying differences in the two studies, and suggesting a synthesis of the results is included as Appendix 7.

10.7 CONCLUSIONS

This study has examined current and future N_2O emissions in the EU, and possible measures for reducing emissions. The quantification of the impact of measures in the agricultural sector is hampered by a lack of detailed understanding of the effects of e.g. changes in cultivation techniques on N_2O emissions, particularly at the field scale, and this is an area where more research is required. Similarly while measures have been identified for the abatement of emissions from nitric acid plant, more R&D may be necessary to confirm the achievable reductions and costs. One further area where R&D might usefully be focused is in the development of a catalytic converter for vehicles which does not increase N_2O emissions from vehicles; with the continued use of current catalytic converters, emissions from this sector are predicted to more than triple by 2010, making road transport the second largest source of emissions in 2010.

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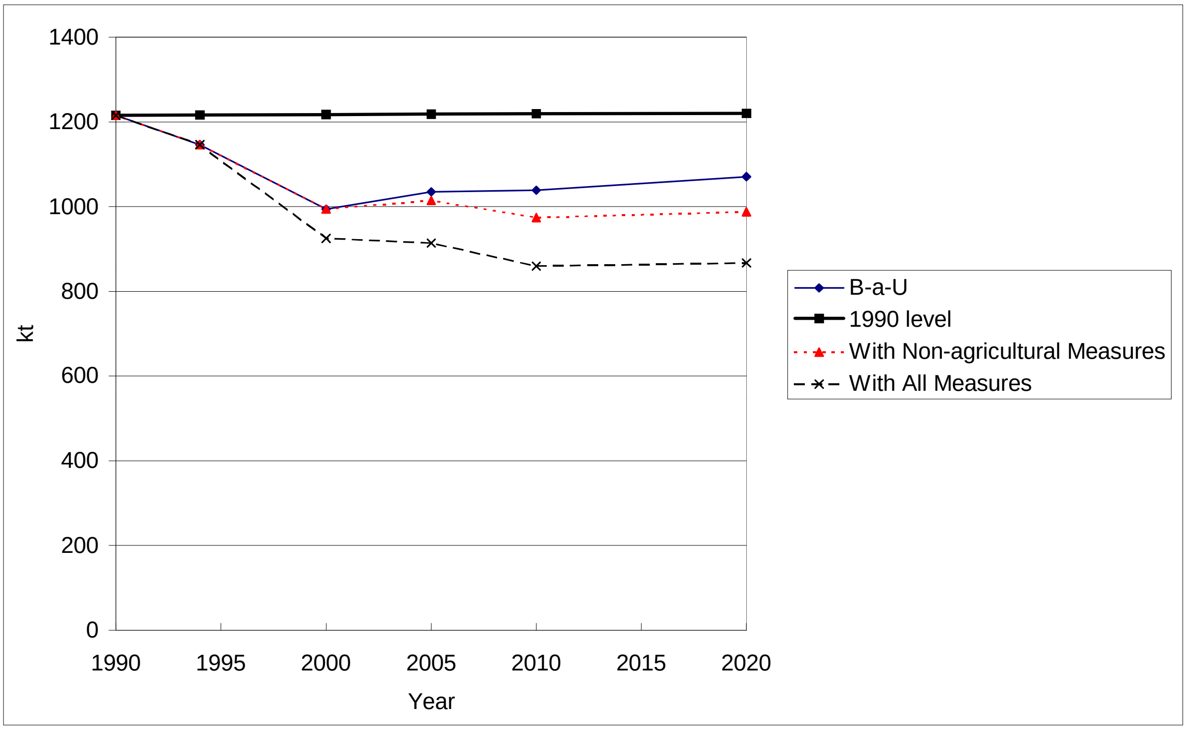
[8] This study which is led by Coherence is producing an economic evaluation of quantitative objectives for climate change (contract No B4-3030/95/000449/MAR/B1).

The cost-effectiveness and reductions of measures in each of the main source sectors has been estimated and the results combined to produce three future scenarios of emissions, shown in Figure 10.4, and described below:

- A 'business as usual scenario' which, as far as possible, takes account of the measures which Member States intend to implement. Under this scenario, emissions are forecast to be 13% below 1990 levels due mainly to the proposed installation of abatement equipment at the main adipic acid plant.
- A scenario with additional measures implemented at the remaining adipic acid plant and at nitric acid production plant, and with measures aimed mainly at reducing CO_2 emissions implemented. Under this scenario additional reductions of 65 kt are achieved; 39 kt from abating emissions from the remaining adipic acid plant and from nitric acid plant, and 26 kt as a 'by-product' of measures aimed mainly at reducing CO_2 emissions. For the purposes of the scenario the CO_2 reductions which the Commission has estimated as achievable from energy efficiency in the industrial, commercial and domestic sectors, increased use of renewables and inter-modal shift in the transport sector were assumed (European Commission, 1997a). Emissions are forecast to be 20% below 1990 levels by 2010. The cost-effectiveness of abating emissions from adipic and nitric acid plant is estimated at about 40 ECU/t N_2O (0.1 ECU/t CO_2-equivalent)
- A scenario (the 'with all measures scenario'), where in addition to the measures identified above, measures are implemented in the agricultural sector. These agricultural measures deliver a reduction of 114 kt in 2010, taking emissions to 29% below 1990 levels. The measures require some substantial changes to CAP and to farming practice, but are in line with the move to the more market orientated approach suggested under Agenda 2000. Measures which require less radical changes were also identified and some of these are relatively cost effective at less than 50 ECU/t CO_2-equivalent. The reductions offered by these measures are however substantially less (about 12 kt).

The EU six gas basket of emissions in 1990 is estimated to be about 4 247 Mt CO_2-equivalent, and a reduction of 340 Mt of CO_2-equivalent is therefore required to meet the EU's Kyoto commitment of an 8% reduction. The fall in nitrous oxide emissions forecast in the 'with measures' scenarios described above of 242 to 356 kt N_2O by 2010 (compared to 1990 emissions) is equivalent to 75 to 110 Mt of CO_2 and could therefore meet between a quarter and a third of the required reduction. For comparison, a parallel study to this one, which examined reducing methane emissions (AEA Technology Environment, 1998), found that methane emissions could be reduced to 39% below their 1990 levels by 2010. This reduction (of 7.2 Mt of methane) was equivalent to 151 Mt of CO_2, and could therefore meet just over half of the reduction required by Kyoto.

Figure 10.4 N_2O Emissions under Business as Usual and With Measures Scenarios (kt)



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Appendix 1

Costing Methodology

A1. Costing Methodology

A1.1 INTRODUCTION

There are two general modelling approaches to estimating the cost of pollution abatement strategies: top–down models and bottom–up models. The former are macroeconomic models that attempt to capture the overall economic impact of an abatement strategy; they tend to analyse aggregate behaviour based on economic indices and elasticities. With top–down models, the overall cost of a pollution abatement strategy is normally expressed in terms of a change in gross domestic product (GDP).

In contrast, bottom–up models look at the microeconomic costs of individual mitigation options. Bottom–up models rely on the detailed analysis of technical potential; focusing on the integration of engineering costs and environmental performance data. With bottom-up models, the overall cost of a pollution abatement strategy includes, for example, investment, operation and maintenance, and energy costs.

Past experience has shown that bottom–up models have problems accounting for consumer behaviour and administration costs; whereas top–down models have problems accounting for different rates of technical change. Essentially, top–down models are better at predicting wider economic effects and bottom–up models are better at simulating detailed technological substitution potential.

The current study which AEA Technology is conducting for DGXI aims to examine the technical potential of abatement options at a detailed level, and therefore uses a bottom–up costing model; specifically, the costing model used in this study is the levelised cost/discounting method.

A1.2 THE LEVELISED COST/DISCOUNTING METHOD

The levelised cost/discounting method essentially uses discounted cash flow techniques to reduce the stream of non-recurring and recurring costs associated with each option to a single present value in a given base year. Furthermore, to facilitate comparison between options with different operating lives, the present value of the total cost stream of each option is annualised over the forecast period of plant operating life. As with normal economic project appraisal, this involves determining the equivalent annual cost of each option. An indicator of the cost-effectiveness of each option is then derived by normalising the equivalent annual cost to the resulting emission reduction, e.g. the tonnes of N_2O abated. As this method uses discounted cash flow techniques, costs and accomplishments are temporally differentiated according to when the pollutants are actually abated.

A1.2.1 The Methodology

The proposed costing methodology comprises the following four steps:

1. collect estimates of the relevant model parameters for each option;
2. determine the present value of each option's total cost stream;
3. annualise the present value of the total cost stream of each option over its operating life;
4. normalise the annualised cost of each option to the resulting emission reduction.

Step 1

The first step is to make estimates of the following model parameters for each mitigation option.

- The non-recurring incremental costs, i.e. the one-off costs incurred to install/implement the mitigation option *k* in period *t*, and the time required to install/implement each option. Where possible, non – recurring costs are disaggregated into the following two categories:

  - purchased equipment costs and.
  - direct and indirect installation costs (i.e. associated costs).

- The annual recurring incremental costs, are disaggregated into the following two categories:

  - the annual incremental costs required to operate mitigation option *k* in period *t*; and, where applicable,
  - the annual savings in recurring costs from operating mitigation option *k* in period *t*.

  Where possible, these two sub–categories of recurring costs will be divided into energy, maintenance and labour costs.

- The operating life of each option, in years (denoted by *t*).

- The appropriate real discount rate, *r*. In agreement with DGXI, a discount rate of 8% was used, to ensure consistency with work carried out on costs of reducing CO_2 emissions.

- The annual quantity of pollutant abated by mitigation option *k* in period *t*.

Examples of the types of costs that might be included within each of the above cost categories is given in Table A1.1.

Where possible, uncertainty in the raw data is addressed through the use of cost and/or performance ranges.

Unless originally quoted in ECU, all of the above costs are converted to ECU using appropriate yearly exchange rate obtained from EUROSTAT (Table A1.2). Costs are converted to 1995 ECUs using the Industrial Producer Price Index for total industry in the EU15 (Table A1.3).

The costs outlined above essentially represent the engineering and financial costs of specific mitigation options. Not included in the cost approach proposed are the macroeconomic and/or social costs of mitigation options. As a result, the impact that an individual mitigation option will have on the level of GDP and human welfare is not addressed in this study.

Table A1.1 Checklist of Capital and Yearly Operating Costs

NON-RECURRING CAPITAL COSTS	
Total Direct Non-recurring Costs	
Purchased Equipment Costs	primary control device auxiliary equipment instrumentation VAT/sales taxes on equipment freight modifications to other equipment
Buildings	
Direct Installation Costs	foundations and supports handling and erection electrical piping insulation painting
Site Preparation	
Total Indirect Non-recurring Costs	
Indirect Installation Costs	engineering construction and field expenses contractor fees start-up performance testing contingencies
Other Non-recurring Costs	
Land – green-field site	
Working Capital	
Off-site Facilities	
ANNUAL RECURRING COSTS	
Variable (Direct) Costs	
Non-fuel Operating Costs	maintenance materials operating, supervisory and maintenance labour staff training replacement parts water treatment waste treatment and disposal
Fuel Operating Costs	electricity, oil, gas etc.
Fixed Operating Costs	
Overheads	
Rates	
Insurance	
Administrative Charges	
Positive Side Effects	
Savings	energy use reductions in quantities of chemicals or solvents
Improved Product Quality	
Useful By-products	

Table A1.2 ECU Exchange Rates: 1 ECU =

Country	1990[1]	1991[1]	1992[1]	1993[1]	1994[1]	1995[1]	1996[2]	1997[3]
USA	1.27	1.24	1.30	1.17	1.19	1.31	1.28	1.25
Germany	2.05	2.05	2.02	1.94	1.92	1.87	1.91	1.95
Netherlands	2.31	2.31	2.27	2.18	2.16	2.10	2.14	2.18
UK	0.71	0.70	0.74	0.78	0.78	0.83	0.82	0.74

[1] Source: EUROSTAT (1997) 96 Yearbook.
[2] Based on monthly average for the year.
[3] Based on average for January only.

Table A1.3 Industrial Producer Price Index: Total Industry (1990 = 100)

Year	1992	1993	1994	1995	1996	1997
Index	104.4	106.1	108.2	112.4	113.3	114.2

Source: EUROSTAT (1997) Eurostatistics: data for short-term economic analysis.

Step 2

Using the relevant parameter values identified in step 1, the second step is to determine, for a suitable base year (denoted as t = 0), the present value of each option's total cost stream. This is given by equation 1.

$$\mathrm{PVC}_0^k = \sum_{t=0}^{\mathrm{T}^k} \left[\mathrm{NRC}_t^k + \mathrm{RC}_t^k\right] \circ \left[1 + r\right]^{-t} \qquad [1]$$

where

PVC_0^k = the present value of the total cost stream for mitigation option *k* in year zero,

NRC_t^k = the non-recurring cost of mitigation option *k* in period *t*,

RC_t^k = the recurring costs to operate mitigation option *k* in period *t*,

T^k = the operating life of mitigation option *k*, and

r = the appropriate discount rate.

Step 3

From the present value of the total cost stream, the third step is to calculate the equivalent annual cost of each mitigation option (i.e. the value of an equal annual payment throughout the option's life, which yields the same present value). This is also referred to as levelising/annualising the present value of the total cost stream, and is computed using equation 2.[1]

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[1] When the annual recurring costs are assumed to remain constant in real terms over the operating life of the measure, the equivalent annual cost can be determined by dividing the non-recurring cost by the appropriate annuity factor and adding this to the annual recurring costs. However, this approach is more difficult to apply when the build time exceeds one year. Hence, it is not used here.

$$\mathrm{EAC}^k = \left[\mathrm{PVC}_0^k\right] \circ \left[r^{-1}\left\{1-(1+r)^{-t}\right\}\right]^{-1} \qquad [2]$$

where

EAC^k = the equivalent annual cost of mitigation option *k*, and

$\left[r^{-1}\left\{1-(1+r)^{-t}\right\}\right]$ = the *t* - year annuity factor for a discount rate of *r*.

Alternatively, the equivalent annual cost of environmental protection measure *k* can be found by multiplying the present value of costs by the appropriate capital recovery factor, i.e.

$$\mathrm{EAC}^k = \left[\mathrm{PVC}^k\right] \circ \left[r(1+r)^t\right] \circ \left[(1+r)^t - 1\right]^{-1}$$

where

$\left[r(1+r)^t\right] \circ \left[(1+r)^t - 1\right]^{-1}$ = the *t* - year capital recovery factor for a discount rate of *r*.

Step 4

The fourth and final step is to normalise the annualised cost of each option to the resulting emission reduction. This will provide an indicator of the cost-effectiveness of the proposed option (it may loosely be interpreted as the marginal cost of the option), and is computed as follows

$$\mathrm{MC}^k = \frac{\mathrm{EAC}^k}{\mathrm{QA}_t^k}$$

where

QA_t^k = the quantity of pollutant abated by mitigation option *k* in period *t*.

That is,

$$\mathrm{MC}^k = \frac{\left\{\sum_{t=0}^{\mathrm{T}^k}\left[\mathrm{NRC}_t^k + \mathrm{RC}_t^k\right] \circ \left[1+r\right]^{-t}\right\} \circ \left\{r^{-1}\left[1-(1+r)^{-t}\right]\right\}^{-1}}{\mathrm{QA}_t^k} \qquad [3]$$

Subject to certain assumptions, other methods exist that will produce identical results. One of these involves discounting the quantity of pollutant abated over the operating life of an option back to a summary statistic, referred to as the present tonnes equivalent (PTE), and dividing the present value of the total cost stream by the PTE. Using this method, the marginal cost of abatement is computed using equation 4.

$$\mathrm{MC}^k = \frac{\left\{ \sum_{t=0}^{\mathrm{T}^k} \left[\mathrm{NRC}_t^k + \mathrm{RC}_t^k \right] \circ \left[1 + r \right]^{-t} \right\}}{\sum_{t=\mathrm{x}}^{\mathrm{T}^k} \left[\mathrm{QPA}_t^k \right] \circ \left[1 + r \right]^{-t}} \qquad [4]$$

where x is the year in which pollution abatement option *k* is implemented or becomes operational, and the denominator is the PTE.

Both approaches, i.e. equations 3 and 4, yield the same result. The second approach has the advantage over the first in that it allows one to account for variations in the quantity of pollutant abated over time. In this study, however, the quantity of pollutant abated by each measure is assumed to remain constant over time. Consequently, we have opted for the use of the first approach, i.e. equation 3. Moreover, the first approach is more intuitively appealing in that it avoids the need to discount annual emission reductions.

A1.3 VARIATIONS IN COSTS ACROSS EUROPE

To gain an insight into how the cost-effectiveness of the various measures might vary across the EU15, each component of the base data has been adjusted to take into account known differences in relative factor prices between the base country, for which detailed cost data exists, and other members of the EU15, for which cost data needs to be estimated. To do this an appropriate relative price index has been constructed for each significant cost component. Table A1.4 summarises those factors used to adjust the individual costs components and Table A1.5 lists the indices used.

Table A1.4 Cost Adjustment Factors

Cost Component	Adjustment Factor
Non-Recurring Costs:	
Purchased Equipment	Purchasing power parities
Associated Installation Costs	Construction and civil engineering costs
Recurring Costs:	
Energy Inputs/Savings	Electricity costs, Gas costs and Fuel costs
Materials Inputs/Savings	Purchasing power parities
Labour Inputs	Average hourly labour costs

Table A1.5 Price Indices (UK = 100)

Country	PPPs	Electricity Prices	Gas Prices	Fuel Costs	Construction Costs	Labour Costs
Austria	134	118	154	130	115	151
Belgium	127	99	112	96	115	162
Denmark	160	101	116	111	107	147
Finland	148	92	116	105	124	134
France	133	88	128	100	98	146
Germany	137	147	162	99	147	177
Greece	95	90	N/A	38	86	53
Ireland	103	96	252	137	88	98
Italy	98	135	138	116	101	138
Luxembourg	122	90	112	69	150	131
Netherlands	128	109	117	90	100	147
Portugal	84	178	N/A	89	49	42
Spain	102	118	126	85	53	115
Sweden	152	57	N/A	75	117	145
UK	100	100	100	100	100	100
United States	95	68	81	75	50	114

Source: OECD (1997) Main Economic Indicators; HMSO (1997) DUKES; EUROSTAT (1997) Yearbook 96; Spoons (1995) European Construction Costs Handbook.

The table should be read vertically. The columns show the number of monetary units needed in each country to purchase some quantity of the specified commodity relative to the cost of purchasing that quantity in the UK. For the individual mitigation options considered, the above indices are re-based to correspond to the currency in which the base cost data was originally sourced. For example, the cost of the some of the measures to abate emissions from gas compressors was based on Dutch data. Therefore, the above indices are re-based to the Netherlands (i.e. NL = 100) and the re-based indices are then used to estimate the costs of that measure in other members of the EU15. Where the base cost data has not been split between the various non-recurring and recurring cost components used in the analysis, a weighted average index has been used, assuming that the recurring and non-recurring costs are allocated equally to each component.

Appendix 2

CORINAIR Data

Table A2.1 Estimated Emissions of N_2O in EU Member States in 1990 (kt)

	A	B	DK	FIN	FR	GER	GRE	IRE	IT	LUX	NLS	P	SP	SW	UK	EU15
1 Public power, cogeneration and district heating	0.7	2.1	0.8	0.7	1.1	10.2	6.9	1.4	16.6	0.0	0.0	2.3	9.2	1.0	3.0	55.9
2 Commercial, institutional and residential combustion	0.2	2.8	0.2	0.2	3.8	6.3	0.4	0.7	8.3	0.0	0.2	0.2	2.6	0.8	0.0	26.8
3 Industrial combustion	0.3	2.6	0.2	0.3	2.1	8.1	0.1	0.4	11.4	0.0	0.0	2.1	6.8	1.3	0.0	35.7
4 Production processes	0.5	4.7	0.0	1.2	93.6	99.4	2.7	0.0	14.8	0.0	1.7	1.9	10.4	2.7	84.9	318.5
5 Extraction and distribution of fossil fuels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	NE	0.0	0.0	0.0
6 Solvent use	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	AZ	0.0	0.0	0.0
7 Road transport	0.4	0.9	0.3	0.4	3.8	9.1	0.3	0.2	3.1	0.0	4.4	0.4	2.0	0.6	0.0	26.0
8 Other mobile sources and machinery	0.0	0.0	0.1	0.7	0.4	0.0	0.4	0.0	2.6	0.0	0.0	0.0	0.4	0.1	0.0	4.8
9 Waste treatment and disposal	0.0	0.1	0.0	0.0	1.3	4.3	0.0	0.0	1.5	0.0	2.4	0.0	0.1	0.0	0.0	9.8
10 Agriculture	3.0	9.0	8.5	10.3	60.8	77.5	12.7	39.5	57.3	0.5	8.7	30.9	63.0	7.9	82.0	471.7
Total Anthropogenic Emissions	**5.4**	**22.2**	**10.3**	**13.8**	**166.9**	**214.8**	**23.6**	**42.2**	**115.5**	**0.6**	**17.4**	**37.9**	**94.3**	**14.4**	**169.9**	**949.3**
11 Nature	2.7	4.0	6.1	17.9	55.7	0.0	181.6	2.8	26.1	0.1	7.4	16.8	107.5	18.6	0.0	447.3
Total	**8.0**	**26.2**	**16.4**	**31.7**	**222.7**	**214.8**	**205.2**	**45.0**	**141.7**	**0.7**	**24.8**	**54.7**	**201.9**	**32.9**	**169.9**	**1396.6**

Table A2.2 Estimated Emissions of N_2O in EU Member States in 1994 (kt)

	A	B	DK	FIN	FR	GER	GRE	IRE	IT	LUX	NLS	P	SP	SW	UK	EU15
1 Public power, cogeneration and district heating	0.1	3.0	1.2	1.0	1.3	12.9	1.4	1.6	19.1	0.0	0.8	2.2	9.3	1.0	7.8	62.8
2 Commercial, institutional and residential combustion	0.6	3.5	0.2	1.3	4.2	4.7	1.0	0.9	7.7	0.0	0.5	0.2	2.5	0.2	0.9	28.4
3 Industrial combustion	0.1	1.8	0.2	1.0	3.0	4.5	1.2	0.4	7.3	0.0	0.4	2.0	6.6	0.8	1.0	30.4
4 Production processes	0.6	5.7	0.0	2.8	97.0	81.4	0.0	2.6	15.3	0.0	11.3	2.2	6.8	2.4	70.3	298.5
5 Extraction and distribution of fossil fuels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 Solvent use	0.8	0.0	0.0	0.2	2.0	6.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.1
7 Road transport	3.9	1.3	0.8	0.8	5.9	19.0	0.1	0.3	3.4	0.1	6.3	0.7	2.3	1.2	6.5	52.7
8 Other mobile sources and machinery	0.7	0.0	0.9	0.2	0.3	0.0	2.3	0.2	4.2	0.0	0.7	0.1	0.3	1.8	2.6	14.3
9 Waste treatment and disposal	0.0	0.1	0.0	0.1	2.6	4.0	0.0	0.0	1.4	0.0	0.5	0.0	0.5	0.0	0.4	9.6
10 Agriculture	6.0	11.7	9.0	9.0	80.1	85.8	8.6	19.9	72.6	0.5	25.4	30.9	60.0	16.1	10.0	445.5
Total Anthropogenic Emissions	**12.7**	**27.0**	**12.2**	**16.4**	**196.5**	**218.5**	**14.7**	**26.0**	**130.9**	**0.7**	**45.9**	**38.4**	**88.3**	**23.6**	**99.5**	**951.3**
11 Nature	0.9	1.3	5.5	0.0	34.9	0.0	163.1	0.0	6.6	0.1	13.6	16.8	107.4	18.6	0.0	368.7
Total	**13.5**	**28.3**	**17.7**	**16.4**	**231.4**	**218.5**	**177.8**	**26.0**	**137.5**	**0.7**	**59.4**	**55.2**	**195.7**	**42.2**	**99.5**	**1,320.0**

- Sources: CORINAIR90 and CORINAIR 94 -

Appendix 3

This Appendix is not currently available in electronic format.

Options to Reduce N_2O Emissions from Agriculture in the EU

Sub-contractor’s report by SSLRC to AEA Technology, 1998

Appendix 4

Costing of Options to Reduce N_2O Emissions from Agriculture

Sub-contractor's report by ADAS to AEA Technology, 1998

ADAS

Final Report

COSTING OF OPTIONS TO
REDUCE N_2O EMISSIONS FROM AGRICULTURE

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June 1998

contents

APPENDIX 1

SUMMARY

In broad terms, normal farming practice appears to take little or no account of the residual nitrogen fertiliser available following a break crop and underestimates the value of animal manures as a source of nitrogen.

Application of animal manures to 220,000 hectares of winter wheat in the UK offer potential fertiliser N reductions of 18 kg per hectare. The potential cost saving to the industry would be £1.3 million and the emission of N_2O-N would be reduced by about 49.5 tonnes (77.8 tonnes of N_2O).

Similar saving could be made for maincrop potatoes, with potential cost savings to agriculture of £343,000 and reduced emission of N_2O-N in the order of 13.4 tonnes (21.1 tonnes of N_2O).

Emission of N_2O-N could also be reduced by reducing fertiliser-N applications below the economic optimum levels. In the case of wheat, the net cost of emission of N_2O -N abatement would be about £17920 per tonne for a 50 kg per hectare reduction of fertiliser-N. A 100 kg reduction of fertiliser-N would have a far greater yield effect but the cost of abatement would thus increase to an estimated £53120 per tonne of N_2O.

In the case of Oilseed rape (OSR), the cost of N_2O-N emission abated would be £9000 per tonne at 50 kg N below optimum and £19000 per tonne at 100 kg N below the optimum level.

Fertiliser-N applications could be reduced by a change from winter to spring cultivars. In the case of barley, the spring crop would on average receive 30 kg N per hectare less than winter. The cost of such a change is estimated to equate to £95,400 per tonne of N_2O-N emissions abated. For OSR, assuming a reduction of 40 kg N per hectare, the cost of N_2O-N abatement is estimated at £164,000 per tonne.

Slow release formulations are not readily available for agricultural use. It is estimated that if such products were widely available and used, the costs could be up to 10% greater than formulas commonly used now.

Fertiliser-N is a cost effective input in the arable sector. Only small changes in crop performance will quickly outweigh potential savings from expenditure on fertilisers. The majority of farmers will be adverse to risking yield reductions and will happily apply some nitrogen in excess of the calculated optimum as an insurance against poor yields.

1. Introduction

This report seeks to evaluate the cost of changing current farming practise in order to reduce N_2O emissions. The report focuses on British farming conditions, with some extrapolation to EU situations where possible.

Estimates of the quantities of N_2O abated by these measures were obtained using standard IPCC methods for estimating N_2O emissions (IPCC/OECD 1997) i.e. N_2O-N emissions will be reduced by 0.0125 kg N for every 1 kg reduction in fertiliser - N use. This is an oversimplification of the situation, as N_2O emissions are likely to be influenced to a greater extent by differences in soil type and conditions and season than the current methodology allows for. However, despite these reservations costs of abatement will be expressed per kg N_2O-N abated (and also per kg N_2O), as estimated by the standard methodology.

The financial consequences of system changes are dependant upon the costs and prices associated with the change. UK agriculture is experiencing dramatic fluctuations in costs and particularly product prices. For example, the wheat price has fallen from highs of £120 and more in the 1995 harvest to between £70 to £80 for the 1997 harvest. At the same time nitrogen fertiliser costs have fluctuated form over 43 pence to under 25 pence per kg of N. The main factors driving these changes are currency exchange rates and the common agriculture policy (CAP). For the purpose of this project, input costs and product prices are based on best estimates for the period to 2000, based on proposed policy reforms and forecast currency changes.

2. Application of fertiliser nitrogen (N) in excess of recommended economic optimum levels.

Two crops have been considered in this part of the report, winter wheat and maincrop potatoes. The British survey of fertiliser practice provided reliable estimates of actual fertiliser-N applications to these and other principal crops over recent years. Table 1 shows the average fertiliser-N applications for the 1992 to 1996 period.

Table 1 Fertiliser-N applications to Winter Wheat and Maincrop Potatoes

	Winter Wheat kg/ha	Main Crop Potatoes kg/ha
1992	188	181
1993	186	191
1994	187	197
1995	194	182
1996	188	180
5 year average	189	186

Source: The British Survey of Fertiliser Practice 1996

Tables 2 and 3 below summarise the fertiliser-N recommendations for winter wheat and maincrop potatoes. Simple comparison between table 1 and tables 2 and 3 suggest that excess application of fertiliser-N is a feature of “normal” farming practice at the present time.

Table 2 Nitrogen recommendations for winter wheat

Soil Type	**Application (kg/ha)**		
	Nitrogen Index[a]		
	0	**1**	**2**
Sandy	175	140	80
Shallow	225	190	130
Deep Silty	180	90	0
Clays	190	110	0
Other Minerals	210	150	70
Organic	120	60	0
Peaty	80	20	0

[a] an assessment of available nitrogen in the soil, based on the expected residues of nitrogen from previous crop. The index range is 0 to 2, with index 0 for fields with small nitrogen reserves, e.g. following cereals, and index 2 for soils with the greatest soil nitrogen reserves, e.g. following grazed grass or intensive vegetable crops.

The recommendations in table 2 above assume a yield potential of 8 tonnes per hectare, which is slightly greater that the average achieved of about 7.4 tonnes per hectare (England and Wales, source HGCA. Cereal Statistics).

Table 3 Nitrogen recommendations for maincrop potatoes

Soil Type	**Application (kg/ha)**		
	Nitrogen Index		
	0	**1**	**2**
Sandy and shallow	240	200	130
Other minerals	220	160	100
Organic	180	130	80
Peaty	130	90	50

In broad terms, it appears that little or no account is being taken for the residual N from previous crop, or from the nitrogen available from organic fertiliser applications

At field level, the optimum N application rate depends on a wide range of factors such as the soil type, previous cropping, soil mineral N levels, the yield potential of the crop, the extent to which organic manures are used on the farm, and so on. It is impossible to assess the extent to which these levels of N application exceed the economic optimum recommendations with absolute accuracy

The cost of fertiliser nitrogen to UK farms is very variable depending on the type and source of fertiliser, the quantity purchased and the world market situation. The UK market has experienced a wide variation in the cost of fertiliser nitrogen price in recent years. For example in the spring of 1993 the average price of ammonium nitrate fertiliser was about 26 pence per kg of N. Price rose to a peak in excess of 42 pence per kg by the spring of 1996.

For the purpose of this report, a cost of 32 pence per kg is assumed for the British situation. This equates to ammonium nitrate (34.5 N) delivered at £110.40 per tonne, which is considered a reasonable annual average for fertiliser N in the UK over the next one to two years. All calculations of potential cost savings in section 2.1 have been made based on this assumption.

2.1 Potential for reducing fertiliser-N applications by taking better account of the N applied as manures.

A separate study on fertiliser applications to wheat crops which received animal manures, indicated an average reduction in fertiliser-N applications of 22 kg per hectare. The N available from the manures was however estimated to be equal to about 40 kg per hectare, so the additional potential saving of 18 kg of fertiliser-N could have been made. The area of wheat land in England and Wales benefiting from animal manures is about 220000 ha (Smith and Chambers, 1995). If the potential reduction of 18 kg of fertiliser-N could be achieved, the total saving would be in the order of 3960 tonnes, which at current prices represents a cost saving to the industry of £1.3 million. The estimated reduction of N_2O-N emissions is 49.5 tonnes (77.8 tonnes of N_2O).

The picture is not as clear in the case of maincrop potatoes, with a 5 year average application rate of 186 kg per hectare of fertiliser-N (The British Survey of Fertiliser Practice, 1996).

A report on fertiliser applications on maincrop potatoes grown on land to which animal manures were applied, shows that on average the reduction in fertiliser-N is only 3 kg per hectare compared to a potential saving of about 40 kg per hectare (Smith and Chambers, 1995). In such circumstances a further 37 kg reduction in fertiliser could be made without detriment to crop yield. Estimates indicate about 35%, or 29000 hectares, of the maincrop potatoes receive applications of animal manures. The potential total fertiliser-N saving is thus calculated to be 1073 tonnes or £343,000. If this level of savings were achieved, the reduction of N_2O-N emissions would be about 13.4 tonnes (21.1 tonnes of N_2O).

It is not possible to extrapolate this data to the EU level as no data is available on overall manure applications. It is possible that similar potential savings could be achieved across most parts of northern and western European countries and less likely in southern Europe, but the topic is too speculative to reach any firm conclusions at this stage. Controls on total nutrient inputs in the Netherlands suggest there may be less scope for saving in that country.

2.2 Potential for reducing fertiliser N applications by taking better account of residual nitrogen from previous crops

The area of wheat grown in the UK varies from season to season due principally to the impact of support prices and Set-Aside requirements. The 1997 census data indicates a total wheat crop of 1.905 million hectares in England and Wales. For the purpose of this project a typical wheat area of 1.9 million acres has been used

Assuming that the majority of break crops are followed by wheat in the arable rotation, then up to 50% of the winter wheat crop could benefit from fertiliser-N savings. On the basis that a potential saving of up to 60 kg per hectare of N, (depending on soil type and the specific previous crop), could be made in such a situation, it is assumed that a saving of at least 25 kg per hectare could be made on all the winter wheat grown. Surveys suggest that typically farmers only make allowance for residues of 10 kg N after such break crops. Therefore the potential saving of 15 kg or more, could be achieved. This offers potential savings of about 14250 tonnes of fertiliser worth £ 4.6 million at current prices. If this level of reduction could be achieved, then an estimated 178 tonnes of N_2O-N (280 tonnes of N_2O) emissions would be abated.

Similar data is available for winter barley crops following break crops. However in this case the allowance for residual N from the previous crops is a mere 1 kg, thus offering a potential reduction of 24 kg per hectare or more. Assuming an estimated 5% of the break crop area is followed by barley, the total excess of fertiliser-N is calculated to be 750 tonnes costing £240,000 at current prices and leading to an emission reduction of about 9 tonnes of N_2O-N (14 tonnes of N_2O).

2.3 Increasing Farmer Awareness

It is believed that current farmer awareness of N_2O emissions, and the links to agriculture, are very low, verging on zero. The issue of nitrate leaching has greater awareness due to Government Legislation together with the press and media activity in relation to Nitrate Sensitive Areas, Nitrate Vulnerable Zones, and the prospect of farmers having to reduce fertiliser-N applications in these areas.

A requirement of this proposal is to estimate the cost of increasing farmer awareness of the issues of over use of fertiliser-N and the possible savings which could be made. While there is clearly a need to increase farmers awareness of the potential savings which could be made to fertiliser-N costs. The cost of increasing awareness will depend greatly on the communication method used.

A series or promotional meetings and press coverage could be relatively inexpensive, but the level of uptake is likely to be modest. Depending on the number of meetings this type of activity could be organised from the £5000 to

£10,000 cost range. The meetings would be targeted in the principle arable regions of the country, for example 2 or 3 in the eastern counties, similar numbers in the midlands, 2 meetings in the south and a further 2 in the north. This number of meeting should help raise the issue of N_2O emissions, but should not be seen as a method to communicate to all farmers unless significantly more meetings were held at local levels to smaller farmer groups. Audiences of 50 to 100 farmers could be expected to attend the meetings, with the turnout being influenced by the quality of the speaker, other commitments and the general level of interest in the subject. Promotion of the potential cost saving to farmers will develop greater interest than promotion of the environmental impacts.

An alternative method might be the production of literature for distribution to all farmers. Based on recent experience the cost of this method of communication would be about £20,000. The target audience would be greater as the booklet could be sent to all farmers. There is however survey work which suggests farmers are not particularly responsive to literature.

A third method would be to have a series of practical demonstration farms on which regular open days and conferences are held at which the savings are made and demonstrated in a very practical way to farmers. The minimum cost of this type of promotion is likely to be in the order of £20,000 to £30,000 per demonstration farm per year. The cost may be more if the farm needs to be set up but this is likely to offer the greatest possible impact over the medium to long term, as these farms would demonstrate practical system changes with identifiable cost benefit to farmers.

A very significant factor in this area of work is the recent decline in the profits achieved by farms across all the major sectors of agriculture. Farmers are under severe pressure to improve profits wherever possible. This could be seen as a positive factor which will help reduce excess fertiliser-N applications. However, in the arable sector, crop yield is by far the most significant factor determining the business profitability. All farmers need to strive to maximise output in order to spread the overheads over a greater tonnage of product. Fertiliser-N has been, and continues to be, a relatively cheap and cost-effective input.

In section 2.1, it is estimated that wheat crops to which animal manures had been applied could have had fertiliser-N reduced by about 18 kg per hectare. The cost saving is only worthwhile provided there is no yield penalty. At a wheat price of £80 per tonne, a yield loss of only 72 kg per hectare (1%) would result in reduced income equal to the savings in fertiliser price. Table 4 shows the sensitivity of this calculation to changes in the wheat price and fertiliser cost. While the cost of fertiliser, and the wheat price, could change significantly over time, the table shows that the break even yield loss is within the range 0.5% to 1.5%. The majority of farmers would consider the risk of reducing yields to be too great in the current climate, and are thus likely to continue to apply fertiliser-N in excess of the recommended (the recommendations are based on field experiments) requirement as an insurance against falling yields.

Table 4 Break-even yield loss from reduced fertiliser-N applications (t/ha)

Fertiliser N pence per kg	Wheat price £ per tonne				
	60	**70**	**80**	**90**	**100**
29	87	75	65	58	52
30	90	77	68	60	54
31	93	80	70	62	56
32	96	82	72	64	58
33	99	85	74	66	59
34	102	87	77	68	61
35	105	90	79	70	63

Note: assumes an average yield of 8 tonnes per hectare

3. Cost implications of sub-optimal fertiliser-N applications

In an attempt to reduce N_2O emissions, fertiliser-N applications could be reduced below the economic optimum levels. The effect of 50 kg per hectare and 100 kg per hectare reductions for winter wheat and winter oilseed rape is evaluated in this section. This option could be assessed for all crops. these examples were chosen because winter wheat is grown over a very large area, while oilseed rape has been the most widely grown break crop.

3.1 Yield response - wheat

The economic impact of reduced fertiliser-N applications on winter wheat crops is particularly sensitive to the effect on crop yield. This in turn will depend upon a whole range of factors such as soil type, crop rotation, season and so on. It is therefore difficult to be precise about the yield response when looking at wheat in the general sense.

Figure 1 below shows the yield response, averaged over 5 years, to different fertiliser-N applications on a clay soil with mineral N index of zero. The financial impact of changes in the system is also shown on the graph, based on an assumed wheat price of £80 per tonne and a fertiliser-N cost of 32 pence per kg of N.

In this particular case the economic optimum fertiliser-N application was in the range 190 kg per hectare to 200 kg per hectare. Table 5 below shows the effect on yield and net margin for fertiliser-N levels 50 kg and 100 kg per hectare below an optimum of 190 kg per hectare. The assumptions used in this calculation are a wheat price of £80 per tonne and a fertiliser-N cost of 32 pence per kg of N.

The overall economic impact of reduced fertiliser-N applications is particularly sensitive to the yield response. Table 6 shows the effect on margin for a range of yield changes resulting from the application of 50 kg and 100 kg fertiliser-N below optimum levels.

Figure 1 **Yeild response and economic impact of reduced fertiliser N applications on Winter Wheat**

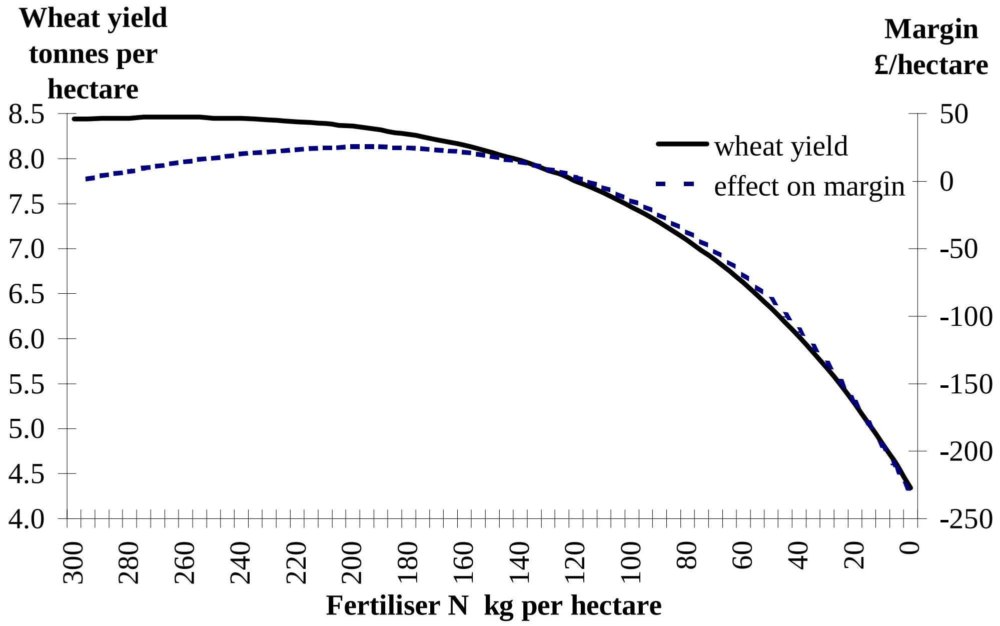


Table 5 Effect of reduced fertiliser-N on Winter Wheat.

Fertiliser N reductions kg / ha	Wheat yield response kg / ha	Net effect on margin £ / ha
50	340	- 11.20
100	1030	- 66.40

Table 6. Sensitivity assessment of effect on margin of winter wheat of reduced fertiliser-N applications.

yield loss	Fertiliser N reduction	
	- 50 kg	-100 kg
kg / ha	£/ha	£/ha
0	16	32
200	**0**	16
400	**-16**	0
600	-32	-16
800	-48	-32
1000	-64	**-48**
1200	-80	**-64**

It is reasonable to assume that a 50 kg per hectare reduction on N would reduce yields by between 200 to 400 kg per hectare and a 100 kg per hectare of N would result in a yield loss in the order of 1000 to 1200 kg. The shaded areas in table 6 show the probable impact on income of expected yield loss due to reduced fertiliser- N application.

Application of this theory to the whole of the wheat crop (1.9 million hectares) shows a potential loss to the UK wheat growers in the order of £22 million for a 50 kg per hectare N reduction increasing to £131 million at the 100 kg N level. The estimated abatement of N_2O-N emissions under such circumstances is 1235 tonnes for a 50 kg per hectare reduction and 2470 tonnes following a 100 kg per hectare reduction in fertiliser-N applications.

The implications of the restriction of fertiliser-N on the UK winter wheat crop are shown in table 7.

Table 7 Cost of abatement of N_2O-N emissions for winter wheat in UK

Fertiliser N reductions		Emissions abated		Lost	Cost per tonne emissions abated	
per ha kg / ha	**total tonnes**	**N_2O-N tonnes**	**N_2O tonnes**	**Margin £ million**	**N_2O-N £/t**	**N_2O £/t**
50	96300	1204	1866	21.6	17920	11404
100	192600	2408	3732	127.9	53120	33804

3.2 Oilseed Rape (OSR)

Assessing the impact of reduced nitrogen applications on OSR in general suffers all the problems already described for wheat. The actual yield response to reduced nitrogen will depend on a range of factors such as rotation, soil type, climatic conditions and so on.

Specific trial data for a three year trial is shown in figure 2 below, which also shows the economic consequence of cost savings and yield loss. It has been assumed that the average OSR price is £180 per tonne (forecast 1998 to 2000) and a fertiliser-N price of 32 pence per kg of N.

In this particular case the economic optimum fertiliser application is calculated to be 215 kg N per hectare at an OSR price of £180 per tonne. Reducing fertiliser-N applications be 50 and 100 kg per hectare would have resulted in lost margin of £5.60 and £23.80 respectively.

Table 8 below shows the overall sensitivity to different yield changes. The normal expectation is a yield loss in the region of 100 to 200 kg per hectare from a 50 kg per hectare N reduction and a 300 to 400 kg per hectare yield penalty from the 100 kg N reduction.

Figure 2

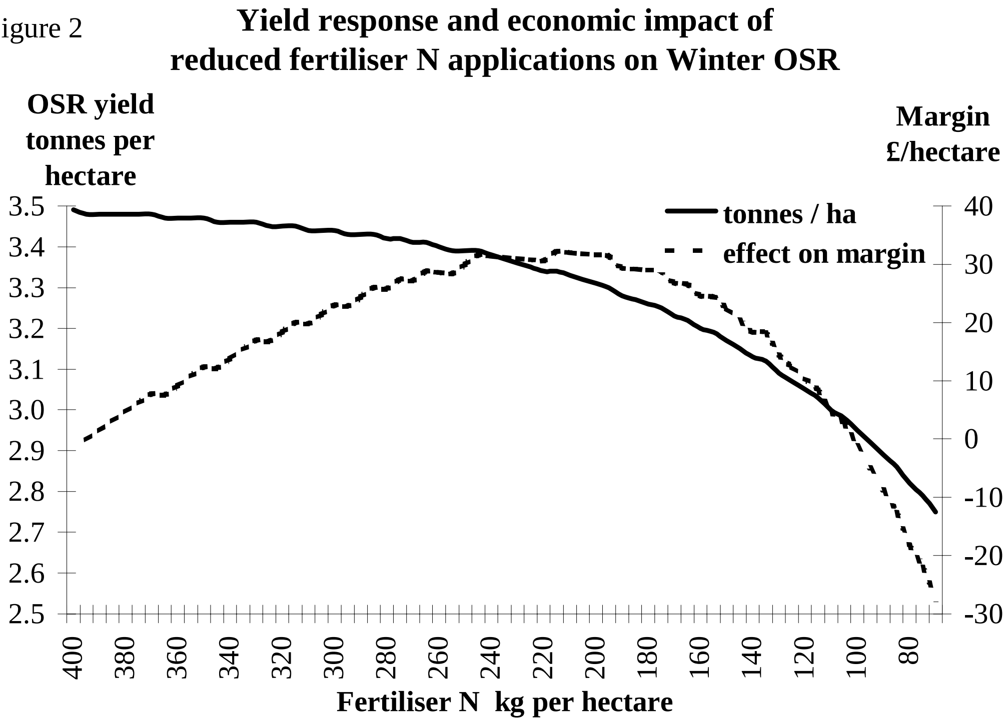


Table 8 Sensitivity assessment of effect on margin of winter oilseed rape of reduced fertiliser-N applications.

yield loss kg / ha	Fertiliser N reduction - 50 kg £/ha	 -100 kg £/ha
0	16	32
100	**-2**	14
200	**-20**	-4
300	-38	**-22**
400	-56	**-40**
500	-74	-58

The total cost of this approach to reduction of N_2O-N emissions would be about £9000 per tonne of N_2O-N abated, for the 50 kg per hectare reduction of fertiliser-N applied. The 100 kg fertiliser-N reduction application equates to a cost of £19000 per tonne of N_2O-N abated.

Table 9 Cost of abatement of N_2O-N emissions for winter oilseed rape

Fertiliser N reductions per hectare kg / ha	 total tonnes	Emissions abated N_2O-N tonnes	 N_2O tonnes	Lost Margin £ million	Cost per tonne emissions abated N_2O-N £/t	 N_2O £/t
50	18800	235	369	2.1	8960	5702
100	37600	470	739	8.9	19040	12116

4. Spring Cultivars

Changing from winter to spring cultivars would reduce the quantities of nitrogen applied to the crop and therefore has some potential to reduce N_2O emissions. The spring-sown crops have lower nitrogen recommendations due to the shorter growing period and lower yield potential as compared to winter sown crops. Consideration is given to such a change in farming practice for barley and oilseed rape crops. These crops have been chosen as examples because they are two of the most widely grown winter crops. Similar estimates could be made in respect of winter wheat and oats, as there are spring-sown cultivars of those crops.

The economic consequence of such a change is difficult to calculate at a global as opposed to farm level. The reason being that individual farmers may have opportunity to change their overall farming system to reduce the impact of the lower gross margins anticipated from the spring sown crops. For example, there may be opportunity to reduce power and machinery costs by operating equipment with smaller capacity as field operations are spread over the autumn and spring period. On other farms with livestock, the farmers may take the opportunity of the uncropped land over the winter period and establish a crop such as stubble turnips to be grazed in the field by sheep.

In wet seasons, farmers with heavy land risk not being able to establish a crop at all due to delays in cultivation and establishment.

The potential benefits for N_2O emissions from spring cultivars may be considered outweighed by the potential environmental problems of bare land over the winter period, or land being used for livestock feeding, and likely increases in nitrate leaching over winter. Moreover, it should be borne in mind that N lost to waters by leaching or runoff also ultimately contributes to N_2O emissions. In the current IPCC methodology N_2O emissions from that source are estimated as 0.025 kg N_2O-N per kg N lost by leaching or runoff. This emission factor is greater than from fertiliser-N inputs or crop residue returns. Thus reducing nitrate leaching, as well as being of benefit in itself, may also help to reduce N_2O emissions.

For the purpose of this report the economic consequence of the change to spring cultivars is limited to the effect at the crop gross margins level, ignoring the other potential benefits from farming system changes and the risk of crop failure.

4.1 Winter Barley to Spring Barley

The change to spring cultivars offers potential savings in all input costs not just nitrogen fertiliser. There is however likely to be a yield penalty associated with spring crops over winter crops due to the shorter growing season. The calculations below assume no change in product price, that is to say both the winter and spring barley will be feed value. In some situations the move to spring cultivars would offer an opportunity to produce a malting sample in some years which would have a price premium over feed barley.

The cost implications of the change from winter to spring cultivars of barley is summarised in table 10 below. Average yield data indicate a 1 tonne per hectare yield loss in the change from winter to spring barley. For the purposes of the report, it has been assumed that 30% of the cropped area produces straw with a value, either used on the farm or sold to other farmers.

In all the variable costs of growing the spring barley are £41 per hectare less than winter barley, however only £12.80 of this difference relates to the lower fertiliser nitrogen applications.

Table 10 Economic effect of changing from winter to spring cultivars of Barley

Output	**Winter £/ha**	**Spring £/ha**	**difference £/ha**
Barley	450	375	
Straw	15	13	
IACS	248	248	
	713	636	77
Variable Costs	192	151	41
Net Margin	521	485	36

In the UK the winter barley cropped area varies year to year. Based on the 1997 harvest data, the total potential cost to the industry from the winter to spring cultivars would be in the order of £30 million. Assuming an average recommendations for fertiliser-N application to spring barley 30 kg/ha less than for winter barley the total nitrogen applications would be reduced by about 25000 tonnes. The reduction in N_2O-N emissions is calculated to be 315 tonnes and the cost per tonne of N_2O-N emission abated is £95,400.

4.2 Winter OSR to Spring OSR

The change from winter to spring cultivars of OSR will have a significant impact on crop yield. In absolute terms the yield loss of at least 1.0 tonnes per hectare could be anticipated, which equates to a 30% reduction.

The change to spring OSR will reduce the fertiliser-N applications by about 100 kg per hectare, thus saving about £32 per hectare in costs. The remaining cost reductions come from the other variable cost savings which would be achieved.

Table 11 below shows the cost of changing from winter to spring cultivars of oilseed rape. The calculation is particularly sensitive to market price change and yield changes. Table 12 shows the sensitivity of the cost difference in table 11 to changes from the assumed 1 tonne yield loss and £180 per tonne market price. Based on the £82 per hectare costs shown below, the total cost of a complete change to spring cultivars would be about £30.8 million

Table 11 Economic effect of changing from winter to spring cultivars of Oilseed rape

Output	Winter £/ha	Spring £/ha	difference £/ha
Oilseeds	594	414	180
IACS	314	314	0
	908	728	180
Variable Costs	280	182	98
Net Margin	628	546	82

Table 12 Sensitivity of cost of replacing winter OSR with spring OSR to yield loss and Oilseed market price

yield	OSR Market Price		£ per tonne	
reduction	140	160	180	200
kg / ha	£/ha	£/ha	£/ha	£/ha
750	7	22	37	52
1000	42	62	82	200
1250	77	102	127	152
1500	112	142	172	202

The cost of reducing the N_2O-N emissions by changing from winter to spring cultivars of OSR is calculated to be £164,000 per tonne of N_2O-N abated, based on an average saving of 40 kg N per hectare.

The overall cost of the change from winter to spring cultivars of barley and oilseed rape is shown in table 13.

Table 13 Cost of abatement of N_2O-N emissions changing from winter to spring cultivars of Barley and Oilseed rape

	Fertiliser-N reductions		Emissions abated		Lost	Cost per tonne emissions abated	
	per hectare kg / ha	total tonnes	N_2O-N tonnes	N_2O tonnes	Margin £ million	N_2O-N £	N_2O £
Barley	30	25179	315	495	30.0	95411	60716
OSR	40	15048	188	296	30.8	164000	104364

5. Costs of alternative fertiliser-N formulations

It has proved particularly difficult to find reliable information on slow release fertilisers applicable to the arable situation. Discussions with representatives of fertiliser companies have not identified products readily available for the arable as oppose to horticultural usage. Discussions with ADAS colleagues have proved equally inconclusive to date.

The current situation is that slow release products are more commonly available and used within the horticultural sector, as the much greater value of some horticultural crops justifies the use of these more expensive products. If they were to be manufactured for widespread use across arable cropping, then the scale of manufacture would offer cost savings with the result that the product could be available to farmers at a cost up to 10% above current costs of fertiliser nitrogen.

The price difference and volatility due to regional distribution cost, world market price changes and the impact of currency changes are of greater significance than the specific cost of slow release formulations compared to formulations widely used at the current time.

The sensitivity of crop margins to different fertiliser-N prices is shown in table 14 over. While fertiliser-N is a significant production cost, particularly in the combinable cropping situation, even 10% changes in product cost have minimal impact on overall gross margins achieved.

Table 14 Gross margin sensitivity to 10% increase in cost of fertiliser nitrogen

	Cost of Fertiliser N as % of all input costs	Effect of 10% fertiliser N cost increase on gross margin	
		£/ha	%
Wheat	21%	-5.88	0.96%
Barley	22%	-5.32	1.02%
OSR	27%	-7.28	1.18%
MC Potatoes	7%	-8.25	0.37%

While this could be considered positive, in that slow release fertilisers may have minimal effect on margins even at greater cost, farmers will always seek to use the cheapest source of fertiliser thus any additional costs could be a deterrent to wide spread usage. In the wider context, table 14 also highlights the difficulties associated with proposed fertiliser taxes aimed at reducing agricultural usage for wider environmental reasons. Fertiliser costs would have to increase several fold before significant change to economic optimum applications rates could be seen.

6. European Perspective

The key issues to arise from the assessment of the UK position are the importance of yield as a component of business success and the relatively low cost of fertiliser-N as an insurance against yield loss. The same principles apply to all other members of the EU.

Looking across the northern and western European countries, crop performance and management systems are similar to those found in the UK. Commodity prices are dominated by the impact of the Common Agricultural Policy (CAP) so farm gate prices are very similar in ECU terms. Currency fluctuations can however have significant impact on farm gate prices , as shown by the situation in the UK, where devaluations in the 1992 to 1995 period contributed to price improvements, and the more recent revaluations of £ sterling have seen dramatic falls in price. Putting all this aside, economic optimum fertiliser-N levels across northern EU countries are very similar to those found in the UK

In very general terms, the management of arable crops across the northern and western EU countries is similar to that found in the UK. Break crops, particularly OSR have been encouraged due to the CAP support systems. It seems reasonable therefore to assume that the estimated 25 kg reduction could be applied more widely. For example, if is assumed a reduction of fertiliser-N could be made on the wheat grown in France Germany and UK (66% of the total EU crop), then total fertiliser N applications would be reduced by about 220 million tonnes. Winter cropping dominates the farming of the cool temperate countries of the EU, and so there will be similar scope for conversion to spring cropping. However, this option will be less readily applicable to southern Europe, where the hot, dry summers are likely to give very poor yields of spring-sown crops. In the far north and east of Europe, where the winters are cold, and the ground snow-covered for several weeks, crops are already predominantly spring-sown.

The average costs of fertiliser N in the three countries is shown below:

	% of UK price
France	123%
Germany	170%

The potential saving for the farmers in France and Germany is thus greater than the £8.00 per hectare calculated for the UK

Appendix I

Sources of information

Agricultural prices 1984 - 1993, Eurostats
The agricultural situation in the European Union 1996 report
The British Survey of Fertiliser Practice crop year 1996, MAFF/FMA/SO
Cereal Statistics 1996, Home grown Cereal Authority
The Digest of Agricultural Census Statistics - United Kingdom 1996,
ADAS crop trial data
IPCC/OECD 1997. Revised 1997 IPPC guidelines for national greenhouse gas inventories. OECD, 2 rue André Pascal, Paris.
Smith K A & Chambers B J, Muck: from waste to resource, Jnl of Institute of Agricultural Engineers, Autumn 1995, p33-38
Sylvester-Bradley Scope for more efficient use of fertiliser nitrogen, Soil Use and Management, Vol 9 No. 3 p 112-117

Glossary

Gross Margin = the margin of all income from crop sales and support payments less the direct growing costs such as seed, fertiliser and sprays.

N index = an assessment of available nitrogen in the soil, based on the expected residues of nitrogen from previous crop. The index range is 0 to 2, with index 0 for fields with small nitrogen reserves, e.g. following cereals, and index 2 for soils with the greatest soil nitrogen reserves, e.g. following grazed grass or intensive vegetable crops.

Appendix 5

Implications of CO_2 Reduction Measures on Emissions of Other Greenhouse Gases

A5. Impact of CO_2 Reduction Measures on Emissions of Other Greenhouse Gases

A5.1 INTRODUCTION

Under the United Nations Framework Convention on Climate Change (FCCC), each European Union (EU) Member State has put in place measures to control future emissions of carbon dioxide (CO_2). CO_2 emissions arise predominantly from the combustion of fossil fuels, and measures to reduce emissions will thus also affect emissions of a number of other gaseous pollutants associated with fossil fuel combustion, or the production of fossil fuels. Pollutants which are affected include the direct greenhouse gases methane (CH_4) which is associated with coal mining and nitrous oxide (N_2O) which is associated with combustion and the indirect greenhouse gases, nitrogen oxides (NO_x) and the non-methane volatile organic compounds (NMVOCs). Of these greenhouse gases, fossil fuel production and combustion are a significant source for CH_4, and NO_x, and a more minor source of N_2O. A methodology for estimating the potential effect which CO_2 reduction measures might have on emissions of these pollutants has thus been developed and is discussed below.

A5.2 CO_2 REDUCTION MEASURES

The major CO_2 reduction measures adopted by EU Member States can be broadly categorised as follows:

1. Energy efficiency/saving in demand sectors;
2. Fuel switching in the electricity supply industry;
3. Increased use of renewables;
4. Increase use of cogeneration;
5. Fiscal incentives;
6. Re-forestation.

In addition to actions being undertaken at national level, there are a number of EU programmes which may assist in meeting the overall CO_2 target of the EU. These programmes include JOULE (research into new energy technologies), THERMIE (support for energy technologies), SAVE (energy efficiency) and ALTENER (renewable energy).

The following sections discuss the likely impacts of each of the CO_2 control measures on emissions of CH_4, NO_x and N_2O.

A5.2.1 Energy efficiency/savings in demand sectors

Energy savings and efficiency measures in demand sectors can be achieved through a variety of mechanisms, but in all cases the result is a reduction in the final demand for energy. Mechanisms for energy efficiency/savings used by EU countries include;

- standards;
- voluntary agreements;
- information dissemination;
- grants;
- taxes.

Standards, information dissemination and grants are frequently used to encourage energy savings in the domestic sector, whereas in industry, voluntary agreements along with information dissemination are common. In the transport sector, many countries use a combination of standards and taxes to reduce final energy demand. In all sectors, the precise consequence of any of these energy efficiency/savings measures on CH_4, NO_x and N_2O emissions will depend on which fuels are being displaced. Determining this would require a very detailed modelling of individual countries energy systems, and such a detailed analysis is beyond the scope of this work. A more 'broad brush' approach has thus been taken, in which the ***average*** effect of reducing energy demand in each of the sectors in each country on CH_4, NO_x and N_2O emissions is calculated.

A5.2.1.1 Domestic, service and industrial sectors

For the domestic, service and industrial sectors, the average ratio of CH_4, NO_x and N_2O emissions to CO_2 emissions from energy use in each demand sector has been calculated for every EU country in 1990. Emissions from the full fuel cycle (i.e. from fuel extraction, processing and distribution as well as combustion) have been considered, thus methane emissions from coal mining, oil production and gas extraction and distribution are included. In the case of electricity use emissions from fuel use in power stations have been estimated. This ratio is then used to calculate the impact on CH_4, NO_x and N_2O emissions of reductions in CO_2 emissions from energy efficiency/savings measures.

A5.2.1.2 Transport sector

For the transport sector this method is not appropriate. The introduction of catalytic converters on petrol cars since 1990 means that the fall in NO_x emissions caused by reduced fuel demand in future years will be less significant and the increase in N_2O emissions more significant than would be calculated using the 1990 ratio of NO_x and N_2O to CO_2 emissions. Therefore, for each EU country, the likely profile of the car fleet in 2000 has been determined and data on the emission characteristics of these vehicles has been used to quantify the NO_x and N_2O savings associated with a reduction in CO_2. The effect on CH_4 is not considered, as transport is a very small source CH_4 emissions.

A5.2.2 Fuel switching in the electricity supply industry

Fuel switching, i.e. substituting a fuel with a lower carbon to energy ratio, such as gas, for a fuel with a high carbon to energy ratio, such as coal. can be used to control CO_2 emissions from the electricity supply industry (ESI). The reduction offered by switching from coal or heavy fuel oil to gas is enhanced in many EU countries, by the use of combined cycle technology with its inherently high thermal efficiency for gas fired generation. In this work the effect of fuel switching in the ESI by replacing existing power stations with combined cycle gas turbines is considered. As in the case of energy efficiency measures, the precise effect of the measure will depend on the type of power station and fuel which is replaced, and again for illustrative purposes it is assumed the emissions being displaced by the CCGT are the average from the generating mix in each EU country. Once again the reduction in emissions is based on full fuel cycle emissions.

A5.2.3 Increased use of renewables

Two cases of increased renewables deployment to control CO_2 emissions have been considered. The first case is the use of 'zero emission' renewables such as wind, solar or hydro and the second is the use of biomass plant such as the gasification of energy crops. 'Zero emission' renewables are those which produce no gaseous emissions during their operational stage. The change in emissions that results from their deployment is thus calculated as being the average emissions from the generating mix in each country. Biomass technologies include the combustion of energy crops, forestry or agricultural wastes and technologies such as anaerobic digestion of farm wastes. While these technologies are essentially CO_2 neutral (i.e. they lead to no net emissions of CO_2) they do lead to emissions of the combustion related pollutant NO_x and to some small emissions of methane. These emissions are thus subtracted from the reduction in emissions which results from displacing an average unit of current generation.

A5.2.4 Increased use of cogeneration

Cogeneration plant have two advantages over grid connected plant as a means of reducing CO_2 emissions. Firstly, they are usually sited close to the point of electricity demand and so do not suffer the transmission losses associated with centralised electricity production. Secondly, the heat produced from a cogeneration plant can be used to displace heat from boilers and thus provide additional fuel savings.

For this work, it is assumed that the cogeneration plant which are deployed in the industrial sector are CCGT with performance and emissions characteristics identical to those assumed in for fuel switching in the ESI. Emissions savings from displaced grid electricity are calculated as above. Emissions savings from displaced heat are calculated on the basis of the mix of fuels used by industry.

Appendix 6

Transport Emissions Model

A6. Transport Emissions Model

A6.1 ROAD VEHICLES

For cars, new vehicle registrations and diesel car registrations up to 1995 were obtained from SMMT World Automotive Statistics. Extra figures for 1996 were obtained from National Automotive Trade Organisations where possible. In addition, figures for total national car parcs (including diesel car numbers) were obtained and used to check predictions where possible.

A6.1.1 Catalytic Converter Penetration

To model the increase of catalytic converters in the petrol car fleet, it is assumed all petrol cars built from 1993 include a three-way catalytic converter, as required under EU Directive. Years preceding this date have various penetration levels for converters, according to historic data for the particular Member State.

A6.1.2 Diesel Engine Penetration

Projected diesel penetration (% of registrations) was calculated using previous penetration levels and the minimum and maximum levels found in mature markets (UK, 20% and France, 45% respectively). Most Member State markets are predicted to reach 20% diesel fleet penetration by 2005. (Source: Automotive Environment Analyst, No. 25, Feb. 1997)

Country	Projected Diesel Penetration
Austria	43% current level maintained to 2020
Belgium	47% current level maintained at 45% to 2020
Denmark	Linear increase to 20% in 2005
Denmark	Linear increase to 20% in 2005
France	47% current level maintained to 2020
Germany	15% in 1995, 20% by 2000 and beyond.
Greece	No data on diesel registrations - Linear increase to 20% in 2005
Ireland	Linear increase to 20% in 2005
Italy	Increase to 20% in 2000
Luxembourg	Current 30% level maintained
Netherlands	Linear increase to 20% - 2005
Portugal	Linear increase to 20% - 2005
Spain	Current 33% level maintained
Sweden	Linear increase to 20% 2005
UK	Current 20% level maintained

A6.1.3 New Car Registration Predictions

Future new car registrations are predicted on the basis of a GDP scaling factor (from a 1995 base) derived for each Member State from figures used for the ‘Energy in Europe’ study. These scaling factors are shown in Table 1 below. The justification for the use of this scaling factor is that the number of new car purchases is linked to individual wealth, which in turn is related, albeit indirectly, to a country’s GDP performance. It may also be expected that the rate of renewal of private cars will increase with individual wealth, thereby affecting the overall vehicle turnover and stock. However, the calculation of this effect is beyond the scope of this exercise.

Table 1 GDP scaling factors used to predict new car registrations

Year	1995	2000	2005	2010	2015	2020
Austria	1.00	1.12	1.24	1.38	1.51	1.63
Belgium	1.00	1.13	1.26	1.41	1.54	1.68
Denmark	1.00	1.15	1.28	1.42	1.54	1.65
Finland	1.00	1.17	1.32	1.48	1.62	1.75
France	1.00	1.13	1.26	1.41	1.54	1.67
Germany	1.00	1.13	1.28	1.43	1.57	1.70
Greece	1.00	1.15	1.36	1.60	1.86	2.15
Ireland	1.00	1.31	1.58	1.81	2.01	2.22
Italy	1.00	1.11	1.24	1.37	1.50	1.62
Luxembourg*	1.00	1.13	1.28	1.43	1.58	1.72
Netherlands	1.00	1.15	1.31	1.49	1.65	1.81
Portugal	1.00	1.17	1.40	1.67	1.95	2.24
Spain	1.00	1.16	1.34	1.54	1.74	1.94
Sweden	1.00	1.13	1.26	1.40	1.52	1.63
UK	1.00	1.15	1.31	1.48	1.63	1.78

*No data available: an average of Netherlands, Belgium, France and Germany used (Neighbouring countries geographically and economically)

A6.1.3.1 Survival Rates

Survival rates for new cars were calculated for the UK as a reference case using detailed data for this country. Survival rates for the other EU15 countries were developed by adapting these rates to fit predicted stock numbers with actual figures for the years 1992 - 1995.

The spreadsheet model developed to calculate vehicle numbers uses all the above information to predict vehicle numbers for:

- Petrol non-catalytic converter
- Petrol with catalytic converter
- Diesel
- Total cars for each member state.

These are summarised for EU15 in Figure 1 below.

A6.1.4 Vehicle Use Demand

The use of private cars for future years was predicted by extending previous years trends for the EU15 countries. Data for the years 1990 to 1994 (source: UN Annual Transport Statistics) on vehicle kilometres driven were extended to 2020 using a least-squares trend. For several countries, insufficient data were available and an overall growth rate, based on the average of the countries for which data were available was used to predict demand. This was the case for Austria, Belgium, Greece, Luxembourg and Portugal. For Italy and Spain, for which data are also sparse, a growth factor based on the other three ‘major’ EU countries, Germany, France and the UK, was used. The vehicle km demand projections are shown in Figure 2.

Figure 1 Predicted vehicle stock, by type for EU15 to 2020

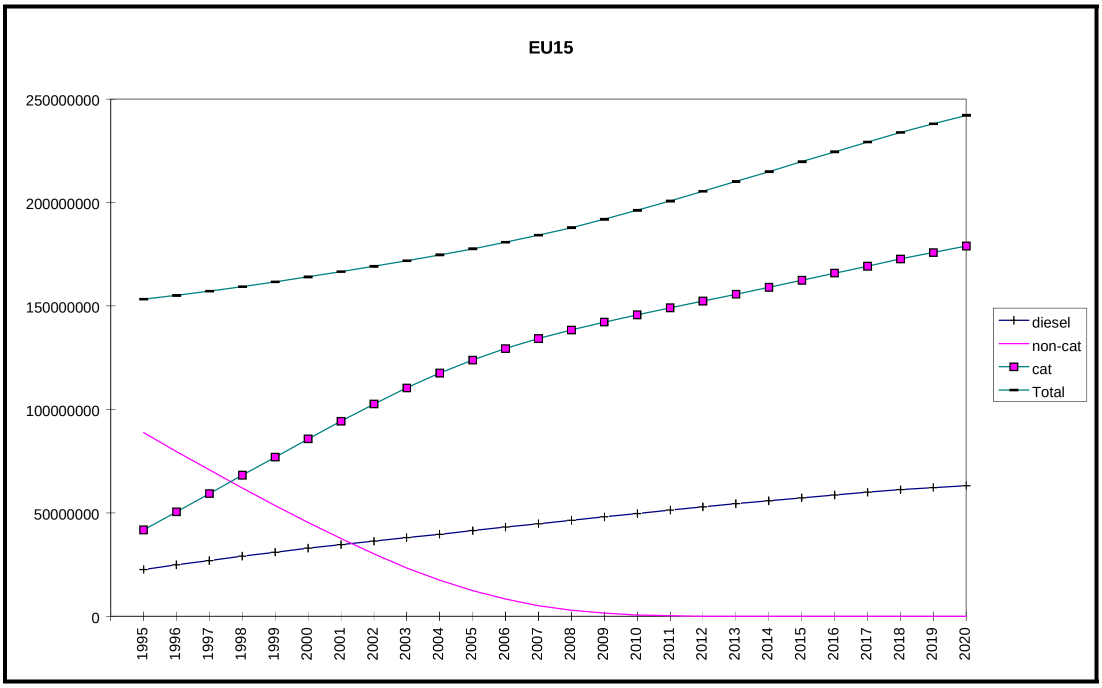
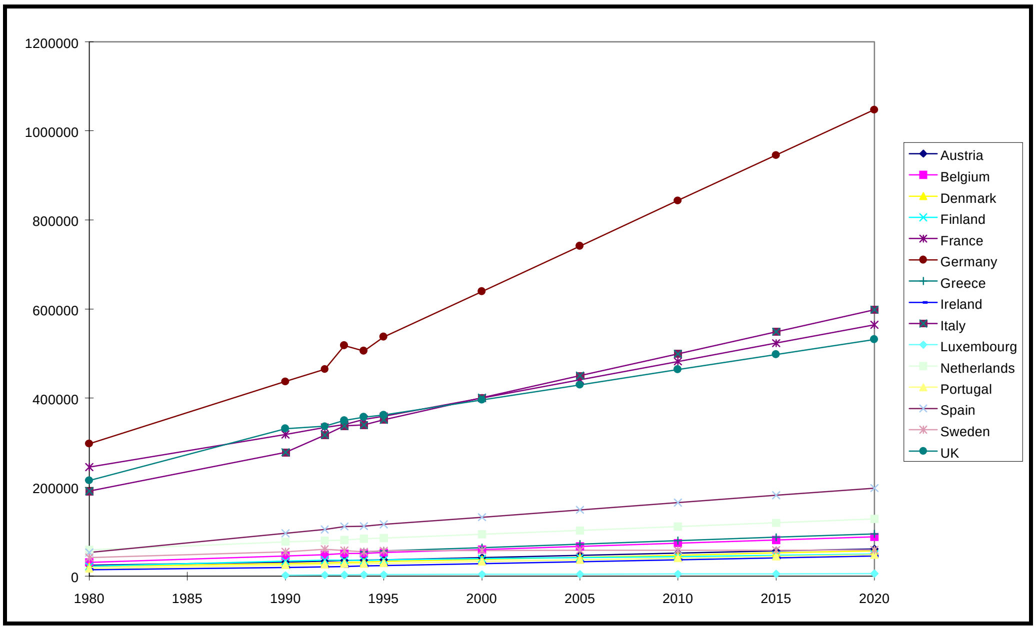


Figure 2 Vehicle km projections for EU15 to 2020



The results of the above stock modelling activities were used to make forecasts of a stock-weighted emission and vehicle km scaling factor to 2020 that was applied to the car segment of 1994 CORINAIR methane emissions. Emissions from non-car road vehicles, for which detailed information was not available, were forecast using the CORINAIR 1994 emissions and a forecast GDP inflator for each Member State. This inflator is thought to adequately represent growth in commercial road vehicle emissions. Other sectors make only negligible contributions to the non-car sector.

A6.2 NON-ROAD MOBILE SOURCES (OTHER TRANSPORT)

In accordance with the CORINAIR nomenclature for emission sources, these are broken down into:

- Off-road vehicles and machines:
    - Agriculture
    - Forestry
    - Industry
    - Military
    - Household
- Railways
- Inland Waterways
- Maritime Activities
- Airports

A6.2.1 Off-Road Vehicles and Machines

The proposed EU directive on Emissions from Non-road mobile sources has, and the latest 'Common Position' adopted by the EU member states will have a negligible effect on methane emissions from these sources[1]. This enabled a simplified methodology to be applied to forecast future emissions.

For future years, forecast is made for all the sectors activities using a single energy use factor (from Energy in Europe studies) that will simply scale vehicle population and therefore emissions. Hours of use, machinery power ratings and load factors are assumed to remain unchanged to 2020.

For the agricultural sector, a specific agricultural growth index was not available. In addition, the stock of non-road machinery is used in a wide range of specific agricultural applications, which may be subject to growth or decline over the period of the forecast. Information on the use of machinery within these agricultural sectors is not available. Therefore, a single energy use factor (again from Energy in Europe studies) was used for scaling future emissions.

As disaggregated data on stock at the Member State level are patchy and incomplete, an overall forecast for EU15 has been completed for these sources.

A6.2.2 Railways

Methane emissions from railway activities are a small proportion of total non-road emissions and are expected to rise in proportion to energy use, assuming there is no increase in electrification (which is already the case across most of EU15). Emissions in 1994 (from CORINAIR data) have been scaled using the Energy in Europe energy use factor for each country. Where 1994 CORINAIR data were incomplete, an estimate of 1994 emissions has been made using data on national totals of diesel locomotive power.

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[1] Samaras and Zierock, Estimation of emissions from Other mobile sources and machinery.

A6.2.3 Inland waterways

Inland waterway vessels are a significant source of emissions within the non-road sector. A proposed EU directive on boat emissions will probably be aimed at recreational vessels under 24m in length, and then only for new craft. Existing diesel-powered freight vessels, which make the largest contribution to emissions will not be affected. In addition, CH_4 emissions are likely to remain unaffected. From 2010, new propulsion systems may be employed on inland vessels which demonstrate improved fuel efficiency of 10-30%. However, the slow stock turnover of this sector would indicate that such vessels will have a negligible effect on methane emissions before 2020.

Emissions in 1994 (from CORINAIR data) have been scaled using the Energy in Europe energy use factor for each country. Where CORINAIR data were incomplete, an estimate of 1994 emissions has been made using data on national totals of tonne-km total carried on inland waterways (in 1993).

A6.2.4 Aircraft

In the air sector, a projection based on commercial fleet energy use to 2010 has been extended to 2020 and applied to 1994 CORINAIR figures for LTO cycles and ground activities for each Member State. It is assumed that this forecast, despite being for overall energy use can be applied to these LTO cycles. Methane emissions increase in proportion to fuel use, and NO_x reduction measures are assumed to have negligible effects on CH_4 emissions.

A6.2.5 Marine

To simplify forecast of this sector, a simple scaling has been applied using the Energy in Europe energy use factors for each Member State. CORINAIR data (1994) for methane emissions is patchy and incomplete. Estimates for several member states were made on the basis of NMVOC data (which were more complete) and also Total goods thoughput of national seaports.

Various new technologies are envisaged in the marine sector (including all-electric ships an d fuel-cell powered vessels). However, the long-term development still required and the slow stock turnover means that negligible effects on emissions are expected.

Appendix 7

Comparison of N_2O Reduction Studies

Paper by Dominique Gusbin, Coherence, Louvain la Neuve, Belgium, November 1998

Contribution of non-CO_2 greenhouse gases to the EU Kyoto target: Evaluation of the reduction potential and costs

1. Background

At the conference of the parties in Kyoto in December 1997, the EU agreed to reduce emissions of the six greenhouse gases (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride) by 8% of 1990 levels by 2010[1]. The target applies to emissions weighted by their (100 year) global warming potential.

Until recently, studies and strategies for addressing climate change mitigation have principally been focused on reducing emissions of carbon dioxide, but the importance of other greenhouse gases and opportunities for their abatement have been increasingly recognised in the last couple of years. In particular, DGXI of the European Commission has lauched three studies considering non-CO_2 greenhouse gases and examining their reduction potential and costs. These studies are:

(1) Economic evaluation of quantitative objectives for climate change, COHERENCE (ongoing); in the framework of this study ECOFYS produced a report in June 1998 on Emission reduction potential and costs for methane and nitrous oxide in the EU-15;
(2) Reductions of the emissions of HFC's, PFC's and SF6 in the European Union, ECOFYS, June 1998;
(3) Options to reduce methane emissions, AEA Technology Environment, September 1998, and
Options to reduce nitrous oxide emissions, AEA Technology Environment, September 1998.

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[1] More precisely, Member States have the choice of a 1990 or 1995 baseline for HFCs, PFCs and SF6, and a limited allowance can be made for sinks in calculating the 8% reduction.

This paper summarises the major findings from the above studies as to the reduction potential and costs of non-CO_2 greenhouse gases emissions in 2010. It also addresses the uncertainties in emissions and costs estimates for some sources and mitigation options. The reduction potential of each gas is estimated in comparison with a business-as-usual scenario to 2010. It is provided both in ktonne of gas considered and in ktonne of CO_2-equivalent using the global warming potential of the gases (100 years). Costs of reduction options or of packages of reduction options are provided in ECU (1995) per tonne of CO2-equivalent abated.

2. Emissions in 1990/1995

Emissions of the six greenhouse gases in the EU are shown in Table 1. Emissions of the three main greenhouse gases in 1990 are those estimated by the Member States and reported in the EU Second Communication to the FCCC. Emissions of the three halogenated gases in 1995 (the reference year for these gases) are those reported and discussed by the Member States at Expert Group meetings [1].

GHG	Emissions in 1990 (Mt)	GWP (100 years)	Emissions in 1990/1995 (*) (Mt CO2-equiv)
CO2	3365	1	3365
CH4	23	21	489
N2O	1	310	315
HFC's		[1000-3000]	37
PFC's		6500; 9200	7
SF6		23900	14
Basket of six			4227
EU Kyoto target in 2010		(% of 1990) (kt CO2 equ.)	-8% 3889

(*) 1995 for halogenated gases.

Table 1: Anthropogenic emissions of CO_2, CH_4, N_2O, HFC's, PFC's and SF6 in the EU in 1990/1995

After allowing for the global warming potential of the gases (100 years), it is clear that non-CO_2 greenhouse gases are significant contributors to greenhouse gases emissions. Methane and nitrous oxide emissions in 1990 are equivalent to 24% of

CO_2 emissions. Emissions of halogenated gases in 1995 are equivalent to slightly less than 2% of CO_2 emissions in 1990.

The main sources of anthropogenic emissions of non-CO_2 greenhouse gases in 1990/1995 are shown in Table 2. It should be noted that the uncertainty in emissions estimates for some sources is significant [2]. This is particularly the case for landfill gas emissions, for N_2O emissions from agricultural soils and for halogenated gases emissions.

The achievement of the EU Kyoto target means that total EU emissions of the six gases in 2010 should not exceed 3889 Mt CO_2-equivalent.

3. Emissions in 2010 under a Business as Usual scenario

To allow the calculation of achievable emission reductions in 2010, business-as-usual projections are calculated for each gas and each of the main sectors.

Emissions under a business-as-usual scenario were estimated in the above studies using similar assumptions regarding background trends in activity indicators (e.g. fuel production and consumption, crop areas, livestock numbers, waste production, industrial production) and management practices (e.g. manure management, reduction in fertiliser use, lower leakage rates from new gas pipelines) [3]. These assumptions are described and discussed in the study reports.

However, business-as-usual projections have been made using sometimes different approaches as to the inclusion or not of the effect of existing policies and measures to reduce greenhouse gases emissions [4]. There is no single approach for dealing with this issue, so the general approach adopted in this paper is not to take into account specific policies and measures which the EU and Member States may have already put in place to reduce emissions. These reductions will be included in the reduction potential of the corresponding measure. Consequently, emission projections may differ from those reported in the above studies and by the Member States because the latter include the effect of some measures already implemented and/or planned [5] [6].

Non-CO_2 greenhouse gases emissions under a business-as-usual scenario are shown by sector in Table 2.

GHG	Sources	1990/1995 (*)	2010 (**)	2010 incr/decr (%)	2010 (in Mt CO2-equ.)
CH4	**Total**	**23309**	**21469**	**-8%**	**451**
	Agriculture	**9946**	**9248**	**-7%**	
	enteric fermentation	7054	6463	-8%	
	animal manures	2022	1928	-5%	
	other	870	857	-2%	
	Waste	**7991**	**8499**	**6%**	
	landfill	6641	7043	6%	
	waste water	1350	1456	8%	
	Energy	**5350**	**3697**	**-31%**	
	coal production	2936	822	-72%	
	oil and gas sectors	1561	2139	37%	
	fuel combustion	853	736	-14%	
	Other	**22**	**25**	**12%**	
N2O	**Total**	**1015**	**1093**	**8%**	**339**
	Agriculture	**417**	**377**	**-9%**	
	Waste	**11**	**11**	**0%**	
	Energy (combustion)	**175**	**268**	**53%**	
	Transport	41	146	256%	
	Other	134	122	-9%	
	Industrial processes	**357**	**381**	**7%**	
	Other	**55**	**55**	**0%**	
Halogenated gases		**58**	**82**	**41%**	**82**
	HFC's	**37**	**65**	**76%**	
	PFC's	**7**	**5**	**-29%**	
	SF6	**14**	**12**	**-14%**	
Basket of non-CO2 gases					**872**

(*) 1990 and in kt for CH4 and N2O; 1995 and in Mt CO2-equ. for HFC, PFC and SF6
(**) in kt for CH4 and N2O; in Mt CO2-equ. for HFC, PFC and SF6

Table 2: Non-CO_2 greenhouse gases in the EU under a business-as-usual scenario (kt/year)

By 2010, methane emissions would fall by 1.8 Mt to 8% below 1990 levels due predominantly to a dramatic decline in emissions from coal mining as coal production falls. There is also a significant reduction in livestock related emissions as cattle numbers are predicted to fall. These reductions are partially offset by increased emissions from landfills due to large volumes of waste produced and hence disposed to landfill and a small rise in emissions from the oil and gas sector due essentially to increased gas consumption levels.

By 2010, nitrous oxide emissions are projected to increase by 8% (78 kt) from 1990. This is mainly due to an increase in emissions (of 93 kt) from road transport, due to the increased penetration of catalytic converters. There is also an increase (of 24 kt) in emissions from production processes which is partially offset by a fall (of 40 kt) in agricultural emissions. The business-as-usual projections do not include reductions of around 240 kt (in 2010) resulting from abatement plans installed or due to be installed at the main adipic acid EU production plants.

Finally, emissions of the three halogenated gases are projected to increase by 41% in 2010 compared to 1990 levels due essentially to a significant increase in HFC's emissions (78%); PFC's and SF_6 emissions are projected to decrease by 29% and 14% respectively over the same period due to a decrease in aluminium production and in the use of high-voltage switches in the EU.

Table 3 summarises the emission projections under a business-as-usual scenario for the basket of six gases. Overall, emissions are projected to increase by 6% in 2010 compared to 1990 levels.

	1990 1995 for halog.	2010 BAU (*)	2010 % of 1990
CO2	3365	3617	7%
CH4	489	451	-8%
N2O	315	339	8%
HFC+PFC+SF6	58	82	41%
Basket of six	4227	4489	6%
Kyoto target		3889	
Reduction needed		600	

(*) CO2 emission projections are calculated on the basis of the pre-Kyoto scenario which assumes an 8% increase in (energy-related) CO2 emissions by 2010 compared to 1990. Other CO2 emissions are assumed to remain constant.

Table 3: Business-as-usual projections for the basket of six gases (in Mt CO_2 equivalent)

The above projections should be regarded with caution; uncertainty in emission estimates for some sources is significant, a new baseline energy scenario is under development, forecasts for the three industrial gases are hampered by inconsistencies, lack of data for some countries and several source categories. For these reasons, Table 3 only gives an order of magnitude of the challenge.

The emission reduction required compared to business-as-usual (as defined in Table 3) is estimated to be about 600 Mt CO_2 equivalent for the six gases. Because this overall challenge excludes the effect of current policies equivalent to around 140 Mt of CO_2 [7], it is comparable to that under the pre-Kyoto communication (COM(97)481 final) where around 500 Mt of additional emission reduction was estimated to be necessary to meet the EU Kyoto target.

4. Emission reduction measures, potential and costs in 2010

Measures have been identified to reduce non-CO_2 emissions in all of the main sectors, together with estimates of the achievable reductions in 2010 compared to the business-as-usual scenario and mitigation costs.

In general, similar mitigation options have been considered in the above studies (see list in Annex 1). The major difference concerns mitigation options for methane in the agricultural sector. On the basis of a recent study by the Agricultural University of Wageningen (Gerbens, 1998), further measures have been considered in the Ecofys study; these measures aim at improving feed conversion efficiency by adjusting animal diets. Another difference, which has however a lower impact on emission reductions, concerns mitigation options for N_2O in the energy sector. The AEAT study has estimated the impact on N_2O emissions of several CO_2 reduction measures such as the introduction of energy efficiency measures and renewables in the energy supply sector, and inter-modal shift in the transport sector.

Although different assumptions have sometimes been made as to the applicability of individual measures, overall both studies have estimated comparable achievable reductions for methane and nitrous oxide emissions provided the same mitigation options are considered.

The reduction costs of the different measures or packages of measures have been estimated on the basis of direct (private) resource costs (i.e. investment costs, operation and maintenance costs, and potential cost savings).

Large cost ranges for some measures and small differences in costing methodology and approach [8] have led to sometimes big differences in cost estimates between the two studies. Nevertheless, a number of measures have been identified in the same cost ranges. Three cost categories are thus considered in this analysis that correspond to different cost ranges, and mitigation options are ranked according to these cost categories. The "low cost" category corresponds to measures identified as having "negative costs"[2] (or as being "cost-positive" according to AEAT study). The "medium cost" category encompasses measures with a marginal reduction cost ranging from 0 to 50 ECU per tonne CO_2 equivalent abated. Finally, the "high cost" category characterises the measures which fall above the limit of 50 ECU per tonne CO_2 equivalent abated.

The potential reductions and costs of non-CO_2 mitigation measures are summarised below.

For methane, the set of options is estimated to offer total reductions of 9 Mt (or 189 Mt CO_2 equivalent) in 2010 and would bring methane emissions down to 53% of 1990 levels. In other words, methane emissions could be reduced by 47% in 2010 compared to 1990 levels. The largest reductions (Table 4.1) arise from measures directed at landfilling of waste (4.7 Mt), although significant reductions are also available in the agricultural sector (2.9 Mt) and in the oil and gas sector (1.3 Mt).

Total reductions include methane reductions from landfills as resulting from the implementation of Member States' current and planned measures (i.e. utilisation or flaring of landfill gas and diversion of organic waste from landfill). These measures are estimated to deliver reductions of 3.2 Mt by 2010. Their implementation is also suggested under the proposed Landfill Directive.

Reductions in enteric fermentation emissions have been estimated on the basis of a single and recent study (1998). Further studies are maybe required to confirm the estimated reduction potential of around 1.6 Mt, which represent more than 50% of reductions estimated in the agricultural sector.

A number of mitigation options were also identified in the energy sector (some recovery of mine methane, various measures in the oil and gas sectors), their potential reductions in 2010 have been estimated at around 1.7 Mt

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[2] Cost savings more than offset the cost of the measure.

80% of total estimated reductions (7.2 Mt) could be reduced at a cost below 50 ECU/tonne CO_2 equivalent.

Sources	Reduction in 2010		Cost range	red. 2010/1990
	(kt)	(Mt CO2-equ.)	(ECU/t CO2-equ.)	(%) (*)
Total	**8999**	**189**		**-47%**
(BaU)				(-8%)
low cost measures	2883	61	< 0	-20%
medium cost measures	4337	91	0-50	-39%
high cost measures	1779	37	> 50	-47%
Agriculture	2874	60		
enteric fermentation	1600	34	< 0	
	83	2	> 50	
animal manures	969	20	0-50	
	222	5	> 50	
Waste				
landfill	4655	98		
	1110	23	< 0	
	2867	60	0-50	
	678	14	> 50	
Energy				
coal production	140	3	< 50	
oil and gas sectors	1330	28		
	173	4	< 0	
	361	8	0-50	
	796	17	> 50	

(*) cumulative, i.e. percentage reduction accounts for lower cost measures.

Table 4.1: Reductions and costs of CH_4 mitigation options

With all measures implemented, nitrous oxide emissions could be reduced by 385 kt (or 119 Mt CO_2 equivalent) in 2010. This would bring emissions 30% below 1990 levels. The largest reductions (Table 4.2) arise from measures directed at adipic and nitric acid production. Reductions of 237 kt result from the installation of abatement equipment at the main adipic acid manufacturing plants in the EU; further reductions of 39 kt are possible by abating emissions at the remaining adipic acid plants and at nitric acid plants.

The "package of options" identified for the agricultural sector offer the second greatest savings, with a reduction potential of 79 kt [9]. Measures identified in the other sector would contribute to less than 8% of total reductions.

Sources	Reduction in 2010		Cost range	red. 2010/1990
	(kt)	(Mt CO2-equ.)	(ECU/t CO2-equ.)	(%) (*)
Total	**385**	**119**		**-30%**
(BaU)				(8%)
low cost measures	3	1	< 0	7%
medium cost measures	277	86	0-50	-20%
agriculture	79	24		
by-product of CO2 red.	26	8		
Agriculture	79	24		
Waste	3	1	< 0	
Energy (combustion)				
Transport	10	3	(**)	
Other	16	5	(**)	
Industrial processes				
adipic acid production	261	81	0-50	
nitric acid production	16	5	0-50	

(*) cumulative, i.e. percentage reduction accounts for lower cost measures.
(**) costs not estimated; by-product of CO2 reduction policies

Table 4.2: Reductions and costs of N_2O mitigation options

The preliminary estimate of potential reductions of halogenated gases emissions reported in the Ecofys study, suggests that emission reductions of 72 Mt CO_2 equivalent would be feasible in 2010 and would bring total emissions of the three gases 82% below 1990 levels. The largest reductions (Table 4.3) arise from measures aimed at HFC reduction (61 Mt CO_2 equivalent).

More than 80% of total estimated reductions have a cost below 50 ECU/tonne CO_2.

Sources	Red. in 2010 (Mt CO2-equ.)	Cost range (ECU/t CO2-equ.)	red. 2010/1990 (%) (*)
Total halogenated gases	**72**		**-82%**
(BaU)			(41%)
low cost measures	0	< 0	41%
medium cost measures	59	0-50	-61%
high cost measures	12	> 50	-82%
HCF's			
HCFC-22 production	9	0-50	
refrigeration	9	0-50	
	12	> 50	
Other	30	0-50	
PFC's			
aluminium production	4	0-50	
SF6			
package of measures	7	0-50	

(*) cumulative, i.e. percentage reduction accounts for lower cost measures.

Table 4.3: Reductions and costs of mitigation options for the three halogenated gases

5. Conclusions

Emissions of non-CO_2 greenhouse gases under a business-as-usual scenario are projected to increase by 1% in 2010 compared to 1990/1995 levels. This is the result of the combination of a downward trend for methane emissions (-8%) and upward trends for nitrous oxide and the three halogenated gases emissions (+11% and +41% respectively).

This examination of measures to reduce non-CO_2 greenhouse gases emissions shows that such measures could make a substantial contribution to the achievement of the EU's Kyoto target.

The implementation of all measures identified would lead to a reduction of 380 Mt CO_2 equivalent in 2010. This would bring total non-CO_2 emissions to 43% (370 Mt CO_2 equivalent) below 1990 levels by 2010.

The EU six gas basket of emissions in 1990 is estimated to be about 4227 Mt CO_2 and a reduction of 600 Mt of CO_2 would be required to meet the EU's Kyoto target.

The identified reduction in non-CO_2 emissions is equivalent to 63% of total reduction needed, and would bring emissions of the six gas basket to 2.5% below 1990 levels by 2010.

Reductions from agricultural measures have been estimated at 85 Mt CO_2 (Table 5), these measures are potentially the most difficult to implement and estimates of their applicability and impact have still high level of uncertainty (this is particularly true for nitrous oxide and for methane from enteric fermentation).

Reductions from non-agricultural measures have been estimated at 295 Mt CO_2 (Table 5), of which half corresponds to reductions resulting from the implementation of existing and planned measures directed at landfilling of waste and adipic acid manufacturing plants. The cost-effectiveness analysis shows that 252 Mt CO_2 can be reduced at a cost below 50 ECU/tonne CO_2. With only non-agricultural measures implemented, emissions of the six gas basket are projected to stabilise at 1990 levels by 2010.

The emissions projections and reductions from measures reported in the two studies on CH4 and N2O and in this synthesis paper are compared in more detail in Annex 2.

Agricultural measures

	Em. reductions in 2010 (Mt CO2 equ)	Costs (ECU/t CO2 equ)
CH4		
	34	< 0
	20	0-50
	7	> 50
N2O		
	24	
Total non-CO2	**85**	

Non agricultural measures

	Em. reductions in 2010 (Mt CO2 equ)	Costs (ECU/t CO2 equ)
CH4		
	27	< 0
	71	0-50
	31	> 50
N2O		
	9	< 0
	86	0-50
HFC, PFC, SF6		
	0	< 0
	59	0-50
	12	> 50
Total non-CO2	**295**	
of which	36	< 0
	216	0-50
	43	> 50
Measures in place	146	
Additional measures	149	

Table 5: Synthesis of reductions and costs of non-CO_2 mitigation options

6. Comments

[1] Expert Group on Climate Change, "Community target - adjustments for extra gases and sinks resulting from Kyoto protocol", fax from DETR dated 19 February 1998; and
Expert Group on Climate Change, Comments to the letter "Burden sharing: data on greenhouse gas emissions and removal by sinks", fax from DETR dated 19 January 1998.

[2] In the AEAT nitrous oxide report, emissions from the agricultural sector were modelled using the revised IPCC methodology (IPCC, 1997) and for the EU were found to be 20% higher than those reported by Member States in their second national communications. This is believed to be due to the fact that not all Member States had yet adopted the revised IPCC methodology. In any case, N_2O emission estimates from agricultural soils have still very high levels of uncertainty.

[3] The only major difference between the studies concerns methane emissions from gas pipeline leakages. Although both studies based their calculation on the pre-Kyoto energy scenario (DGXVII, July 1997), AEAT assumes an overall better improvement of gas pipeline systems due to significantly lower leakage rates from new polyethylene gas distibution pipes, based on UK figures. Overall, methane emissions from oil and gas sectors are estimated to increase by only 10% between 1990 and 2010 in the AEAT study, compared to 37% in the Ecofys study. Gas consumption in the EU would increase by 98% over the same period. The above difference in BAU emission trend has little impact on the calculation of the reduction potential which is based on mitigation options independent of the leakage rate of new gas pipelines. In this paper, the Ecofys BAU emission trend was chosen.

[4] The AEAT business-as-usual projections of nitrous oxide emissions take into account the abatement measures taken at the main adipic acid manufacturing plants, while the Ecofys business-as-usual projections of nitrous oxide emissions do not. On the contrary, the Ecofys business-as-usual projections of methane emissions from landfills take into account the abatement measures taken or planned by the Member States (according to the *Expert Group's work on EU common and coordinated measures (landfill emissions))*, while the AEAT business-as-usual projections do not.

[5] Business-as-usual projections of methane emissions are similar to the ones reported in the AEAT report (a decrease by 9% in 2010 below 1990 levels), the difference comes from the oil and gas sector where emissions are predicted to increase less (see [3]); they are however far different from Ecofys' projections (a decrease by 26% in 2010 below 1990 levels) because the latter include the effect of existing and planned policies and measures to reduce emissions from landfills. If these measures were taken into account in the BaU projections reported here, methane emissions would have fallen by 22% in 2010 below 1990 levels.

Business-as-usual projections of nitrous oxide emissions are similar to the ones reported in the Ecofys report (an increase by 9% in 2010 above1990 levels), the small difference comes from the agricultural sector where emissions are predicted to decrease less; they are however far different from AEAT projections (a decrease by 15% in 2010 below 1990 levels) because these include the effect of existing measures to reduce emissions from adipic acid manufacturing plants (industrial processes). If these measures were taken into account in the BaU projections reported here, nitrous oxide emissions would have fallen by 16% in 2010 below 1990 levels.

[6] Emissions in 1990 provided in the above studies are not always in close agreement with emissions provided by the Member States and reported the EU Second Communication. This is believed to be due to the fact that Member States, Ecofys and AEAT have not used the same methodology for estimating emissions. In order to ensure consistency with national estimates, emission projections have been scaled by the difference in the 1990 emission estimates.

[7] According to AEAT and Ecofys' studies, current Member States policies would allow to reduce methane emissions from landfills by around 73 Mt of CO_2 and nitrous oxide emissions from adipic acid production by 73 Mt of CO_2.

[8] Both studies have used a bottom-up costing approach to estimate the cost-effectiveness of the various measures: only direct resource costs are taken into account, namely investment, operation and maintenance, energy costs and cost savings. The assessment does not include any positive or negative macroeconomic impacts that might occur if certain mainly economic instruments are used to implement the technical measures, nor any estimate of social resource costs or secondary environmental benefits. Costs are calculated as the ratio between the yearly costs of the measure and the resulting yearly emission reduction. The calculation of the yearly costs differ however slightly in the two

studies; in the AEAT study, a levelised cost/discounting method is used with a discounting rate of 8%; in the Ecofys study the total cost stream is only annualised over the lifetime of the equipment, the annuity factor is calculated with a discounting rate of 15%. Differences in methodology are however small compared to differences in costs associated with some mitigation options.

[9] The reduction potential is derived by scaling AEAT's reduction estimate of 114 kt by the ratio between AEAT's estimate of 1990 agricultural N2O emissions (using a revised methodology) and the value for 1990 reported in this paper in Table 2.

Annex

Comparison between figures provided in the studies and in the synthesis paper: CH4 and N2O

METHANE

	1990	2010 BAU		2010 without agr. measures		2010 with all measures included		reduction 2010 without agr.	reduction 2010 all measures	reduction 2010 from agr.
	Mt CO2	Mt CO2	% of 1990	Mt CO2	% of 1990	Mt CO2	% of 1990	Mt CO2	Mt CO2	Mt CO2
Ecofys (Coherence report)	492	364	-26%	290	-41%	239	-51%	74	125	50
AEAT (*)	490	443	-10%	314	-36%	294	-40%	129	149	20
Paper of 20 Oct.98	489	451	-8%	322	-34%	262	-46%	129	189	60
		(1) (2)		(3)						(4)

NITROUS OXIDE

	1990	2010 BAU		2010 without agr. measures		2010 with all measures included		reduction 2010 without agr.	reduction 2010 all measures	reduction 2010 from agr.
	Mt CO2	Mt CO2	% of 1990	Mt CO2	% of 1990	Mt CO2	% of 1990	Mt CO2	Mt CO2	Mt CO2
Ecofys (Coherence report)	313	342	9%	250	-20%	229	-27%	92	113	21
AEAT	377	322	-15%	302	-20%	266	-29%	20	56	36
Paper of 20 Oct.98	315	339	8%	244	-23%	220	-30%	95	119	24
	(5)		(6)				(7)	(6)		

(*) Figures for 2010 have been revised from the September report.

EU's Kyoto target

	Basket of six 1990/1995 Mt CO2	Basket of six 2010 BAU Mt CO2	Mt CO2 Reduction needed in 2010
Ecofys (Coherence report)	4228	4405	515
AEAT	4290	4464	517
Paper of 20 Oct.98	4227	4489	600
	(8)	(8)	

Contribution of GHG to EU's Kyoto target

	Reduction needed in 2010	CH4 non-agr.	CH4 agr.	N2O non-agr.	N2O agr.	halog. gases	CO2
Ecofys (Coherence report)	515	74	50	92	21	72	205
AEAT	517	129	20	20	36	72	240
Paper of 20 Oct.98	600	129	60	95	24	72	220
						(9)	(10)

Explanation of major differences

(1): Ecofys' BAU scenario includes existing and planned measures to reduce CH4 from landfills. The reduction potential in 2010 is therefore lower than in AEAT study.
AEAT study and the paper do not incorporate in the BAU scenario CH4 abatement measures in place.

(2): AEAT's BAU assumes significant reductions from new gas distribution pipes based on UK figures (leakage rate from new pipes is calculated as a percentage of leakage rate of old distribution pipelines in the UK; the same percentage is applied in all MS despite the fact that MS other than UK have average leakage rates of existing distribution network far lower than in the UK). However, the AEAT methodology has the advantage to distinguish between the transmission and distribution systems for additional gas consumption, which is important as the latter is the main source of methane emissions.
The Ecofys approach is more global in the sense that methane emissions are estimated on the basis of total gas throughput (or inland consumption) and an average "target" leakage rate for the overall gas network of at most 0.5% in 2010 (the average leakage rates in the MS ranged from 0.5% to 2% in 1990). One may however argue that it is too approximative as it does not account for the characteristics of the national gas networks (e.g. operating pressure, length of transmission network versus length of distribution network, length according to the material of the pipes etc).

(3): The level of emissions is lower in Ecofys' study because it assumes higher reductions from measures in the gas sector (compressors and replacement of old grey cast iron pipes)

(4): Agricultural measures are different in Ecofys and AEAT syudies. The reduction potential is higher in the synthesis paper because it sums up the effect of measures in both studies.

(5): In the AEAT study, agricultural emissions for 1990 and future years have been calculated using the revised IPCC methodology; for the EU they were found to be 20% higher than those reported in the EU second communication and used by Ecofys and in the synthesis paper.

(6): AEAT' s BAU scenario includes existing N2O abatement plans at the main adipic acid manufacturing plants; so BAU emissions are lower than in the two other analyses.
The reduction potential in 2010 is therefore lower than in the other two analyses. Ecofys' study and the paper do not incorporate in the BAU scenario N2O abatement measures in place.

(7): Emission projections with all measures included are lower in the paper than in the other two studies because it sums up the effect of measures considered in the two studies (no measure in the waste water sector in AEAT's study (reduction of 1 Mt CO2); no measure in the energy sector in Ecofys'study (reduction of 8 Mt CO2)).

(8): CO2 and halogenated gases emissions as in Table 3 of the paper.

(9): Reduction potential taken from Table 4.3 of the paper.

(10): CO2 contribution to the EU's Kyoto target if all measures identified for non-CO2 greenhouse gases are implemented irrespective of their cost and political applicability.
If only abatement measures with a cost lower than 50 ECU/t CO2 were implemented, CO2 contribution would be higher by 20 to 30% (270 to 300 Mt).