Analysis of international and European policy instruments: pollution swapping

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Alterra, Wageningen, 31 May 2007

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Service contract "Integrated measures in agriculture to reduce ammonia emissions"
Contract number 070501/2005/422822/MAR/C1

Task 2

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Alterra, Wageningen, 31 May 2007

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SUMMARY

The European Commission, Directorate-General Environment, has contracted Alterra, Wageningen UR for the "Service contract: integrated measures in agriculture to reduce ammonia emissions". The general objective of the service contract is to have defined the most appropriate integrated and consistent actions to reduce various environmental impacts (notably water, air, climate change) from agriculture. Specifically, the objective is to have developed and applied a methodology allowing the assessment and quantification of the costs and the effects of various policies and measures aiming at reducing the impact of agriculture on ammonia emissions and the interactions between water and air quality and climate change. Both ancillary benefits and trade-offs of measures have to be identified. The impacts and feasibility of the most promising measures have to be analysed in depth. The service contract contains the following five tasks:

Task 1. *Develop an integrated approach.*
Task 2. *Analysis of International and European instruments*
Task 3. *In depth assessment of the most promising measures*
Task 4. *Impact assessment of a possible modification of the IPCC directive*
Task 5. *Stakeholder consultation, presentations, workshops.*

This Report describes the results of Task 2 'Analysis of International and European policy instruments'. The aim of this task is to analyze the existing International and European policy instruments aiming at reducing emissions of ammonia, nitrous oxide and methane to the atmosphere and nitrate to groundwater and surface waters. Specifically, the study addresses the possible synergies and/or possible antagonisms in these policies, and provides suggestions and recommendations to ensure an optimal coherence.

The following policy instruments have been assessed in terms of synergistic effects and antagonistic effects (pollution swapping):

- Nitrate leaching abatement measures of the Nitrate Directive (as well as the Groundwater Directive and Water Framework Directive);
- Ammonia abatement measures of UNECE-CLTRAP, plus the IPPC and NEC Directives;
- Measures of the Birds and Habitats Directives;
- Cross-compliance measures linked to the Reform of the Common Agricultural Policy;
- Measures of the Rural Development Regulation; and
- Measures to decrease nitrous oxide and methane emissions, relevant for the Kyoto Protocol under the Framework Convention on Climate Change.

The term "pollution swapping" refers to a special side-effect of policies and measures, i.e., the unwanted increase of another pollutant, and/or the unwanted increase of the emission of the target pollutant elsewhere. The assessments in this report are qualitative, and based on a simple conceptual model and a categorization of policies and measures in six categories. Quantitative assessments are made elsewhere under Tasks 1, 3 and 4.
In this study, two types of pollution swapping have been distinguished:

- Type 1: swapping to other pollutants (i.e., decreasing the loss of one N species at the expense of other N species, or of other non-N pollutants); and
- Type 2 swapping to other areas (i.e., transferring the pollution potential from one area to another).

Obviously, type 2 pollution swapping can be beneficial if the emissions are removed from sensitive areas to less sensitive areas, even though the total emissions are not decreased.

Measures were categorized in six categories according to their pollution swapping potential and their effectiveness in decreasing emissions:
(i) Mitigation or abatement of N species emissions (e.g., low-emission storage and application of animal manure to decrease NH_3 emissions; no manure application in winter and the growth of cover crops to decrease nitrate leaching);
(ii) Controlling N input (e.g., low-protein animal feeding, balanced fertilization);
(iii) Extensification of agricultural production and environmental protection (e.g., in the framework of Rural Development Regulation 1692/2005 and the Birds and Habitats Directives);
(iv) Regulations on animal welfare (e.g., minimal limits for the space and bedding material of animal housing systems, may effect animal feed use efficiency and emissions of NH_3, N_2O and CH_4);
(v) Improving the competitiveness of agricultural sectors (e.g., through modernization of farm buildings, improving infrastructure; may effect emissions of NH_3, N_2O and CH_4); and
(vi) Spatial zoning (e.g., restriction on farm activities near Natura 2000 areas and special obligations (Action Program measures) in Nitrate Vulnerable Zones).

The results indicate that abatement measures for nitrate leaching (in the framework of Nitrates Directive) and ammonia emission (in the framework of UNECE-CLTRAP, and the IPPC and NEC Directives) may both contribute to type 1 'pollution swapping', but that the potential of ammonia emission abatement measures to contribute to pollution swapping is larger than that of the nitrate leaching abatement measures. Spatial zoning of Nitrate Vulnerable Zones in the context of the Nitrates Directive and of Nature 2000 within the context of the Bird and Habitat Directives may contribute to type 2 pollution swapping.

The following recommendations have been made:

- The measures dealing with N input control in the Nitrates Directive (Balanced N fertilization) under the UNECE – CLRTAP and the IPPC and NEC Directives (protein content of the animal, integrated N management) should be the guiding and over- arching principle of controlling the NH_3 and N_2O emission and NO_3 leaching control, as these measures lead to increase N use efficiency.
- The implementation and enforcement of the measures of the Nitrates Directive must be considered jointly with those of UNECE – CLRTAP and the IPPC and NEC Directives, so as to circumvent Type 1 pollution swapping.
- In addition to NH_3 emission ceilings, input limits for N from animal manure and NO_3 concentration in groundwater and surface waters, there is scope for formulating targets for N use efficiency for specified farming systems.
- There is scope for introducing effective and efficient economic incentives to abate NH_3 and N_2O emissions and NO_3 leaching simultaneously, provided that N input control is the guiding and overall arching principle and that there is a well-balanced and joint implementation.

- Providing incentives via Rural Development measures to the N use efficiency for specified farming systems may provide opportunities for rewarding those farmers that go beyond certain standard criteria and thereby decreasing N losses in an integrated way.
- A tax on N fertilizer (or on fossil energy sources) and / or on protein-rich animal feed stuffs may also contribute to N input control and to increasing N use efficiency, and thereby on decreasing N losses in an integrated way. However, a tax on N fertilizer and/or protein-rich animal feed will also penalise farmers that use N fertilizer and protein-rich animal feed judiciously, and was therefore considered unfeasible in the recent past. With a greater priority in EU policy on climate change, fossil energy use and N emission control, new perspectives may emerge.
- Some of the animal welfare regulations for animal housing should be combined with NH_3 and N_2O abatement measures and NO_3 leaching abatement measures, as regulations ensuring minimum standard surface areas and bedding materials for animals may lead to increases of these emissions.
- In addition to spatial *zoning* of areas with high nature values and/or vulnerable to NO_3 leaching (within the context of the Nitrates Directive and the Birds and Habitats Directives), there is scope for spatial *planning* of N polluting agricultural activities in areas that are less vulnerable. This can be relevant also given the trends towards conglomerating large, specialized and intensive farms in areas with better opportunities to decrease production costs (low prices of labour and land, and hence cost-specific advantages).
- The role of the agro-complex (suppliers, farmers, processing industry and retailers) has so far received little or no attention in decreasing N losses from agriculture. This is surprising, as the agro-complex and especially suppliers, processing industry and retailers play a dominant role in (the development of) agriculture. It is suggested to explore the potentials of the agro-complex in improving N use efficiency and decreasing N losses from agriculture.

1 INTRODUCTION

The European Commission, Directorate-General Environment has contracted Alterra, Wageningen UR for the "Service contract: integrated measures in agriculture to reduce ammonia emissions". The general objective of the service contract is to have defined the most appropriate integrated and consistent actions to reduce various environmental impacts (notably water, air, climate change) from agriculture. Specifically, the objective is to have developed and applied a methodology allowing the assessment and quantification of the costs and the effects of various policies and measures aiming at reducing the impact of agriculture on water air pollution and climate change. Both ancillary benefits and trade-offs of measures have to be identified. The impacts and feasibility of the most promising measures have to be analysed in depth. The service contract contains the following five tasks:

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This report describes the results of task 2 'Analysis of International and European policy instruments'. The general aim of this task is defined as follows:
To qualitatively analyze the existing International and European policy instruments aiming at reducing emissions of ammonia, nitrous oxide and methane to the atmosphere and nitrate to groundwater and surface waters.
Specifically, the policy instruments have to be assessed in terms of synergistic effects and antagonistic effects (pollution swapping). Pollution swapping refers to a special side-effect of policies and measures, i.e., the unwanted increase of another pollutant, and/or the increase of the emission of the target pollutant elsewhere. The assessments in this report are qualitative, and based on a simple conceptual model and a categorization of policies and measures in six categories. Quantitative assessments are made in Tasks 1, 3 and 4.

The output of this task has been defined as a technical report describing the results of the abovementioned analysis, and this is provided by the present report. The next chapter (Chapter 2) provides background information about the cycling and loss of nitrogen (N) species from agriculture, and of the possible measure to decrease these losses. It provides also a brief overview of the measures of the policy instrument that affect the cycling and losses of N from agriculture. Further, it elaborates the definition of pollution swapping mechanisms as applied in this study. Chapter 3 briefly summarizes the methodology and Chapter 4 provides an overview of the assessments. Chapter 5 finally discusses the implications of the main findings of this study, summarizes the conclusions and provides some suggestions.

2 BACKGROUND DESCRIPTION

2.1 Nitrogen cycling and the nitrogen cascade

Nitrogen (N) is one of the most widely distributed elements on earth. It is a key element in protein, and the growth of plants heavily depends on the availability of N. The atmosphere is the largest reservoir of N (Schlesinger, 1991), but most of this N is present as molecular N_2, and this N is not directly available to most plant species. On earth, most of the N is locked up in soils, sediments and rocks, and is also inaccessible for plant roots (e.g., organically bound N and NH_4^+ fixed in clays and shale). As a consequence, the productivity of many ecosystems and especially agroecosystems is limited by shortage of plant-available N (Schlesinger, 1991).

The availability of relatively cheap N fertilizers from the 1950s onwards has contributed to a boost in crop production. Indeed, fertilizer N has made a substantial contribution to the tripling of global food production over the past 50 years (Smil, 2000; 2001). The availability of the N fertilizers has indirectly also contributed to the rapid increase in the number of farm animals and the production of N in animal manure (Steinfeld et al., 2006). Currently, roughly equal amounts of N become available in global N fertilizer production and in global animal manure production. Unfortunately, both the distributions of fertilizer N use and animal manure production over the globe are not uniform (Mosier et al., 2004; Smil 2002; Steinfeld et al., 2006).

In some areas of the world, relatively large amounts of N fertilizers are used, and large amounts of farm animals are kept on relatively small areas. Excessive use of N in amounts that exceed plant needs can lead to various problems related to human health, and ecosystem vulnerability. Even moderate but injudicious use of N may lead to various environmental problems. N appears in various species, with various oxidation states, mobility and reactivity. The term "reactive N" (Nr) includes all biologically active, photochemically reactive, and radiatively active N compounds in the atmosphere and biosphere of the Earth, i.e. inorganic reduced forms of N (e.g., NH_3, NH_4^+), inorganic oxidized forms (e.g., NO_x, HNO_3, N_2O, NO_3^-), and organic compounds (e.g., urea, amines, proteins).

Galloway (2003) and Galloway et al. (2002) made an integral analysis of the cause - effect relationship between the creation of reactive N and a sequence of environmental effects, using the so-called "nitrogen cascade" (Figure 1). Observed environmental effects include:

- decreased species diversity and acidification of non-agricultural soils because of deposition of NH_3 (e.g. De Vries et al., 1995);
- pollution of ground water and drinking water due to nitrate leaching;
- eutrophication of surface waters, including excess algal growth and a decrease in natural diversity due to N leaching and run-off;
- global warming because of emission of N_2O;
- impacts on human health, due to particle matter ($PM_{2.5}$) and smog formation,
- impacts on human health and plants due to ozone for which NO_x is a precursor, and
- stratospheric ozone destruction due to N_2O.

The nitrogen cascade illustrates the movement of human-produced reactive N as it cycles through various environmental reservoirs in the atmosphere, terrestrial ecosystems, and aquatic ecosystems before it returns to the atmosphere as non-reactive N_2 following denitrification. The nitrogen cascade illustrates the multiple effects N has in the environment. The cascade also illustrates the complexity involved of reducing one emission pathway, without consideration of the total N supply (Erisman et al., 2005).

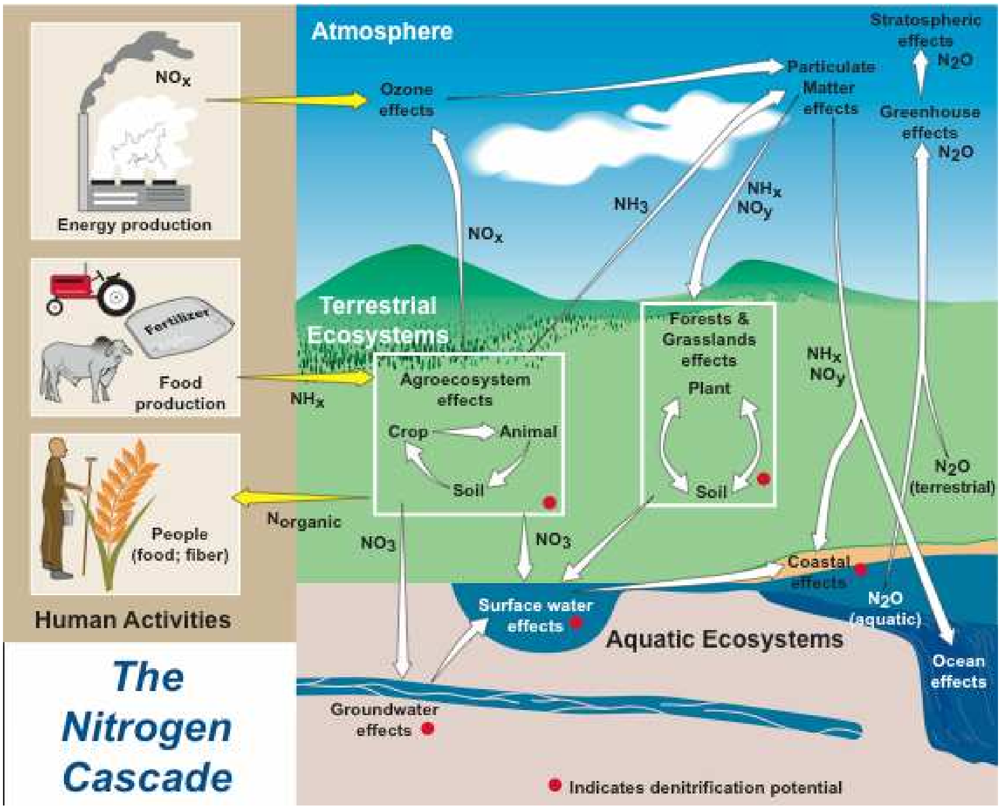

Figure 1 The Nitrogen Cascade (From UNEP, 2004).

2.2 Nitrogen emissions from agriculture in the EU

The amount of N used in EU agriculture is large, relative to other sectors and also relative to other continents (e.g., Kuczybski et al., 2005; Van Egmond et al., 2002; Mosier et al., 2004). Currently, agriculture is a main source of nitrate in groundwater, of N and P in surface waters and of ammonia and nitrous oxide in the atmosphere. Estimates suggest that the contribution of agriculture to the emissions of ammonia is about 80 - 90% and that of nitrous oxide in the range of 30 to 60% (Bouwman et al., 1997; Mosier et al., 1998; Kuczybski et al., 2005; EEA, 2005). The contribution of agriculture to the loading of surface waters with N is a matter of great uncertainty; the OECD gives a range of 30 to 80% for N and of 20 to 45% for P (OECD, 2001). The European Environmental Agency (EEA) gives a range of 50 to 80% for N and P (EEA, 2005).

Ammonia emissions play a significant role in national and international environmental policy (Kuczybski et al., 2005). Ever since evidence was brought to the stage – in the early 1980’s – that NH_3 was contributing to environmental acidification, several countries have been working on legislation to abate NH_3 emissions and hence to reduce acidification and eutrophication. However, it has only been with the 1999 Gothenburg Protocol of the UNECE and the EU National Emissions Ceilings (NEC) Directive, also of 1999, that international commitments have been made to reduce ammonia emissions. Many Member States appear to be able to reach the National Emission Ceilings of the NEC Directive for 2010, but others not (Figure 2). This means that still major effort is needed for various countries (Kuczybski et al., 2005). In addition, it should be recognized that, even if the present ceilings are met, ammonia will still make a major contribution to acidification, eutrophication and particulate matter problem across Europe. In addition, there remain significant interactions between ammonia and other forms of pollution including the global greenhouse balance and water eutrophication by nitrates and phosphorus.

Figure 2. Overview of estimated total ammonia emissions (in kton per year) in EU Member States and some other countries in 2000 and according to projections for 2010 and 2020 according to various scenarios. Current emission ceilings for 2010 in the framework of the NEC Directive are shown in the fourth column. Note that the CAFÉ baseline was made in 2004 before the mid-term Review of the Common Agricultural Policy (CAP), while the National projections and the CAPRI- mid-term scenarios for 2020 do include the effects of the reform of the CAP. Note also that emissions from agriculture are about 92% of the total emissions (Source: Amann et al., 2006a).

	2000	*2010* National agricultural projections	*2010* Emission ceiling	*Projection for 2020* National agricultural projections	CAPRI mid-term scenario	CAFE baseline
Austria	60	57	66	59	59	54
Belgium	87	87	74	84	86	76
Cyprus	7	7	9	7	7	6
Czech Rep.	84	76	80	75	77	65
Denmark	90	78	69	73	73	78
Estonia	9	10	29	10	10	12
Finland	35	30	31	26	32	32
France	691	644	780	640	664	702
Germany	602	473	550	450	453	603
Greece	54	48	73	45	46	52
Hungary	77	75	90	83	69	85
Ireland	122	98	116	89	100	121
Italy	428	406	419	396	366	399
Latvia	13	14	44	14	12	16
Lithuania	37	36	84	39	39	57
Luxembourg	6	6	7	6	6	6
Malta	2	1	3	2	2	1
Netherlands	151	125	128	140	133	140
Poland	317	316	468	317	349	333
Portugal	77	73	90	66	62	67
Slovakia	31	30	39	31	30	33
Slovenia	20	21	20	20	19	20
Spain	394	355	353	363	362	370
Sweden	55	50	57	50	48	49
UK	328	267	297	268	282	310
EU-25	3778	3383 0	3976	3353	3386	3686
Bulgaria	70	64		66	65	
Croatia	28	30		32	32	
Romania	151	146		147	147	
Turkey	429	457		499	500	
Norway	24	21		20	21	
Switzerland	53	48		45	50	

Depending on soil type and land use, a substantial portion of European groundwater bodies is affected by nitrate from agricultural sources (Van Egmond et al., 2002; EEA, 2003). In various areas of Europe, the nitrate concentration in shallow groundwater exceeds the standards of 50 mg per l of the Nitrate Directive (Fraters et al., 2005, Zwart et al., 2006). For the Rhine River, the fourth largest river basin in Europe (after Volga, Danube, and Wisla) with a total surface area of 185,000 km^2, agriculture contributes 40 and

32% of the total loading of N and P, respectively (Van der Veeren, 2002). Levels of P have generally been decreasing in rivers and lakes in EU-15 during the 1990s. This decrease reflects the general improvement of the sewage treatment and the ban of P in detergents, but the loss of P from agriculture to surface waters has changed little.

The emissions of N_2O from agricultural soils reflect the use of N fertilizer and animal manure; the larger the use, the larger the emissions. Emissions are highest from wet soils and soils with high organic matter contents. In terms of CO_2-equivalents, the European greenhouse gas emissions from agricultural soils are composed of 1% CH_4, 11% CO_2, and 89% N_2O (Freibauer et al., 2003).

2.3 Measures to mitigate N emissions

Livestock farming systems are an important source of NH_3 and N_2O emissons to the atmosphere and nitrate to the groundwater. Four major compartments are distinguished in whole livestock farming systems, i.e. livestock, manure, land and crop (animal feed) (Figure 3). Nutrients cycle through these compartments. Animals utilize only a fraction (5 to 45%) of the N in the feed for the production of milk, meat, eggs and offspring (animal products) exported from the system. The greater part is excreted via faeces and urine, which is stored and managed for some time in various types of manure storage systems, or deposited directly on land and allowed to decompose in situ. Following storage, manure is applied to agricultural land to fertilize crops including grasslands. However, only about 30 to 60% of the manure N will be utilized by growing crops for the production of plant protein, and only the protein in the harvested fraction of the crop will feed people or livestock. Hence, in a livestock farming system only a minor fraction (usually less than 10%) of the N from manure is exported from the farm in animal products; the greater part will have dissipated into the wider environment.

There are many opportunities and places for N to escape from livestock farming systems. Significant losses of gaseous N compounds may occur via volatilization of NH_3, and via emissions of N_2O, nitric oxide (NO), and di-nitrogen (N_2) from nitrification and denitrification processes. The gaseous N compounds may escape from faeces and urine during storage in manure storage systems (lagoons, pits, manure heaps, manure silos), after deposition on pastures and paddocks by free ranging animals and after application of manure and fertilizers to agricultural land.

In addition, N may be lost from soil via leaching and runoff. An extensive of possible measures to decrease nitrate leaching has been presented by Cuttle et al., 2004).

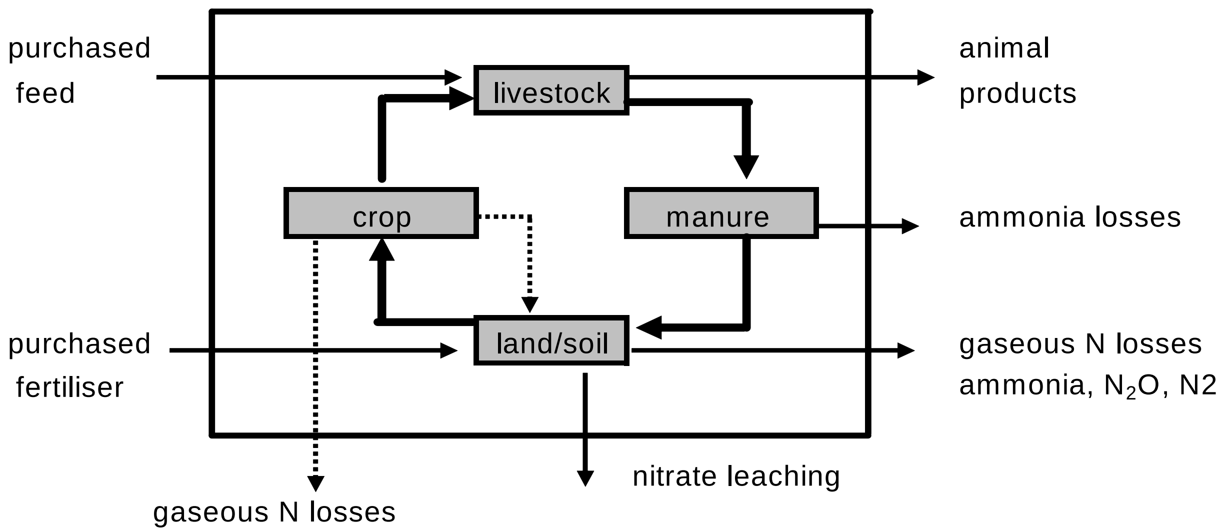

Figure 3. Simplified diagram of a whole livestock farming system, showing the four main compartments livestock, manure, land/soil and crop. The land/soil and crop compartments can be separated physically from the livestock and manure compartments, as is the case in specialized livestock farming systems without land. Arrows indicate the flows of N in products and as gaseous N losses (Oenema et al., 2001)

<u>N emission from animal housing</u>

Housed animals deposit faeces and urine in the housing system on litter, concrete floors, or fully or partially slatted floors. There is a wide variety of animal housing systems, ranging from simple shelters where animals find protection against sun, rain, cold and or wind, to climate controlled and mechanically vented large housing systems for e.g. poultry in battery cages and finishing hogs. Manure storage and manure management differs widely among these housing systems, ranging from paddocks and unpaved feedlots in dry climates to cubicle houses with slurry storage underneath slatted floors, to the manure belt system underneath battery cages in mechanically vented poultry housing systems with forced drying of the poultry manure (Kuczybski et al., 2005; Geers and Madec, 2006).

Animal manure collected in housing systems has to be stored for some time inside or outside the housing system until timely spreading of the manure on the field. In animal housing systems with (partially) slatted floors, the urine and faeces are mixed and stored as slurry in pits and channels underneath the slats. When the storage capacity inside the housing system is small, slurry will be stored outside in silos, tanks and lagoons. In tie stalls with litter, faeces mixed with litter and liquid manure are collected daily and stored outside in separate storage systems. In deep litter systems in organic farming, faeces and urine are absorbed by straw and compacted by the loose housed animals. The stacked manure will be removed from the deep litter system only two to three times a year and transported to a manure heap outside for another storage period, or it is directly applied to agricultural land. The total storage period of slurries and manure may range from a few weeks to more than 9 months. Because of the differences in housing system, manure management and storage period, there are large differences in N losses via emissions of

NH_3, NO, N_2O and N_2 between systems. There are also significant differences in methane emissions between manure management systems (Kuczybski et al., 2005).

The volatilization of NH_3 from the urine and faeces in slurry inside the animal housing system is related to the NH_4^+ concentration, pH and surface area of the slurry and to the temperature and ventilation in the housing system (Monteny, 2000; Sommer et al., 2006). The potential for NH_3 volatilization from slurry is large, because of the abundance of NH_4^+ and the relatively high pH of the slurry. Ammonia is emitted from both the (slatted) floors fouled with urine and faeces and from the slurry channels under slats. The larger the area fouled by the animals, the larger the NH_3 loss. The ventilation of the housing system determines the air exchange between the housing system and the outside atmosphere and thereby also the NH_3 loss; the larger the ventilation the larger the loss (e.g. Aarnink, 1997; Groot Koerkamp, 1994). Thus, emission may be mitigated by decreasing the fouled area either by decreasing the slatted area, by tying the animals or by decreasing the ventilation. Frequent cleaning of the floor also decreases NH_3 losses. Table 1 summarizes options to mitigate NH_3 emission from dairy cow buildings. Slurry stored in pits and channels underneath slatted floors is not a significant source of N_2O, NO or N_2, because very little NH_4^+ from the slurry is nitrified in the highly anoxic environment.

N emission from manure storage

Ammonia emission from slurry in open tanks, silos and lagoons ranges from 6 to 30% of the total N in stored slurry (Sommer, 1997; Harper et al., 2000). The NH_3 loss is related to environmental conditions (temperature and wind), slurry composition and surface area. Losses are larger from pig slurry than from cattle slurry, due to differences in NH_4^+ content. A cover on the slurry significantly decreases NH_3 loss. The cover may be a natural surface crust formed by solids floating on the surface, a cover of straw, peat or floating expanded clay particles, or a roof. Covers greatly decrease the air exchange rate between the surface of the slurry and the atmosphere by creating a stagnant air layer above the slurry through which NH_3 has to be transported by the slow process of diffusion.

Although anaerobically stored slurry is not a significant source of N_2O, NO or N_2, drying conditions may establish an environment at the surface where NH_4^+ from the slurry is nitrified and where N_2O, NO or N_2 is produced (Hüther et al., 1997).

Currently, there is much interest in various Member States in the EU in the anaerobic digestion of animal manure, with or without crop additions, to generate biogas (e.g., Holm-Nielsen, 2006). This trend of increased treatment and digestion of slurry may have also consequences for the emissions of NH_3, and N_2O. Digested slurry has relatively high concentrations of NH_4 and relatively little degradable C compared to undigested slurry more, and thereby has a higher potential for NH_3 volatilization and a lower potential for denitrification induced N_2O emission (e.g. Velthof et al., 2003).

Table 1: Overview of the working principle of emission reducing measures and reduction of the NH_3 emission reported in literature (in % compared to slatted floors). After Monteny and Erisman (1998).

Measure	Process involved	Control factor	Maximal reduction
Feeding strategies	urine and faeces production	urea concentration	39
Slurry handling:			
* flushing with water	enzymatic conversion	urea concentration	17
* formaldehyde flushing	enzymatic conversion	urease activity	50
* slurry acidification	dissociation	pH	37
+ additionally flushing slats with acidified slurry	dissociation	pH	60
Floor systems:			
* V-shaped solid floors	air exchange/ volatilization	air velocity	52
+ flushing with water	enzymatic conversion	urea concentration	65
+ formaldehyde flushing	enzymatic conversion	urease activity	80
Housing systems:			
* reduced slatted floor area	volatilization	emitting area of floor/pit	10
* tie stalls	volatilization	emitting area of floor/pit	28

<u>N emission from soil applied manure and fertilizers</u>

Application of animal slurry to soil induces a sequence of reactions. High rates of NH_3 volatilization have been measured following surface application of animal slurry (e.g., Pain et al., 1989), but generally, the rate of NH_3 volatilization is very low after a few days (Huijsmans, 2003; Oenema et al., 1993). Hence, 50% of the total NH_3 loss typically occurs within 4 to 12 h after slurry application (Pain et al., 1989). The rate of NH_3 volatilization from slurry applied to soil is related to the total NH_4^++NH_3 concentration and water content of the manure and to wind speed, humidity and temperature; the higher the temperature the larger the NH_3 loss.

Incorporating slurry into the soil is a most effective way of decreasing NH_3 volatilization. Different techniques are available, such as deep injection, shallow injection, incorporation of slurry by ploughing or by rotary harrow, and application of slurry with trailing hoses. Generally, highest reduction in NH_3 emission is obtained when slurry is immediately incorporated in the soil following surface application or directly injected 5 to 20 cm into the soil (Webb et al., 2005).

Commonly, ammonia emissions are much smaller from mineral fertilizers than from animal manures, except for urea. Ammonia emission is higher from urea than from ammonium-nitrate fertilizer, because urea is naturally decomposed to liberate ammonia, generating areas of locally high soil pH which favours ammonia emission (Velthof et al., 1990). Emissions from ammonium sulphate fertilizers may be somewhat larger than that of ammonium-nitrate fertilizer, especially on carbonate-rich soils, but are much lower than that of urea fertilizers.

The application of manure to soil increases the contents of NH_4^+, and of easily mineralizable N and C in the topsoil. This in turn may increase nitrification and subsequently denitrification locally by which NO, N_2O and N_2 are produced. Organic compounds from slurry and manure provide readily available substrate for denitrifiers (Dendooven et al., 1998). Application of animal slurries to soils increases the emission of N_2O, but there are large differences between types of manures due to differences in composition (Velthof et al., 2003). So far, most studies suggest that the N_2O emission from animal slurries applied to grassland is less than the N_2O emission from an equivalent amount of nitrate-based N fertilizer (e.g., Egginton and Smith, 1986; Velthof and Oenema, 1993; Velthof et al., 1997).

Nitrogen application rates via manure and fertilizers exceeding the N removal by harvest products may result in nitrate leaching to groundwater and surface waters (e.g. Van Beek et al., 2003; Ten Berge et al., 2004). At similar application rates of plant-available N, the risk of leaching of manure N differs from that of N fertilizer, because on the one hand part of the organic N is mineralized after the growing season (increasing the risk of leaching), but on the other hand the organic matter in manure increases denitrification (decreasing the risk of leaching).There are a large number of possible measures to decrease the leaching of nitrate to groundwater and surface waters (Cuttle et al., 2004).

<u>N emission from grazed pastures</u>

The loss of NH_3 from grazed pastures is related to fertilizer input, pasture productivity, grazing intensity, protein content of the herbage and environmental conditions. There are strong seasonal variations due to variations in weather conditions, grazing periods and fertilizer applications (Bussink and Oenema, 1996). Fertilizer N increases herbage production and the N content of the herbage. As a consequence, more animals can graze the pasture and more N is excreted by the grazing animals. Further, a larger fraction of excreted N will be excreted via urine than via dung when the protein content of the herbage increases.

Urine and dung are sources of both NO_3^- and available organic C and, therefore, the denitrification activity can be very high in urine- and dung-affected soil (Van Groenigen et al., 2005). Treading and trampling by grazing animals also contribute to denitrifying activity because of soil compaction. Urine patches contain large amounts of N, and N leaching losses in grazed grassland are usually related to urine (and dung) patches, especially for grazing in autumn (Hack ten Broeke et al., 1996). Adjustment of the grazing regimes strongly affects N leaching losses. However, it also affects the amounts N excreted and stored in house and in manure storage systems, and hence the N emissions from these compartments of the farming system. To avoid pollution swapping, grazing systems should be optimized considering the environmental and agricultural (economic) aspect on the whole farming system.

It is worth to note here that the relative loss of excreted N as NH_3 is much less from grazed systems than from housed systems. This is because in housed systems, emissions occur from each of housing, storage and manure spreading, e.g. leading to 20-60% loss of the excreted N as NH_3. By contrast, in a grazed system, the excreted N is much more effectively retained in the plant-soil system, with typically 5-10% of the excreted N volatilized as NH_3. This means that dairy and beef cattle systems favouring longer grazing periods have a relatively low NH_3 loss, but a relatively high potential for NO_3 leaching and N_2O emissions. Conversely, systems that restrict grazing likely increase NH_3 emissions and decrease N losses via NO_3 leaching and N_2O emission.

Effect of the composition animal feed

Adjusting the composition of the animal feed can be an effective tool to decrease N excretion per animal and NH_3 emissions from animal manure (e.g., Kulling et al., 2001; 2003; Broderick, 2003; Flachowsky and Lebzien, 2005; Jondreville and Dourmad, 2005; Mateos et al., 2005; Misselbrook et al., 2005; Velthof et al., 2005; Geers and Madec, 2006). Changing the crude protein and energy contents, the digestibility and/or the salt content of the animal feed will affect urinary N excretion more than fecal N excretion, and will result in changes in the N content, mineral composition and pH of animal manure slurry. Lowering the protein content will lower the N excretion and thereby the NH_3 emissions potential. Increasing the energy content of the feed will increase the fatty acid production in the slurry and thereby will lower the pH and the NH_3 emission potential of the slurry. Animal nutrition may also affect the N and C transformations in the manure during storage and after soil application, and thereby affect N_2O emission (Velthof et al., 2005). The potentials of improved animal feeding and management to decrease gaseous N emissions, without decreasing production efficiency, are significant, but requiring significant research and demonstration efforts (Børsting et al., 2003; Flachowsky and Lebzien, 2005; Jondreville and Dourmad, 2005; Mateos et al., 2005). The potential to decrease the N excretion and P excretion by animals differs greatly between farms. Data presented in Figure 4 indicates that the N excretion of fattening pigs on specialized farms ranges from ~10 to ~15 kg per pig place per year, and that the P_2O_5 excretion ranges from 3 to 6 kg per year. The scatter suggests that there may be some errors involved in the recording of the data, but the variation also indicates that there is scope for (further) lowering of the N and P excretion of fattening pigs by 10 – 50 % (Hubeek and de Hoop 2004).

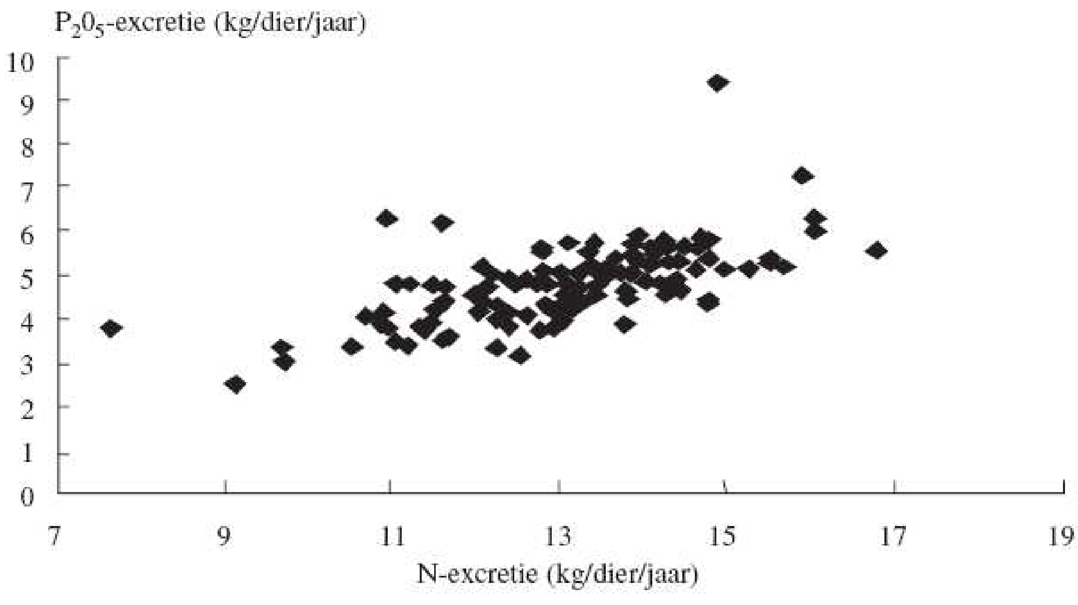

Figure 4. Relationship between the mean excretion of N and P (in P2O5) by fattening pigs at farm level in 1999-2000, for specialized fattening pig farms in The Netherlands. (Source FADN database, Hubeek and de Hoop, 2004).

2.4 Brief overview of environmental policy instruments in EU

In response to the environmental side effects of the increased availability of fertilizer N and animal manure in agriculture, a series of environmental policies and measures have been implemented in national and EU legislation. Some of these policies and measures specifically aim at decreasing the emissions of NH_3 to the atmosphere, the leaching of NO_3^- to groundwater and surface waters, and the emissions of greenhouse gases, notably N_2O, CH_4 and CO_2 to the atmosphere. Other policies address wider agri-environment issues, and are less focused on pollution management, although they may have significant implications for losses of N from agriculture.

Currently, agriculture and especially the use of animal manure and fertilizers are affected by four categories of EU policies and measures:

i. Agenda 2000 and the reform of CAP, including Cross Compliance, Agri-Environmental and Rural Development regulations;
ii. Water Framework Directive, including the Nitrates Directive and Groundwater Directive;
iii. Air related Directives (National Emission Ceiling, Air Quality, and Integrated Pollution and Prevention Control Directives, and policies related to the Kyoto Protocol); and
iv. Nature conservation legislation, the Birds and Habitats Directives

The coherence between these policy instruments and the point of action are shown in Figure. 5. The policy instruments are briefly summarized below.

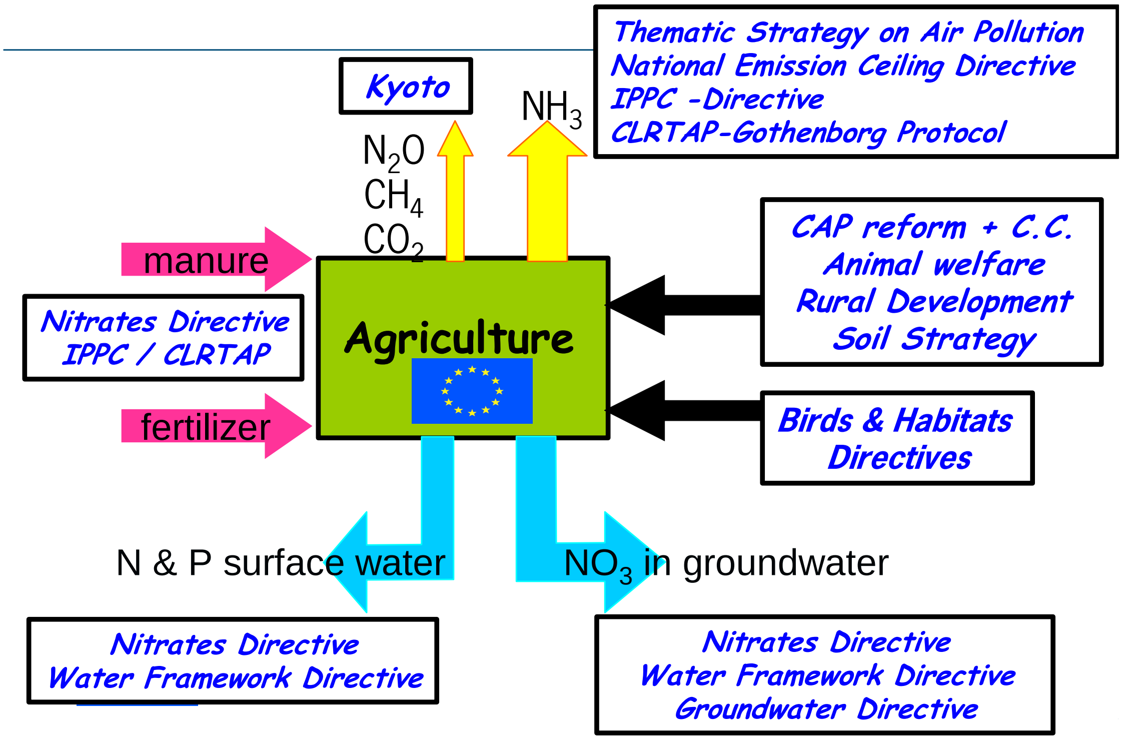

Figure 5. Overview of the EU policy instruments directly and indirectly acting on the use and losses of N in agriculture. The emission of NH_3 is addressed by the Thematic Strategy on air pollution (TS), National Emission Ceilings Directive (NEC), Convention on Long Range Transport of Atmospheric Pollutants (CLTRAP), and the Directive on Integrated Pollution, Prevention and Control (IPPC). These policies also address to some extent animal feeding and integrated N management, and thereby influence to some extent also the animal manure N and fertilizer N. Inputs of N via fertilizer and animal manure and N losses to groundwater and surface waters are addressed by the Nitrates Directives, Groundwater Directive and Water Framework Directive. The CAP reform, together with the Rural Development Regulations, Agri-Environmental measures and Cross Compliance measures, and the Birds Directive and Habitats Directive and the Animal Welfare Directive will provide additional constraints to agricultural activities, and hence on the cycling and loss of N.

Agenda 2000 and the reform of the CAP

Agenda 2000 is an action program launched in 1997 by the EU to increase competitiveness, to enhance standards of food safety and quality, and to ensure a fair standard of living for the agricultural community (e.g. Meester et al., 2005; Bascou et al., 2006). It addresses the reform of the CAP and the structural policy, including a further decoupling of production and income support. In environmental terms, the focus of Agenda 2000 is on (i) less-favoured areas and areas with environmental restrictions, and (ii) on agricultural production methods designed to protect the environment and to maintain the countryside. Hence, farmers who apply good farming practices, decrease livestock density, upkeep the landscape, and/or conserve areas with high nature value, receive economic benefits in order to cover both the compulsory environmental programs as well as changes on the extensification premium.

Cross-compliance was introduced in the EU by the Agenda 2000 CAP reform (http://ec.europa.eu/agriculture/envir/index_en.htm#crosscom; see also Meester et al., 2005; Bascou et al., 2006). Member states are allowed to link environmental conditions to direct payments granted to farmers. In June 2003 cross-compliance became an obligatory element of CAP. There are two major aspects of cross-compliance in the Single Farm Payment: (i) Compliance with 19 Statutory Management Requirements (SMRs) (initially, there were 18, but one SMR was added via Council Regulation (CR) No 21/2004 in Jan 2004, amending CR 1782/2003) covering the environment, food safety, animal and plant health and animal welfare (set out in Annex III of CR 1782/2003), (ii) Compliance with a requirement to maintain land in Good Agricultural and Environmental Condition (GAEC). Definitions of GAEC are specified at national or regional level and should warrant appropriate soil protection, ensure a minimum level of maintenance of land and avoid the deterioration of habitats (set out in Annex IV of CR 1782/2003).

Rural Development is playing an increasingly important role in helping rural areas to meet the economic, social and environmental challenges of the 21st century, following the reform of the CAP. Rural areas make up 90 percent of the territory of the enlarged EU. The Rural Development policy 2007-2013 focuses on three thematic axes laid down in the rural development regulation (see Council Regulation 1698/2005, http://eur-lex.europa.eu/LexUriServ/site/en/oj/2005/l_277/l_27720051021en00010040.pdf)

- improving competitiveness for farming and forestry;
- improving the environment and countryside; and
- improving the quality of life and diversification of the rural economy.

For each set of priorities, the EU strategic guidelines suggest several key actions. Member States must prepare their national rural development strategies on the basis of six community strategic guidelines, which help to:

- identify the areas where the use of EU support for rural development creates the most value added at EU level;
- make the link with the main EU priorities (e.g., 'knowledge society' and ensuring ongoing sustainable growth by means of the Lisbon Strategy; climate-change measures and sustainable growth);
- ensure consistency with other EU policies, in particular cohesion and environment; and
- accompany the implementation of the new market orientated CAP and the necessary restructuring in the old and new Member States.

The six strategic guidelines are:

1. Improving the competitiveness of the agricultural and forestry sectors
2. Improving the environment and the countryside
3. Improving the quality of life in rural areas and encouraging diversification
4. Building local capacity for employment and diversification
5. Translating priorities into programmes
6. Complementarities between community instruments.

In particular, the first three have relevance to N utilization and the emission of N species, and these have been included in the assessments made in Chapter 4.5 (see below).

Water Framework Directive (including Nitrate Directive)

The Water Framework Directive 2000/60/EC is the most substantial piece of EU water legislation to have been signed to date. It requires all inland and coastal waters to reach "good ecological status" by 2015 (http://ec.europa.eu/environment/water/water-framework). It will do this by establishing a river basin district structure within which demanding environmental objectives will be set, including ecological targets for surface waters. It addresses all compounds that affect the ecological status of surface waters, including N and P from agriculture. The Water Framework Directive allows Member States the flexibility to define specific ambitions, targets and time frames, albeit under the constraints of proper underpinning and justifications (MNP, 2006).

The Water Framework Directive establishes also a framework for the "Integrated Program on Water Quality Management". The WFD encompasses a large number of other directives. So far, most important for agriculture is the Nitrate Directive (91/676/EC*),* which has been agreed upon by all member states in 1991 and which must have been implemented by 2003, and the Groundwater Directive (COM (2003) 550), which has been agreed on 17 October 2006 (final version will appear early 2007).

The main objective of the Nitrate Directive (Council Directive 91/676/EEC) is "to decrease water pollution caused or induced by nitrates from agricultural sources and prevent further such pollution" (http://ec.europa.eu/environment/water/water-nitrates). For this, all member states have to take various measures (i.e., designate nitrate vulnerable zones (NVZs) and establish action and monitoring programs as well as a code of good agricultural practices for these zones). Nitrate vulnerable zones must be designated on the basis of monitoring results which indicate that the groundwater and surface waters in these zones are or could be affected by nitrate pollution from agriculture. The action program must contain mandatory measures relating to: (i) periods when application of animal manure and fertilizers is prohibited; (ii) capacity of and facilities for storage of animal manure; and (iii) limits to the amounts of animal manure and fertilizers applied to land. In addition to these measures, Codes of Good Agricultural Practices (GAP) are defined for different agricultural systems which are expected to be required to meet the targets of the Nitrate Directive. Member states are obliged to monitor the nitrate concentrations of groundwater and surface waters to assess the impact of the measures, and to report the results to the European Commission. So far, there is a wide variation between member states in the interpretation of vulnerable zones and in the interpretation and implementation of action programs and codes of good agricultural practices (Zwart et al., 2006; De Clercq et al., 2001).

The purpose of the Groundwater Directive (Daughter Directive of the Water Framework Directive (WFD)) is to establish specific measures to prevent and control groundwater pollution. The proposal for a Groundwater Directive (COM(2003) 550) was agreed on 17 October 2006, and the timetable of its implementation is related to the WFD (http://ec.europa.eu/environment/water/water-framework/groundwater.html).
The Directive includes special criteria for assessing good chemical status, criteria for identifying significant and sustained upward trends in the concentration of pollutants from human activity in groundwater and criteria for defining the starting points for trend reversals. It proposes a common methodology for testing the statistical significance of these trends. Member States shall reverse the trend for those bodies of groundwater where significant and sustained upward trends in pollutant concentrations are identified, through the program of measures referred to in Article 11 of WFD (2000/60/EC). For nitrate (NO_3) in groundwater, reference is made to measures and targets of the Nitrates Directive (91/676/EEC).

Air Quality related Directives and the Thematic Strategy on air pollution
Air quality is one of the areas in which European Commission has been most active in recent years. In 1996, the Environment Council adopted a Framework Directive on Ambient Air (96/62/EC) which addresses ambient air quality assessment and

management. The Air Quality Framework Directive includes a series of daughter directives, which set the numerical limit values for atmospheric pollutants. The daughter directive Air Quality Directive (1999/30/EC) relates to limit values for among others nitrogen oxides (NO_x) and particle matter (PM_{10}) in ambient air. The limit values for NO_x for the protection of vegetation had to be met by 2001. The health limit values for PM_{10} had to be met by 2005. Particle matter in the air contributes to reduced visibility and to human health effects, and ammonia and ammonium contributes a significant fraction (15-30%) to the formation of particle matter in the air. However, there is no concentration limit for NH_3 in any of the Air Quality daughter Directives, and the main emphasis as indicated above is on urban and combustion source air pollutants

By September 2005, the Commission adopted the Thematic Strategy on Air Pollution (COM(2005) 446 final). The objective of this Strategy is to meet the objectives of the Community's Sixth Environmental Action Plan on air quality: '*to attain levels of air quality that do not give rise to significant negative effects on, and risks to human health and the environment by 2020'.* The Clean Air for Europe (CAFÉ) program (COM(2005) 447) has produced the scientific basis for the 'Thematic Strategy on Air Pollution'. CAFÉ is the program of technical analysis and policy development that underpinned the development of the Thematic Strategy. Various health and environmental ambition levels for 2020 have been evaluated in CAFÉ and a global ambition level has been proposed in the Strategy. The work showed that ammonia emissions significantly contribute to eutrophication (N enrichment ~ 60%), acidification (proton loading ~ 40%) and to the formation of secondary particulate matter in the atmosphere (~ 30-40%). The main source of the ammonia in the atmosphere is agriculture (cattle farming for about ~ 40%, pig and poultry ~ 40%, and the use of N-fertilisers ~ 20%) (Amann et al., 2006). Work of the CAFÉ process also showed that additional efforts (relative to the Framework Directive for ambient air, Com 1996/62, and its daughter directives) were needed to achieve the objective of the Sixth Environmental Action Program**.**

As a first approach, the following policy measures were identified in the Thematic Strategy on Air Pollution:
1 . Revision of the emission ceilings under the National Emission Ceiling directive (NEC) (2000/1258/EC) — integration of new objectives for eutrophication, acidification and for particulate matter. As a consequence, new emission ceilings for ammonia have been developed by 2006 (Amann et al., 2006) as well as new guidelines for the national programs required under the NEC directive (see also below).
2. A possible extension of the Integrated Prevention and Pollution Control (IPPC) directive, to include installations for intensive cattle rearing and a possible revision of the current thresholds for installations for the intensive rearing of pigs and poultry.
3. In the context of the current rural development regulation and the Commission proposals for rural development for 2007-13, the Commission encourages the Member States to make full use of the measures related to farm modernisation, meeting standards and agro-environment to tackle ammonia emissions from agricultural sources.

The National Emission Ceilings Directive (NEC - Directive 2001/81/EC) sets upper limits for each Member State for the total emissions in 2010 of the four pollutants responsible for acidification, eutrophication and ground-level ozone pollution (SO_2, NO_x, VOCs and NH_3), but leaves it largely to the Member States to decide which measures to take in order to comply. The pollutants concerned are transported in large quantities across national boundaries. The aim of NEC Directive is to limit emissions of acidifying and eutrophying pollutants and ozone precursors. In addition the Directive aims at moving towards the long-term objectives of not exceeding critical levels and loads and of effective protection of all people against recognised health risks from air pollution by establishing national emission ceilings, taking the years 2010 and 2020 as benchmarks. The emission ceilings for ammonia in 2010 are shown in Figure 2.

Parallel to the development of the NEC Directive, the EU Member States together with Central and Eastern European countries, the United States and Canada have signed the "multi-pollutant" protocol under the UN-ECE Convention on Long-Range Transboundary Air Pollution (the so-called Gothenburg protocol, UNECE, 1999). The emission ceilings in the protocol are equal or less ambitious than those of the NEC Directive. The Convention on Long Range Transboundary Air Pollution (CLTRAP) was adopted in 1979 and entered into force in 1983. The Convention has been extended by 8 protocols, amongst others the 1999 Gothenburg protocol to abate Acidification, Eutrophication and Ground-level Ozone, which includes in Annex IX the measures for the control of emissions of ammonia from agricultural sources.

The NH_3 emission abatement techniques listed under CLTRAP and IPPC Directive (see below) are basically the same. The Expert Group that works on the Guidance Document on Control Techniques for Preventing and Abating Emissions of Ammonia (EB.AIR/WG.5/1999/8/REV.3) distinguishes three categories of techniques:

- Category 1: well established techniques, considered to be practical, where quantitative data on abatement efficiency are present
- Category 2: promising techniques, but research still needed
- Category 3: techniques shown to be ineffective or unpractical according to present knowledge

The Integrated Pollution Prevention and Control (IPPC) Directive was established in 1996 (http://ec.europa.eu/environment/ippc/index.htm; European Commission, 1996), aiming at minimizing pollution from various point sources (see *Annex I of the Directive*) in the European Union, amongst others NH_3 from agriculture. Under this Directive, intensive animal production facilities (pig and poultry farms, with > 2000 fattening pigs; >750 sows; or > 40,000 head of poultry) are required to apply control techniques for preventing NH_3 emissions according to Best Available Technology (BAT). Measures that can be applied (e.g. storage, improved housing systems, air purification, manure handling and treatment, manure application) are described in detail in the BAT Reference documents (BREF), including their emission factor (kg per animal place and year), and an assessment of economic aspects (costs/benefits), animal welfare aspects etc. (European Commission, 2003)

It should be noted that IPPC covers an integrated approach to the management of pollution from intensively managed installations, including both local and transboundary pollution, and all pollutant releases to air and water, including noise and energy-saving measures. In the case of the livestock sector, however, ammonia has been recognized as the central air pollution threat under IPPC, with less attention so far given to other forms of pollution from agricultural installations, such as greenhouse gases, particles and leaching losses.

The requirement for BAT will contribute to reducing Europe-wide ammonia emissions and transboundary transport. In addition, installations included under the terms of IPPC can only legally operate if an IPPC permit is issued. Such a permit may be refused if the operation of the installation will lead to significant adverse effects relevant to other EU

Directives, such as the Habitats and Birds Directives (see below). Hence, in addition to contributing to an overall reduction in ammonia emissions from Europe, IPPC provides an important tool for the local and regional management of ammonia emissions and their environmental effects.

The United Nations Framework Convention on Climate Change is the main international agreement addressing the issue of climate change. It took effect in 1994. In 1997 the Kyoto Protocol was established. UNFCCC requires parties to use the Revised 1996 IPCC (Intergovermental Panel on Climate Change) Guidelines for National Greenhouse Gas Inventories. In this perspective, the EU has adopted Council Decision 93/389/EEC, and later the amended Council Decision 99/296/EC. Targets have been set for the total emissions of six greenhouse gases, three of which are most relevant for agriculture, namely CO_2, CH_4 and N_2O. Currently, there is a large interest in further decreasing greenhouse gas emissions (http://ec.europa.eu/environment/climat/emission.htm) and in the interactions between N and the emissions of CO_2, CH_4 and N_2O. The latter is the central issue of the EU-funded project NitroEurope. The net effect of N on the greenhouse gas emission balance remains a key research question and at present no N specific actions are required under any international policy measure. It is up to the countries how they will meet the Kyoto greenhouse gas emission targets. So far, most emphasis is on CO_2. Sutton et al. (2006) listed a number of possible trade offs between N and greenhouses (Table 2.)

Table 2: Effects of increased reactive nitrogen (N_r) supply on net greenhouse exchange (NGE). The overall response of NGE to N will depend on the balance of these competing effects and will differ regionally according to soil, climate and ecosystem type. (after Sutton et al., 2006).

N_r increases equivalent GHG emission	**Effect of N_r unclear or variable**	**N_r decreases equivalent GHG emission**
N_2O (inc. secondary N_2O from NH_3 emissions and NO_3^- leaching)	Cattle and other ruminant CH_4	Increased CO_2 uptake by plants
CH_4 from wetlands	Decomposition of Soil Organic Matter (SOM) to release CO_2	N aerosol scatter light and increase potential cloud formation
O_3 (from NO_x) reducing CO_2 uptake by plants		

Nature conservation legislation; the Birds and Habitats Directives

Preventing the loss of biodiversity and improving nature conservation are receiving increasing attention in EU policy. Biodiversity underpins the flow of ecosystem goods and services (food, fuel, fibre, air quality, water flow and quality, soil fertility and cycling of nutrients). It is also a key resource for tourism. Yet, some two-thirds of ecosystem services worldwide are in decline (MEA, 2005). In the EU, this decline is expressed in collapsing fish stocks, damage to soils, and disappearing wildlife (EEA, 2006).

The policy framework for preventing biodiversity loss is via the Birds and Habitats Directives which is being implemented through Natura 2000, an EU-wide network of protected areas, which now covers some 18% of the territory of the EU-15 and is being extended to the EU-25 and seas (http://ec.europa.eu/environment/nature/nature_conservation/eu_nature_legislation/habitats_directive/index_en.htm).

Two EU Directives deal with the conservation of European wildlife, focusing on the protection of species and habitats through site designation. The 1979 Birds Directive identified 193 endangered species and sub-species for which the Member States are required to designate Special Protection Areas (SPAs). Over 4000 SPAs have been designated to date, covering 8% of EU territory. The 1992 Habitats Directive aims to protect other wildlife species and habitats. Each Member State is required to identify sites of European importance (Special Areas of Conservation, SACs) and to put in place a special management plan to protect them, combining long-term conservation with economic and social activities, as part of a sustainable development strategy. These sites, together with those of the Birds Directive, make up the Natura 2000 network. The Natura 2000 network already comprises more than 18 000 sites, covering over 17% of EU territory.

The Directives require that each Member State contribute to the creation of Natura 2000 in proportion to the representation within its territory of the natural habitat types and the habitats of species. Member States are required to improve the ecological coherence of Natura 2000 by maintaining, and where appropriate developing, features of the landscape which are of major importance for wild fauna and flora. For Special Areas of Conservation (SACs), Member States are required to establish the necessary conservation measures involving appropriate management plans specifically designed for the sites or integrated into other development plans. The Directives also specifiy that Member States should endeavour in their land-use planning and development policies to improving the ecological coherence of the Natura 2000 network.(Neven and Kistenkas, 2005).

Article 6 of the Habitats Directive deals with the Management of the Natura 2000 areas. It provides guidance to the management of the Natura 2000 areas. It also provides guidance to the spatial zoning and planning of activities near Natura 2000 sites.

The Birds and Habitats Directives will impose restrictions on farming activities within and around the Natura 2000 areas. These restrictions include limits on livestock density, fertilizer and animal manure applications, ammonia emissions, and on grazing (animals). Thereby, the Birds and Habitats Directives may influence the emissions of NH_3, N_2O and CH_4 and the leaching of NO_3. At present, there is little experience among member states of how these provisions will act in practice. For example, it is already well established under Article 6.3 that a plan or project should only be approved so long as it is shown that it does not cause significant adverse effects to any Natura 2000 site. This condition provides a link to the operation of planning permission processes and the review and assesssment under IPPC. By contrast, further experience is required to clarify how the requirement to protect the integrity of Natura 2000 sites will be met where other linked regulations and review processes do not apply. This is relevant in the case of non-IPPC farming activities which are already operational or (for new developments) do not require planning approval. Further investigation of such possible loopholes to the implemention of the Habitats and Birds Directives is essential if significant negative effects of ammonia on Natura 2000 sites are to be avoided.

2.5 Pollution swapping

Pollution swapping refers to a special side-effect of environmental policies and measures, i.e., the unwanted increase of another pollutant, and/or the unwanted increase of the emission of the target pollutant and/or other pollutants elsewhere. Hence, two types of pollution swapping are distinguished in this study:

- Type 1 swapping to other pollutants (i.e., decreasing the loss of one N species at the expense of other N species);
- Type 2 swapping to other areas (i.e., transferring the pollution potential from one area to another).

Type 1 pollution swapping is generally seen as a response to governmental policies that focus on one N loss form (Hatch et al., 2004; Chambers and Oenema, 2004; Monteny et al., 2001; Erisman et al., 2005). Examples include:

- policies that have closed periods for spreading animal manure in autumn to minimize nitrate leaching losses and promote spring application to growing crops may exacerbate NH_3 emissions;
- policies that require the ploughing of manure rapidly into the soil to minimize NH_3 emissions may increase N_2O emissions;
- policies focused on decreasing NH_3 losses from manure result in manure with a higher N content, which, following its application to land, may increase nitrate leaching and N_2O emissions from soils;
- policies that aim at reducing grazing of cattle to decrease nitrate leaching may result in higher NH_3 and CH_4 emissions, because more animal manure has to be stored for a longer time.
- The use of no-till systems to encourage carbon sequestration in arable soils may exacerbate nitrous oxide emissions.

The possibilities for type 1 pollution swapping are not always fully recognized, because of the narrow focus of research and policies, especially in the recent past. The cause of type 1 pollution swapping can be most easily demonstrated via the so-called 'hole in the pipe' model (Figure 6). The 'hole in the pipe' model symbolizes the leaky N cycle in agricultural systems. There are inputs of N into these systems via e.g. fertilizers and animal manure (left side of the graph) and there are outputs from the systems, via harvested crop and livestock products. Within the system (visualized via the pipe), transformations and transfer processes take place, whereby a range of N species may escape (visualized via the holes in the pipe). Blocking one or two of the holes in the pipe usually leads to increased fluxes from other holes, unless the total input is decreased, and/or the total output via crop and livestock products is increased. This reasoning usually forms the basis for using an integrated or whole-farm systems approach or input-output balance approach. The N budget indicator is sensitive to decreases in N inputs (e.g., fertiliser use, manure inputs etc.) and to increases in N utilisation efficiency per unit of output (e.g., N outputs in milk and meat products etc.). Hence, integrated assessments and analyses of whole-farm systems are needed to assess the effects of mitigation measures on the target N loss species alongside other N loss routes (plus other losses of concern).

The reasoning given above does not preclude the assertion that leakages are (not) equally damaging to the environment and or human health. One may argue that losses via NH_3 volatilization are more damaging to the environment per mole of N than the leaching of NO_3 to groundwater and surface waters, or vice versa (e.g., Angus et al., 2003, 2006).

However, this is outside the scope of this study. The only point to be made here is that the 'law of mass conservation' simply tells us that blocking one loss pathway will increase one or more other loss pathways, unless the N input is decreased or the N output via use products is increased proportionally. Summarizing, type 1 pollution swapping refers to exchange of one N loss pathway for one or more other loss pathways, without changing the total amount of N lost to the environment.

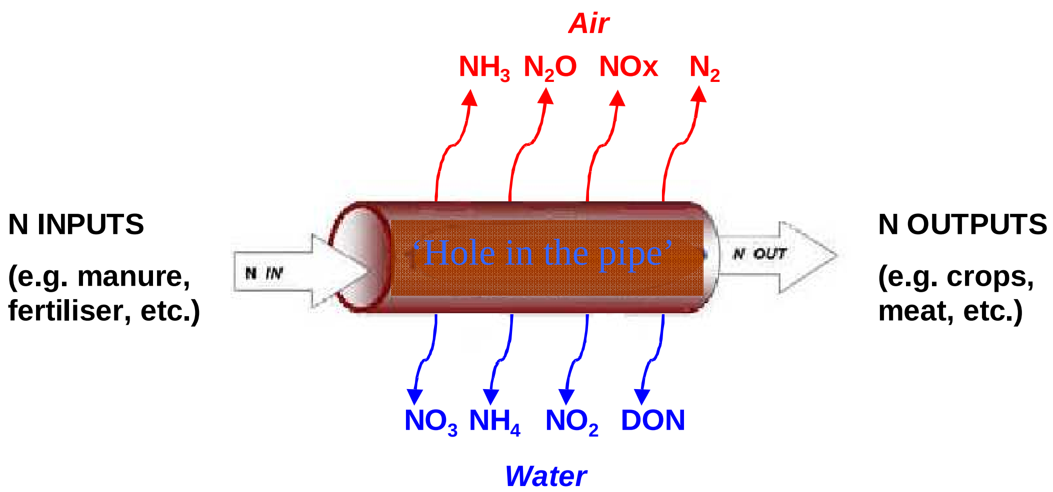

Figure 6. Nitrogen emissions from agricultural systems to the air and water environments, visualized by the 'hole of the pipe' model. Inputs via fertiliser and organic manure nitrogen (N) additions, biological N fixation, and atmospheric deposition are positioned on the left-hand side of the figure. Outputs via crop harvest and livestock products are on the right-hand side. Please note that N may be stored (temporally) in the soil (in the pipe), and thereby may contribute to a delay in swapping. Note also that the release of di-nitrogen (N_2) is often considered to be a benign emission relative to that of the other N species emissions, but that the emission of N_2 does result in the loss of N from the system to the environment and hence to a lower N use efficiency.

Type 2 pollution swapping (swapping pollution to other areas) is sometimes also called 'externalization' of N losses (and possible other environmental side effects). It occurs for example when policies with limits on manure application on areas of land force intensive livestock farms to transfer the surplus animal manure to arable farmers elsewhere. By doing so, also the risks of N losses via for example NH_3 and N_2O emissions are transferred to elsewhere. The transfer of manure and its emission potential is of course beneficial for the area of concern and can be considered as an appropriate component in optimizing overall nitrogen management to minimize the negative effects on priority issues. By contrast, it should be remembered that the total emissions of gaseous N emissions will not necessarily decrease. They may even increase due to the increasing handling actions, while some decreases could potentially occur, e.g. application of the manures to soils less liable to N_2O emission.. Overall however, the gaseous N emission potential is simply transferred to other areas. Other possible N loss pathways (e.g., NO_3 leaching) may decrease following the transfer of manure N to other areas, when the manure N replaces N fertilizer and the manure N can be utilized by the crops effectively. Hence, transferring manure N from areas with high livestock density to areas with low livestock density is only effective in reducing overall N inputs if it replaces N fertilizer and it can be utilized effectively.

A variant of type 2 pollution swapping (swapping pollution to other areas) may follow from zoning restrictions within the framework of the Nitrate Directive and especially the Birds and Habitats Directives (Natura 2000 areas). Zoning restrictions may expel farms from the designated areas to outside these areas, while the total production capacity does not diminish (as is the case when production rights and quota exist). In this case, the decreased environmental pressure within the designated areas decreases at the expense of increasing environmental pressures elsewhere. Of course, this can be highly beneficial when the vulnerability of the designated area is much higher than the area outside the designated area (the 'pollutant' may even become benign, for example when it contributes to decreasing N shortages in some areas), but the total emission does not decrease; it is simply transferred to other areas.

Summarizing, type 2 pollution swapping (swapping to other areas) results from implementing policy and measures to decrease the environmental pressure within a specific area, without limiting the total agricultural production. The law of mass conservation tells us that the environmental pressure will be transferred to elsewhere, to outside the designated areas. Such transfers may be an extremely beneficial tool to protecting priority receptors, such as Natura 2000 sites (e.g. Dragosits et al., 2006), but will show little benefit when expressed as national emissions ceilings.

Finally, it should of course be noted that 'pollution swapping' is not solely related to environmental policies and measures. There are many activities in agriculture that may contribute to externalization of environmental effects and to pollution swapping. A typical example in this case is the import of animal feed from elsewhere. However, these aspects (not directly related to the EU environmental policies) fall outside the scope of this study.

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3 METHODOLOGY

Following the request by the European Commission, and in agreement with the Inception Report of the current contract, a desk study has been carried out to analyze existing European and international instruments, aiming at reducing emissions to the atmosphere of nitrous oxide, methane and ammonia and nitrate to waters. The following policy instruments have been analysed qualitatively:

- The Codes of Good Agricultural Practice in the Nitrate Directive (Annex II of the Nitrate Directive)
- The Measures included in the action programmes established in application of the Nitrate Directive (Annex III of the Nitrate Directive)
- Additional measures described in action programmes of countries for the Nitrate Directive (additional to the measure and Codes of Good Agricultural Practice of Annexes II and III).
- The measures in the Annex IX of the Convention on Long-range Transboundary Air Pollution
- Measures defined in national programmes established to comply with the National Emissions Ceilings Directive
- Measures defined in national permits in application of the IPPC Directive
- UNFCCC/IPCC measures to reduce non-CO_2 greenhouse gases
- Cross-compliance measures applicable within the framework of the CAP ensure respect of (i) statutory management requirements stemming from provisions of 19 community legal acts in the area of the environment, food safety, animal and plant health and animal welfare, (ii) minimum standards of Good Agricultural and Environmental Conditions (GAECs) (iii) obligation to maintain the ratio of permanent pasture over total utilized agricultural area (UAA).
- Measures of the Rural Development Regulation (1698/2005)
- Possible measures to achieve the objectives of the Bird and Habitat Directives (grazing, buffers)

Firstly, all separate measures in the existing policy instruments have been identified. Secondly, the effects of the different instruments and separate measures have been assessed in terms of reducing the emissions of nitrous oxide and methane, ammonia and nitrate. The assessments are qualitative, made on the basis of literature data and expert judgments. Special attention has been given to synergies and antagonisms of the instruments. Measures were categorized in six categories according to their pollution swapping potential and their effectiveness in decreasing emissions (see also chapter 2.5), namely:
(i) *Mitigation or abatement of N species emissions, without targeting N input*. This category of measure has the potential of type 1 pollution swapping (antagonistic effects);
(ii) *Controlling N input*; for example, measures focused on reducing the input of N via fertilizers and animal manure to land and the protein content of the animal feed. This category of measure has the potential of synergistic effects. They decrease the emissions per unit of surface area and per unit of product.

(iii) *Agri-environmental measures focused on the extensification of agricultural production (abandoning production potential) and environmental protection.* This category of measures has the potential of decreasing the emissions of NH_3, N_2O and CH_4 and the leaching of NO_3 simultaneously. They decrease the emissions per unit of surface area but not necessary the emissions per unit of product.
(iv) R*egulations on animal welfare.* This type of measures likely increase the emissions of NH_3, N_2O and CH_4 due to the larger areas where animal foul and the larger use of bedding material. Also the feed conversion of the animals may increase, i.e., the animals require more feed to produce 'useful' animal products (meat, milk, eggs). Hence, this type of measure involves a trade-off between animal welfare and environmental pollution.
(v) *Measures aimed at improving the competitiveness of the agricultural sectors.* This type of measures can have variable effects on the total emissions. Improved competitiveness likely results from innovations and investments aimed at either increased production potential, decreasing cost of production, and/or compliance to Community standards. If the incentives for improving the competitiveness of farming include guidance for investments in low-emission animal housing and manure management systems, then the increased competitiveness goes hand in hand with decreased emissions. This type of measure likely decreases the emissions per unit of product.
(vi) *Spatial zoning and landscape structure*, i.e., delineating areas where measures mentioned under (i), (ii) and (iii) and perhaps (iv) apply. This refers especially to the Nitrates Directive and the Birds and Habitats Directives. Spatial zoning is meant to decrease the environmental pressure in the designated zone. However, there is the potential of increasing the environmental pressure in surrounding areas (type 2 pollution swapping to other areas), especially when the production capacity of the farms is not decreased. In the latter case, the animals and/or the animal manure or the crops that can no longer be kept or grown within the designated areas will be transferred to the surrounding areas. This makes the assessment of the pollution swapping issues of spatial zoning complex, also because of differences between Member States. In addition to regional zoning, measures may address local landscape structure to maximize buffering of the system, and this may include measures such as woodland or wetland buffer strips, where increased nitrogen recapture aims to improve overall nitrogen utilization. (See Sutton et al. 2004)

On the basis of this categorization, a qualitative assessment was made. No distinction has been made between mandatory measures from the EU Directives mentioned above and (country-specific) voluntary measures, implemented by Member States for example to comply with the NH_3 emission ceilings of the NEC Directive. Also, it was assumed that the measures were implemented fully; hence the issue of penetration, adoption and feasibility of the measures in practice was not taken into account in this assessment.

4 RESULTS

4.1 Policies and measures to decrease nitrate pollution

4.1.1 Description of nitrate policies and measures

As indicated briefly in paragraph 2.4, there are three main policy instruments that target nitrate in groundwater and/or surface waters, and that describe measures to decrease and/or to prevent nitrate pollution:
- Nitrates Directive
- Groundwater Directive; and
- Water Framework Directive.

The measures of these Directives are briefly described below.

Council Directive 91/676/EEC (hereafter referred to as the Nitrates Directive) concerning the protection of waters against pollution caused by nitrates from agricultural sources was adopted on 12 December 1991. It aims at reducing water pollution caused or induced by nitrate from agricultural sources and, further, at preventing such pollution. The Nitrates Directive obliges member states to take several actions to realise this objective.

Firstly, member states are obliged to designate areas in their territory (Nitrate Vulnerable Zones or NVZs) that drain into fresh surface waters and/or groundwater (Article 3, Annex 1) that contain, or could contain more than 50 mg/l nitrate if actions prescribed in the Nitrates Directive are not taken. This is valid for freshwater bodies, estuaries, coastal waters and marine waters that are now eutrophic or that in the near future may become eutrophic if actions prescribed in the Nitrates Directive are not taken. *Secondly*, the Nitrates Directive compels member states to establish Action Programmes with respect to designated NVZs so that the objectives of the Nitrates Directive can be realised (Article 5). *Thirdly*, member states are obliged to implement suitable monitoring programmes to establish the extent of nitrate pollution in waters and to assess the effectiveness of the Action Programmes (Article 5, sub 6; see §1.4 for more details).

Two types of strategies to decrease nitrate pollution can be distinguished in the Nitrate Directive, i.e. via (i) Codes of Good Agricultural Practice and via (ii) Action programmes in designated areas.

Codes of Good Agricultural Practice for the whole country with the aim of providing for all waters a general level of protection against pollution. These codes of good agricultural practice are on a voluntary basis (including provision of training and information for farmers), and should cover the following items (Annex II of the Nitrates Directive), in so far as they are relevant:

1. periods when the land application of fertilizer is inappropriate;

2. the land application of fertilizer to steeply sloping ground;
3. the land application of fertilizer to water-saturated, flooded, frozen or snow-covered ground;
4. the conditions for land application of fertilizer near water courses;
5. the capacity and construction of storage vessels for livestock manures, including measures to prevent water pollution by run-off and seepage into the groundwater and surface water of liquids containing livestock manures and effluents from stored plant materials such as silage;
6. procedures for the land application, including rate and uniformity of spreading, of both chemical fertilizer and livestock manure, that will maintain nutrient losses to water at an acceptable level.

Member States may also include in their code(s) of good agricultural practices the following items:

7. land use management, including the use of crop rotation systems and the proportion of the land area devoted to permanent crops relative to annual tillage crops;
8. the maintenance of a minimum quantity of vegetation cover during (rainy) periods that will take up the nitrogen from the soil that could otherwise cause nitrate pollution of water;
9. the establishment of fertilizer plans on a farm-by-farm basis and the keeping of records on fertilizer use;
10. the prevention of water pollution from run-off and the downward water movement beyond the reach of crop roots in irrigation systems.

Action programmes in designated areas shall include the measures of Annex III of the directive and also the measures for the Codes of Good Agricultural Practice mentioned before. For most measures only outlines are given and the Member States can implement these measures in different ways.

1. The measures shall include rules relating to:
    1. periods when the land application of certain types of fertilizer is prohibited;
    2. the capacity of storage vessels for livestock manure; this capacity must exceed that required for storage throughout the longest period during which land application in the vulnerable zone is prohibited, except where it can be demonstrated to the competent authority that any quantity of manure in excess of the actual storage capacity will be disposed of in a manner which will not cause harm to the environment;
    3. limitation of the land application of fertilizers, consistent with good agricultural practice and taking into account the characteristics of the vulnerable zone concerned, in particular:
        i. soil conditions, soil type and slope;
        ii. climatic conditions, rainfall and irrigation;
        iii. land use and agricultural practices, including crop rotation systems; and to be based on a balance between:

- the foreseeable nitrogen requirements of the crops, and
- the nitrogen supply to the crops from the soil and from fertilization corresponding to:
- the amount of nitrogen present in the soil at the moment when the crop starts to use it to a significant degree (outstanding amounts at the end of winter),
- the supply of nitrogen through the net mineralization of the reserves of organic nitrogen in the soil,
- additions of nitrogen compounds from livestock manure,
- additions of nitrogen compounds from chemical and other fertilizers.

2. These measures will ensure that, for each farm or livestock unit, the amount of livestock manure applied to the land each year, including by the animals themselves, shall not exceed a specified amount per hectare. The specified amount per hectare be the amount of manure containing 170 kg N. However: for the first four year action programme Member States may allow an amount of manure containing up to 210 kg N. During and after the first four-year action programme, Member States may fix different amounts from those referred to above. These amounts must be fixed so as not to prejudice the achievement of the objectives specified in Article 1 and must be justified on the basis of objectives criteria, for example:
    - long growing seasons,
    - crops with high nitrogen uptake,
    - high net precipitation in the vulnerable zone,
    - soils with exceptionally high denitrification capacity.

The forthcoming Groundwater Directive (COM(2003) 550) aims at preventing and controlling groundwater pollution, including the pollution of nitrate from agricultural sources. The Directive includes special criteria for identifying significant and sustained upward trends in the concentration of nitrate in groundwater and criteria for defining the starting points for trend reversals. It refers to in Article 11 of the Water Framework Directive (WFD) (2000/60/EC) for taking measures to reverse the trend for groundwater where significant and sustained upward trends in nitrate concentrations are identified. This should be done on the basis of groundwater monitoring and groundwater risk assessments. Annex 1 of the Groundwater Directive states that the quality standard for nitrate (50 mg/l) applies to all bodies of groundwater, with the exception of the Nitrate Vulnerable Zones identified under Directive 91/676/EEC (where the Nitrate Directive applies).

For each groundwater body, the degree to which it is at risk of failing to meet the objectives has to be assessed. Article 11 of WFD and Annex VI of the WFD specifies the measures that need to be taken in the case the concentrations of pollutants (including nitrate) have an upward trend. The Directive is not prescriptive; it simply states that '*measures have to be taken to achieve the objectives*' (good chemical status of the groundwater and no upward trend in the concentration of pollutants). Measures have to be taken at the level of groundwater water bodies and at the level of river basin districts. A distinction is made between basic measures and additional measures. For the latter category it is indicated that the list is not exhaustive. Most of the measures deal with the extraction and sustainable use of groundwater and with preventing point discharges of pollutants to groundwater bodies. Annex VI, part A, measure (v) of the Water Framework Directive mentions 'emission abatement measures', without further specification. In practice, this means that if upward trends in nitrate concentrations in the groundwater occur in areas outside NVZ, emission abatement measures have to be taken. It is likely that such measures include those of the Nitrates Directive (e.g., good agriculture practices, balanced fertilization, and restricted fertilization).

Summarizing, Groundwater Directive and the Water Framework Directive are more target-oriented than the Nitrates Directive. The Nitrates Directive is rather means-oriented and provides a lot of detail as regards the measures that need to be taken to achieve the target.

4.1.2 Assessment of nitrate policies and measures

The assessment described here focuses on the measures of the Nitrates Directive. It is still unclear which (additional) measures member states will implement to satisfy the (nitrate, nitrogen, phosphorus) targets of the Groundwater Directive and the Water Framework Directive. Detailed analysis of possible approaches would therefore be speculative.

The implementation of Codes of Good Agricultural Practices, the designation of Nitrate vulnerable Zones (NVZs) and the measures detailed in Action Programmes differ between Member States (of the EU-15; the new Member States lag behind as regards the implementation). These differences are in part related to differences in agricultural systems and the environmental conditions, but the differences in implementation also reflect the degree of freedom of choice provided by the Nitrates Directive (Zwart et al., 2006).

Despite the delay in implementation, the Nitrates Directive has contributed to a more efficient use of N from animal manure and fertilizers. From the 1990s onwards N fertilizer use in EU-25+ has started to decrease, and although this decrease can not be attribute solely to the implementation of the Nitrates Directive, it is true that it has contributed to a more judicious use of animal manure and fertilizer in Europe. This is most clearly seen in Denmark, Netherlands, Belgium and United Kingdom, where nitrate concentrations in groundwater and surface have decreased significantly over the last 10-15 years (Dalsgaard et al., 2006; Van Grinsven et al., 2005; De Clercq et al., 2001). There are also reports indicating that the Nitrates Directive has contributed to decreasing NH_3 and N_2O emissions (e.g., Van Grinsven et al., 2005; Velthof et al., 2005). However, there are still many sites with groundwater and surface waters having more than 50 mg/l of nitrate (Zwart et al., 2006).

There is a wide variation in the length of the periods in which application of fertilizers and organic fertilizers is prohibited. In general there is a certain, albeit weak, relation between the latitude of a region and the start and length of the period in which application is prohibited (Zwart et al., 2006). In northern regions the restriction period starts earlier and lasts longer than in southern regions, which seems logical in view of the differences in climate conditions. The capacity to store manure is generally related to the period in which application is prohibited and most member states require storage facilities which are safely constructed in order to prevent leaching of manure to the environment. Most member states have restrictions regarding the application to sloping soils, but also with some variation in the steepness of the slope. A similar variation can be found in the restricted areas near water courses, both between and with Member States. The application of manures and/or N fertilizer to water-logged or frozen or snow covered soils is prohibited in almost all member states. Rational fertilisation is common in most Member States. Measures regarding crop rotation, vegetation cover and fertilization plans are sometimes on a voluntary basis, even for NVZ-areas. As an example, Table 3 illustrates the measures of the Action Programme in Austria, which applies to its total territory.

Table 3. Summary overview of measures of the Action Program of Austria; an example (after Zwart et al., 2006).

Measure of the Nitrate Directive	Measures of the Austrian Action Program
Period of prohibition of fertilizer application	- 30 Nov-1 Feb All nitrogenous fertilizers - 15 Oct – 15 Feb agricultural land without vegetation cover - 15 Nov – 15 Feb agricultural land with vegetation cover - 1 Oct – start of banning period: 60 kg pure N is allowed - Manure, compost and sewage sludge compost are allowed until 30 Nov
Restrictions of fertilizer and manure applications on sloped soils	- Restriction if the slope is >20% until 2003 - Restriction if the slope is >10% as from 2003 - Total N < 100 kg /ha - Application in batches - Specific measures (not specified) for crops with late spring development (e.g. sugar beet maize) - Immediate incorporation f organic fertilizers
Restrictions of fertilizer and manure applications on soaked, frozen or snow-covered soils	- Application is prohibited
Restrictions of fertilizer and manure applications near water courses (Buffer zones)	- A buffer strip of 5-20 m is required as from 2003
Effluent storage works	
Capacity of manure storage	- 6 months as from 2003
Rational fertilization (e.g. split application, limitations)	- 175 total N for land without vegetation cover

	- 210 total N for land with vegetation cover - Application in accordance with requirements - Immediate incorporation of slurry, liquid manure and sewage sludge on bare land - Split application for 'fast acting' nitrogen inputs
Crop rotation, permanent crop maintenance	No provisions
Vegetation cover in rainy periods, winter	No provisions
Fertilization plans, spreading records	No provisions
Other measures	**Voluntary under the Öpul Programme** - Limitation of stock density to 2 L.U. per ha - Limitation in fertilizer use - Completely refraining from chemical fertilizes (organic farming) - A green cover in fruit and wine production - Sowing without ploughing - Protection and re-establishing of specific biotopes and habitats
Date for application limits for manure applications - 210 kg N/ha/year - 170 kg N ha/year	 - 1999 - 18-12-2002

The Nitrate Directive aims at decreasing or preventing the pollution of groundwater and surface waters with nitrates from agricultural sources. As indicated above, the measures of the Nitrate Directive may also affect the emissions of NH_3 and of the greenhouse gases (GHG) nitrous oxide (N_2O) and methane (CH_4) to a variable degree, depending on the actual implementation (management) and the environmental conditions (climate, soils, morphology). In this project, all measures of the Nitrates Directive were critically assessed on the basis of their potential to affect also NH_3 and GHG emissions, using literature data and expert judgement. Results of this assessment in qualitative terms are summarized in Table 4. Various studies presented in literature provide underpinning for the qualitative assessments made in Table 4 (e.g., Chambers and Oenema, 2004; Erisman et al., 2005; 2006; Van Grinsven et al., 2003; 2005. A quantitative assessment of various measures has been presented by Velthof et al., 2007)

The assessment of pollution swapping issues is presented in Table 4. It can be seen that most of the measures proposed by the Nitrate Directive affect the emissions of NH_3 and GHG, but the effects greatly depend on site-specific conditions and on the management. For example, in a recent extensive field study in the UK, the effects of the timing of livestock manure application (spring, summer, autumn, winter) on NH_3 emissions and nitrate leaching greatly depended on weather conditions (Williams et al., 2006). The authors concluded that there is a need to ensure that slurry management practices, primarily designed to reduce nitrate leaching losses (i.e., moving from autumn to late spring/early summer application timings), do not exacerbate ammonia emissions under warmer conditions and where slurry infiltration into the soil are reduced. Other examples can be found in Hatch et al. (2004), Follet and Hatfield (2001), Cuttle et al. (2004), Erisman et al. (2005), Soliva et al (2006), Petersen (2006). They all emphasize the need for an integrated approach to slurry N management.

Roughly, the measures proposed by the Nitrate Directive fall in the categories (i) and (ii) mentioned in Chapter 3. The category (ii) measures also decreases NH_3 and GHG emissions (synergistic effects). This holds especially for measures that restrict the input of N sources into agriculture, i.e. balanced fertilization, restrictions on fertilizer application on sloping grounds and frozen fields. The category (i) measures tend to increase NH_3 and CH_4 emissions (antagonistic effect), though they may decrease N_2O emissions (synergistic effects). This holds especially for measures that restrict the timing of manure application. There is another (third) group of measures which have 'neutral' effects on NH_3, N_2O and CH_4 emissions. This holds for measures that deal with the implementation of green covers in winter (cover crops), crop rotations, the need to record the fertilizations. However, when the changes in soil cover and or the planning of fertilization leads to drastic changes in the C and N cycling, there may be also changes in NH_3 and N_2O emissions (they become category (ii) measures). Summarizing, the effects of measures proposed by the Nitrate Directive to decrease nitrate leaching do affect the emissions of NH_3 and GHG, but the effects greatly depend on site-specific conditions and the management.

Table 4. Assessment of possibility of pollution swapping of measures taken within the framework of the Nitrates Directive (ND), in terms of increased ammonia (NH_3) emissions and increased greenhouse gas (GHG) emissions (i.e. nitrous oxide, N_2O and methane CH_4). Note that only Type 1 pollution swapping is considered here.

Measures of ND	Effect on NH_3 emissions	Effect on GHG emissions
1. Prohibition of mineral fertiliser application in winter	May increase NH_3 emissions, especially when weather outside the growing season is less rainy and more warm	- May decrease direct and indirect N_2O emissions from nitrate leaching, especially when weather outside the growing season is less rainy and applied N is readily taken up by the crop. But may increase indirect N_2O emissions from NH_3 deposition. - No apparent effect on CH_4 emissions
2. Prohibition of organic fertiliser (manure) application in winter	May increase NH_3 emissions, especially when weather outside the growing season is less rainy and more warm	- May decrease direct and indirect N_2O emissions from nitrate leaching, especially when weather outside the growing season is less rainy and applied N is readily taken up by the crop. But may increase indirect N_2O emissions from NH_3 deposition. - May increase CH_4 emissions from manure storage, because of longer storage periods

3. Restrictions for application on steeply sloping ground	May decreases NH_3 emissions when total N input decreases. There will be no effect when the available N is applied elsewhere (as will be the case with livestock manure).	- May decrease direct and indirect N_2O emissions when total N input on decreases. - There will be little effect on N_2O emissions when the available N is applied elsewhere (as will the case with livestock manure) - No apparent effect on CH_4 emissions
4. Restrictions for application on soaked, frozen or snow-covered soils	- May decrease NH_3 emissions, especially when weather outside the growing season allows easy infiltration of manure N in the soil. - May increase NH_3 emissions, especially when weather outside the growing season is less rainy and more warm	- May decrease direct and indirect N_2O emissions, especially when weather outside the growing season is less rainy and applied N is readily taken up by the crop. Note, freeze-thaw cycles are well-known for emitting large amounts of N_2O; preventing N application to frozen land may therefore decrease emissions. - May increase CH_4 emissions from manure storage, because of longer storage periods
5. Restriction for application near water courses 5-30, range in required distance (m)	May decreases NH_3 emissions when total N input decreases. There will be no net effect on emissions when the available N is applied elsewhere (as will be the case with livestock manure), although the measure may be useful to reduce NH_3 deposition adjacent to priority sensitive habitats.	- May decrease direct and indirect N_2O emissions when total N input on decreases. - There will be little effect on N_2O emissions when the available N is applied elsewhere (as will the case with livestock manure). Where land adjacent to water courses is particularly wet and liable to N2O release, some reduction in overall N2O emission may be achieved. - No effect on CH_4 emissions
6. Effluent storage	May decreases NH_3 emissions when storage vessels are covered; if not covered, emissions may increase.	- May decreases direct and indirect N_2O emissions when effluents are stored an applied subsequently to land properly. - No effect on CH_4 emissions
7. Manure storage (duration) (months)	May increase NH_3 emissions, especially when manure storage facility is not properly covered.	- May increase direct and indirect N_2O emissions from manure storages. However, direct and indirect N_2O emissions associated with the subsequent land application of the manure may be decrease, depending on timing (see 2 and 4). - May increase CH_4 emissions from manure storage, because of longer storage periods, depending also on manure type and storage conditions
8. Balanced fertilisation (e.g.	May decreases NH_3 emissions, especially when	May decrease both direct and indirect N_2O emissions, when N input decreases

splitting, fertilisation limitations)	urea and ammonium-based fertilizers are replace by nitrate and ammonium-nitrate based fertilizers [the comparison does not make full sense], and when the total N input decreases.	However, may increase direct and indirect N_2O emissions when urea and ammonium-based fertilizers are replaced by nitrate and ammonium-nitrate based fertilizers, because latter fertilizers have higher emissions factors. - No effect on CH_4 emissions
9. Crop rotation, permanent crop maintenance	- No effect on NH_3 emissions	- Effects of this measure on direct and indirect N_2O emissions depend on associated changes in soil organic carbon and N fertilization regime. - No effect on CH_4 emissions
10. Vegetation cover in rainy periods, winter	- No effect on NH_3 emissions	- May decrease both direct and indirect N_2O emissions, when NO_3 leaching losses decrease and total N input decreases. However, may increase direct N_2O emissions when soil organic carbon increases. - No effect on CH_4 emissions
11. Fertilisation plans, spreading records	- No effect on NH_3 emissions	- No effect on N_2O emissions - No effect on CH_4 emissions
12. Application limits for animal manure (170 kg N/ha/year)	- Decreases local NH_3 emission and may decrease total NH_3 emissions, especially when total N input decreases. However, when the amount of manure produced remains constant, the manure surplus needs to be transferred to other areas, and total NH_3 emissions may increase because of increases in storage time and transactions costs.	- May decrease both direct and indirect N_2O emissions, when N input decreases. However, when the amount of manure produced remains constant, the manure surplus needs to be transferred to other areas, and N_2O emissions may remain constant. However, when part of the animal manure N is replaced by fertilizer N, N_2O emissions may increase because of the larger N_2O emission factor for fertilizer than for manure. - May decrease CH_4 emissions from manure storage, when amount of manure decreases, but increases when the amount of manure produced remains constant and storage time increases.
13. Other measures		

4.2 Policies and measures to abate ammonia emissions

4.2.1 escription of policies and measures to abate ammonia emissions

The Integrated Pollution Prevention and Control Directive (IPPC Directive) imposes a requirement (permit) for industrial and agricultural activities with a high pollution potential. This permit can only be issued if certain environmental conditions are met. Hence, companies bear responsibility for preventing and reducing any pollution they may cause. The IPPC Directive concerns new or existing industrial and agricultural activities, as defined in Annex I to the Directive, including intensive livestock farming (pigs, poultry). As regards agricultural activities, the IPPC focuses particularly on ammonia emissions from large intensive livestock farming systems. The IPPC Directive is based on several principles, namely (1) an integrated approach, (2) best available techniques, (3) flexibility and (4) public participation.

1. The integrated approach means that the permits must take into account the whole environmental performance of the installation, covering, e.g., emissions to air, water and land, generation of waste, use of raw materials, energy efficiency, noise, prevention of accidents, and restoration of the site upon closure. The purpose of the Directive is to ensure a high level of protection of the environment taken as a whole.
2. The permit conditions must be based on *Best Available Techniques* (*BAT*), as defined in the IPPC Directive.
3. The IPPC Directive contains elements of flexibility by allowing the licensing authorities, in determining permit conditions, to take into account:
   (a) the technical characteristics of the installation,
   (b) its geographical location and
   (c) the local environmental conditions.
4. The Directive ensures that the public has a right to participate in the decision making process, and to be informed of its consequences, by having access to
   (a) permit applications in order to give opinions,
   (b) permits,
   (c) results of the monitoring of releases and
   (d) the European Pollutant Emission Register (EPER).

In order to receive a permit an agricultural installation must comply with certain basic obligations. In particular, it must:

- use all appropriate pollution-prevention measures, namely the Best Available Techniques (which produce the least waste, use less hazardous substances, enable the recovery and recycling of substances generated, etc.);
- prevent all large-scale pollution;
- prevent, recycle or dispose of waste in the least polluting way possible;
- efficient energy use;
- ensure accident prevention and damage limitation;
- return sites to their original state when the activity is over.

In addition, the decision to issue a permit must contain a number of specific requirements, in particular including:

- emission limit values for polluting substances;
- any soil, water and air protection measures required;
- waste management measures;
- measures to be taken in exceptional circumstances (leaks, malfunctions, temporary or permanent stoppages, etc.);
- minimising of long-distance or transboundary pollution;
- release monitoring;
- and all other appropriate measures.

As indicated before, the permits for starting Intensive Rearing of Poultry and Pigs must contain conditions based on best available techniques (BAT) as defined in the Article 2.11 of the IPPC Directive. A reference document on BAT (BREF) was finalized in 2003 (European Commission, 2003), under the supervision of a large group of international experts. Although it mainly focuses (in detail) on low emission housing systems for fattening pigs, sows, laying hens and broilers, it also addresses low emission storage and land application of manure. High resolution drawings of various housing systems are included, as well as information about ammonia emissions and costs (see: http://eippcb.jrc.es/pages/FActivities.htm). Though the IPPC is based on the principle of an integrated approach, including animal welfare, noise, ammonia, nitrous oxide, methane, energy and resource use and wastes, the objectives and (best available) techniques for mitigating these environmental concerns have been formulated in a rather qualitative way, except for ammonia and the economic costs for ammonia abatement technology

There are a large number of BATs mentioned in the BREF for intensive rearing of pigs and poultry (European Commission, 2003). Good agricultural practice is an essential part of BAT. For improving the general environmental performance of an intensive livestock operation, BAT includes the flowing:

- identify and implement education and training programs for farm staff;
- keep records of water and energy use, amounts of livestock feeds and wastes, and the field application of fertilizers and animal manure;
- plan the application of the animal manure to land properly

The BATs for the land spreading of animal manure makes reference to the Code of Good Agricultural Practice of the Nitrates Directive, and entails that the principle of BAT is based on the following four actions:

- applying nutritional measures;
- balancing the manure that is going to be spread with the available land and crop requirements and – if applied – with other fertilizers
- managing the land spreading of the manure; and
- only using the techniques that are BAT for the spreading of manure on land

BAT includes the minimization of the emissions from manure applied to land by balancing the amount of manure with the foreseeable requirements of the crops (nitrogen and phosphorus and the mineral supply to the crop from soil and fertilizers. BAT also requires that account be taken of the characteristics of the land when applying the animal manure, in particular soil conditions and slope, climatic conditions and rainfall. Evidently, these elements of BAT are not meant to decrease ammonia emissions, but to increase the efficient utilization of N and P by the crop and to minimize the emissions of these nutrients to groundwater and surface water, and thereby to prevent type 1 pollution swapping.

However, spreading of animal manure to land is not included under the IPPC Directive if this is not carried out in/on an installation. According to the definition of installation in the IPPC Directive (to be regulated by a permit), the term "installation" means a "stationary technical unit where one or more activities listed in Annex I *(in this case, intensive rearing of poultry or pigs)* are carried out, and any other directly associated activities which have a technical connection with the activities carried out on that site and which could have an effect on emissions and pollution". This is interpreted by the Commission that manure spreading would be legally covered only in cases where the spreading is carried out on the site of the installation and that a technical connection (e.g. a pipe) is used. Some Member States do include spreading more generally under the IPPC Directive but they go further than the requirements of the Directive (which they are allowed to do).

Guidelines for ammonia abatement have also been developed and are being updated by Working Group on Ammonia Abatement of the UNECE Convention on Long Range Transboundary Air Pollution (CLRTAP). In a guidance document (Framework Advisory Code of Good Agricultural Practice to reduce Ammonia Emissions; to be found at: http://www.unece.org/env/documents/2001/eb/wg5/eb.air.wg.5.2001.7.e.pdf), an overview is presented of the best available techniques to reduce ammonia emissions from all major on-farm sources (animal house, storage, spreading manure), and for all animal categories (including cattle). Besides emission reduction potential compared to traditional systems (e.g. uncovered storages), also economic data (investments, costs) are provided. This document is updated on a regular basis, under supervision of the CLTRAP Expert Group on Ammonia Abatement (established under the Working Group on Strategies and Review). The Code of Good Agricultural Practice to reduce Ammonia Emissions of the UNECE- CLRTAP comprises six sections, as follows:

1. Nitrogen management that takes into account the entire N cycle;
2. Livestock feeding strategies;
3. Low-emission manure spreading techniques;
4. Low-emission manure storage techniques;
5. Low-emission animal housing techniques;
6. Limiting ammonia emissions from the use of mineral N fertilizer

The Code includes guidance on reducing ammonia emissions from all the major agricultural sources for which practical and widely applicable techniques are available. Also, the Code explicitly mentions the risk of type 1 pollution swapping, by stating: *"It is important to note that ammonia conserved by the introduction of an abatement measure at one stage of manure management can be readily lost at a "downstream" stage of management. Where abatement measures are used for housing and/or manure stores, it is essential to use a suitable, low emission technique for applying the manure to land. Although reducing ammonia emissions from* *applying manures to land should increase the amount of N available for uptake by plants, in some circumstances it may also increase the potential for N loss by other pathways, through nitrate leaching for example. It is important to consider this risk when planning and implementing ammonia abatement strategies"*

The issue of type 1 pollution swapping is further addressed in the section on 'Nitrogen management that takes into account the entire N cycle'. This section provides the following qualitative guidelines for timely and careful N application:

- Calculate the N in livestock manure applications that will become available for crop uptake in the following year;
- Calculate the N left in residues of the previous crop, especially if grassland and field forage crops was ploughed up;
- Take account of N mineralization in soils that have large (>6%) soil organic matter content, or where livestock manures have been applied in large amounts over several years;
- Use acknowledged national methods for predicting plant-available soil nitrogen;
- Where soil is well supplied with available N (for example because grassland has recently been ploughed) have the soil analysed for its mineral N content;
- Nitrogen fertilizer and livestock manure applications should be timed according to periods of N uptake by the crop, i.e. shortly before the onset of rapid crop growth;
- Avoid large application rates of manures that supply nitrogen (and other plant nutrients) in excess of crop requirements.

These guidelines are very similar to the Code of Good Agricultural Practice of the Nitrates Directive (see section 4.1). Also for the other items of Code of Good Agricultural Practice to reduce Ammonia Emissions detailed guidelines have been made for Livestock feeding strategies, low-emission manure spreading techniques, low-emission manure storage techniques, low-emission animal housing techniques, and the use of mineral N fertilizer that limit ammonia emissions.

Examples of the ammonia abatement options for cattle houses, and manure storage are presented below in Tables 5 and 6. The last column in the tables makes the link between the listed measures and categories defined the RAINS model (reference), which is used by the CLRTAP for the integrated assessment of possible mitigation strategies.

Table 5. Overview of ammonia abatement measures in the CLTRAP Framework Advisory Code of Good Agricultural Practice to reduce Ammonia Emissions from cattle housing stables.

Housing type	**Reduction (%)**	**Ammonia emission (kg/cowplace.year)**	**RAINS category**
Cubicle house	-	11	Cattle, liquid systems
Tying stall	60	4.4	Cattle, liquid systems? Adapted system
Grooved floor	25	8.3	Cattle, liquid systems. Adapted system
Solid manure, sloped floor or deep litter system	30	7.5	Cattle, solid systems. Adapted system.
Flushing and scraping systems	25	No practical data	Cattle, liquid system. Adapted system

The ammonia abatement options presented in the BREF under the IPPC Directive and in the Framework Advisory Code under UNECE-CLTRAP are very similar, except for cattle which is not included in the IPPC.

Table 6a. Overview of ammonia abatement measures for manure storage in the CLTRAP Framework Advisory Code of Good Agricultural Practice to reduce Ammonia Emissions.

Abatement measure	**Livestock class**	**Ammonia reduction (%)**	**Applicability**	**BAT for IPPC pigs ?**	**Costs Euro/m3.y**	**RAINS Category**
Lid, tent, roof	all	80	Concrete or steel tanks and silos	Yes	8	Covered storage of manure
Plastic sheet or floating cover	all	60	Small earth banked lagoons	Yes	1.25	Covered storage of manure
Plastic sheet or floating cover	all	60	Large earth banked lagoons	Yes	1.25	Covered storage of manure
Low tech floating cover (peat, chopped straw, LCA…)	all	40	Concrete or steel tanks and silos	Yes	1.10	Covered storage of manure
Natural crust on tank or lagoon	Cattle	35-50	Not when mixing is required upon spreading	Yes	0	Covered storage of manure
Replacement of lagoons with tanks	All	?		Not assessed	14.9 (cost of tank: 6.94)	
Storage bag	All	100	Bag sizes may be limited for use on larger farms	Not assessed	2.5	Covered storage of manure

Table 6b. Ammonia abatement efficiencies of manure application techniques (UNECE, 1999).

Method	Abatement efficiency, %
Trailing hose	30
Trailing show	40
Injection, open slot	60
Injection, closed slot	80
Incorporation of surface applied manure directly into the soil	80

4.2.2 Assessment of policies and measures to abate ammonia emissions

As indicated among others in Tables 5 and 6 and in various reports, the ammonia abatement measures of Framework Advisory Code under UNECE-CLTRAP and the

BREF under the IPPC Directive provide a useful list of measures that can be used to significantly reduce ammonia emissions. For example, the total ammonia emissions from agriculture in the Netherlands decreased from about 240 Gg in 1985 to about 140 Gg in 2000, due to among other the implementation of low-emission techniques for the storage and application of animal manure. Also the implementation of measures of the Nitrates Directive have contributed to this decrease, as well as the implementation of the milk quota system from 1994 onwards which reduced the size of the Dutch dairy herd (Van Grinsven et al., 2003; 2005).

Table 7 summarizes the possible ammonia abatement measures, categorized following the RAINS model classification, as these are the most common measures used in the assessment of the mitigation of ammonia emissions from agriculture. Impacts on nitrate leaching and greenhouse gas emissions are presented to show the potential mutual strengthening or swapping.

Table 7. Assessment of possible pollution swapping by Best Available Technique (BAT) measures taken within the framework of the IPPC, and in the Framework Advisory Code as developed by the Working Group on Ammonia Abatement of the UNECE Convention on Long Range Transboundary Air Pollution (CLRTAP), in terms of increased nitrate (NO_3) leaching and increased greenhouse gas (GHG) emissions (i.e. nitrous oxide, N_2O and methane CH_4).

BAT Measures	Effect on nitrate leaching	Effect on GHG emissions
1. Low Nitrogen Fodder (dietary changes)	- Low nitrogen fodder decreases the total N input into the system and thereby decreases almost all N losses and N loss pathways. - May decreases NO_3 leaching especially from grazing animals	- Decrease direct and indirect N_2O emissions, because the total N input into the system decreases. - Likely no effect on CH_4 emissions.
2. Stable Adaptation by improved design and construction of the floor (primarily to reduce NH_3 emission)	- May increase NO_3 leaching, if the increased N amounts saved in the manure are not taken into account during land application of the manure	- May increase direct (and indirect from leached N) N_2O emissions, if the increased N amounts in the manure are not taken into account during land application of the manure - Decreases indirect N_2O emissions (originating from volatilized NH_3) - Likely no effect on CH_4 emissions, if duration of manures storage does not change.
3. Covered Manure Storage (reducing NH3)	- May increase NO_3 leaching, if the increased N amounts saved in the manure are not taken into account during land application of the manure	- May increase direct (and indirect from leached N) N_2O emissions, if the increased N amounts in the manure are not taken into account during land application of the manure - Decreases indirect N_2O emissions (originating from volatilized NH_3) - May increase CH_4 emissions, because of less oxidation in the surface crust.
4. Biofiltration (air purification) for animal houses	- The effect on NO_3 leaching depends on the fate of the N in the filter/filtrate. There will be little effect when the trapped N is used as N fertilizer.	- Decreases indirect N_2O emissions (originating from volatilized NH_3) - Some filters (composts) release N_2O and these techniques may than increase N_2O emissions. - Likely no effect on CH_4 emissions
5. Low Ammonia emission application of manure	- May increase NO_3 leaching, if the increased N amounts saved in the manure are not taken into account during land application of the manure	- Decreases indirect N_2O emissions (originating from volatilized NH_3) - May increase direct N_2O emissions in case of manure injection. - Likely no effect on CH_4 emissions
6. Substitution of urea with ammonium	- May increase NO_3 leaching, if the decreased N losses as NH_3 are not taken into account	- Decreases indirect N_2O emissions (originating from volatilized NH_3) - May increase direct N_2O

nitrate decreasing NH3 emission	during application of the fertilizers.	emissions as nitrate-based and ammonium-nitrate based fertilizers show higher emissions than urea on average. - Likely no effect on CH_4 emissions
7. Incineration of poultry manure (reducing NH3 emission)	- May decreases NO_3 leaching, if the incinerated poultry manure is not substituted by other N sources	- May increase NO_x emissions and direct and indirect N_2O emissions if the storage, drying and incineration does not occur properly. - Likely no effect on CH_4 emissions
8. Nitrogen management; balancing manure nutrients with other fertilizers to crop requirements	- Will improve N utilization by the crop and will decreases NO_3 leaching,	- Will decrease direct and indirect N_2O emissions. - Likely no effect on CH_4 emissions

As follows from the assessments made in Table 7, most of the BAT measures of the IPPC directly or indirectly affect nitrate leaching and the emissions of GHG, but again the overall effects greatly depend on site-specific conditions and on the integration of the measures in the overall N management (BAT 8 in Table 7); there must be emphasis on increasing the overall N use efficiency, rather than simply reducing the losses via NH_3 volatilization. Various studies presented in literature provide underpinning for the qualitative assessments made in Table 7 (e.g., Chambers and Oenema, 2004; Erisman et al., 2005; 2006; Van Grinsven et al., 2003; 2005. A quantitative assessment of various measures has been presented by Velthof et al., 2007).

Basically, the BAT on animal feeding is an effective and efficient measure as it decreases both NH_3 emissions, NO_3 leaching and direct and indirect N_2O emissions. This measure can be characterized as a highly integrated measure. Results of experiments and also of the practice have shown the great potential of this measure. Phase feeding in pig and poultry husbandry has become common practice in most EU Member States and has led to a substantial decrease in the N excretion of these animals (e.g., Geers and Madec, 2006, and references therein) and thereby also to a decrease in the amounts of N lost via NH_3 emission, NO_3 leaching and direct and indirect N_2O emissions. Further decreases in N excretion are possible via improving the balance of dietary amino acids in the diet. This can be done through combining different protein sources and or/ the utilization of industrial amino acids. However, the development of such advanced feeding techniques for reducing the N excretion of pigs and poultry requires a good knowledge of amino acid availability in the feedstuffs and of the changes in amino acids requirements according to the growing stage or physiological status of the animals. Also the costs of the feeding may increase (Dourmad and Jondrevill, 2006). Hence, proper incentives may be needed initially to further decrease the protein content of the animal feed.

The BAT measures 'stable adaptations', 'covered manure storages', 'low-emission application techniques', 'biofiltration' and replacing urea fertilizers by (ammonium-nitrated) based fertilizers specifically aim at decreasing the loss of NH_3 from the livestock manure. These measures are category (i) type of measures (See chapter 3); they 'block a hole in the pipe' (see Figure 6), but these measures will likely lead to pollution swapping if not combined with BAT 8 (integrated management), with a correction of the total N input into the system for the decreased losses via NH_3 emissions. Hence, these measures are only effective and efficient when the total N input into the system is decreased with an amount equivalent to the amount of NH_3-N trapped.

The BAT measure 'incineration of manure' has different 'faces'. It harbours the potential of an effective and efficient measure, as it removes reactive N from the system. The prerequisite is that all reactive N is transformed into N_2 without emissions of NH_3, NO, and N_2O. This requires proper technology and management, because the N content is relatively high and the risk of emissions from the incineration process is not negligible. But more data are needed on this. The overall impression is that the losses are smaller than if left on the field. However, the technique has also been questioned in terms of resource utilization, as it transforms the nutrients contained in the manure in a non or less available form, while the organic matter in the manure could/should be used to replenish the soil organic matter pool (Jenny, 1980). When the ashes and slacks with valuable nutrients like phosphorus are dumped off-site, the nutrients are withdrawn from the nutrient cycle, which is not a sustainable solution for scarce resources like phosphorus.

Summarizing, the BAT measures of the IPPC Directive can be categorized in two categories, i.e., integral measures with the potential of having synergistic effects and measures with pollution swapping potential. The measures of BATs 1 and 8 are considered to be integral measures that decrease the total amount of N into the systems and thereby have the synergistic potential of decreasing both NH_3 emission, NO_3 leaching and direct and indirect N_2O emissions. The measures of BATs 2, 3, 4, 5 and 6 have the potential of pollution swapping (antagonistic effects) as they all decrease NH_3 emissions and thereby lead to more N in the manure and fertilizer, which subsequently may increase NO_3 leaching and direct N_2O emissions if no corrections are made for the increased amounts of N in the manure and fertilizer. Therefore, BATs 2, 3, 4, and 5 must be implemented simultaneously (to circumvent that the NH_3 trapped in low-emission stables and manure storage systems is lost in a later stage during the application of animal manure to land), and they must be combined with BAT 8 (and BAT 1) to prevent pollution swapping to NO_3 leaching and N_2O emission. As explained before, BAT 7 is a special type of measure; it leads to the removal of nutrients and organic carbon from the agricultural system in exchange of heat. It can be assessed as a category (ii) type of measure, as it harbours the risk of pollution swapping, but it can be evaluated as well as a category (i) type of measure as it decreases the amount of reactive N and thereby has the synergistic potential of decreasing both NH_3 emission, NO_3 leaching and direct and indirect N_2O emissions.

The forthcoming policy measures identified in the Thematic Strategy on Air Pollution, to satisfy the objectives of the 6th Environmental Action Plan on air quality, include (see section 2.4):
1. Revision of the emission ceilings under the NEC Directive;
2. A possible extension of the IPPC directive, to include installations for intensive cattle rearing and a possible revision of the current thresholds for installations for the intensive rearing of pigs and poultry; and
3. Making full use of measures of the Rural Development Regulation, related to farm modernisation, meeting standards and agro-environment, to tackle ammonia emissions from agricultural sources.

Evidently, these policy measures contribute to decreasing emissions. The measures proposed under 2 and 3 include the measures listed in Table 7, and the assessment of pollution swapping issues is not different from the assessment made above. Again, great emphasis should be given to the joint implementation of BATs 2, 3, 4, 5 and 6 with BATs 1 and 8, to prevent pollution swapping to NO_3 leaching and N_2O emission.

4.3 Birds and Habitats Directives

Two EU Directives deal with the conservation of European wildlife, focusing on the protection of sites as well as species. The 1979 Birds Directive identified 193 endangered species and sub-species for which the Member States are required to designate Special Protection Areas (SPAs). The 1992 Habitats Directive aims to protect other wildlife species and habitats. Each Member State is required to identify sites of European importance (Special Areas of Conservation (SACs) and to put in place a special management plan to protect them, combining long-term conservation with economic and social activities, as part of a sustainable development strategy (http://ec.europa.eu/environment/nature/). These sites, together with those of the Birds Directive, make up the Natura 2000 network.

4.3.1. Assessment of the measures of the Birds and Habitats Directives

Though the Birds Directive and Habitats Directive contain a large list of requirements and measures to protect biodiversity and habitats, the effects on N cycling and on NH_3 emission, NO_3 leaching and N_2O and CH_4 emissions are confined to specific areas, and therefore the effects of the BHDs are regionally and overall relatively small in relation to the objective to reach national emissions ceilings and EU wide reductions in emissions. By contrast, the Habitats Directive (including the Birds Directive) takes a precautionary approach reflecting the EU intention to afford a high level of protection to the network of Natura 2000 sites. This precautionary approach provides the basis for substantial controls to polluting activities, unless these can be shown not to be having a significant adverse effect on Natura 2000 sites. Although the emphasis to date has been on reducing on-site activities which lead to adverse effects, the Directives imply a requirement to assess the polluting effect of both nearby and transboundary air pollution sources. In the case of nitrogen from agriculture, the most wide-spread effects occur from ammonia so that the Habitats Directive may require substantial reductions to ammonia emissions.

The process of SPA and SAC designation will likely result in the inclusion into Natura 2000 of natural and semi-natural areas, where agriculture will be mostly absent or present in an extensive form. Natura 2000 management plans and species action plans are being elaborated by the Member States. Once completed, they will impose restrictions on farmers within Natura 2000 areas as well as outside those areas. The management measures are focused on species and habitat protection and may also set limits to livestock density and ammonia emissions (to decrease eutrophication and the acidification (proton loading). Hence, there are requirements and measures taken within the framework of the Birds Directive and Habitats Directive that do affect nitrogen cycling and NH_3 emission, NO_3 leaching and N_2O and CH_4 emissions. These effects may also follow from mitigation and compensatory measures taken within the framework of the Birds Directive and Habitats Directive. Mitigation measures are needed to minimizing or canceling negative effects of projects on habitats. Compensatory measures encompass (i) re-creating a habitat, (ii) improving an habitat, (iii) establishing a new habitat. Such mitigation and compensatory measures usually involve agri-environmental measures which lead to an extensification of agricultural practices and a decrease in livestock density and N inputs. Examples include:

- delayed grazing and mowing of grasslands in spring,
- maximum livestock densities,
- zones with limits for NH_3 emissions from agriculture
- specific guidelines and provisions for grazing management,
- establishment of buffer strips near water courses and Natura 2000 sites,
- surface water and wetland management leading to higher groundwater levels,
- abolishment of farms in and near Natura 2000 sites.

Basically, the measures of the Birds and Habitat Directives relate to spatial zoning (category (vi)) and agri-environmental measures focused on the extensification of agricultural production (category (iii)). Because of the spatial zoning activities, they have the potential of a type 2 pollution swapping mechanism, and because of the extensification of agricultural production, they have the potential of decreasing the total emissions per unit surface area but not necessary per unit of agricultural produce. The decrease in total N inputs associated with extensification decrease total N losses, including the losses via NH_3 emission, NO_3 leaching and N_2O and CH_4 emissions. The measures taken within the framework of the Birds Directive and Habitat Directive usually also lead to a decrease in agricultural output per unit surface area and also to a decrease in N utilization, i.e., a lower N retention per unit agricultural produce. This may hold especially for measures that prescribe extensive grazing, expand wetland areas by raising groundwater levels in order to (re-)establish wetland flora and fauna. Expanding wetland areas and raising groundwater levels may lead to a lower N utilization in crop production because of increased N losses via (de)nitrification. Possibly, the enhanced N losses via (de)nitrification in re-established wetlands also increase the emissions of N_2O and CH_4 (Van Dasselaar et al., 1999a, 1999b; Velthof and Oenema, 1995).

Summarizing, the Habitats Directive is a very powerful driver to safeguard biodiversity and to lower NH_3 emissions, by virtue of the precautionary approach. However, we must accept that this is an area of ongoing development in learning to implement the existing legislation and that more effort needs to be given to understanding the wider implications and opportunities (see also Dragosits et al., 2006; Sutton et al., 2004).

4.4 Cross compliance measures

Cross-compliance was introduced in the EU by the Agenda 2000 Common Agricultural Policy (CAP) reform. From then on, member states were allowed to link environmental conditions to direct payments to farmers, independent of their production level. In June 2003 cross-compliance has become an obligatory element of CAP. This provides farmers greater freedom to decide what crops and livestock to produce. Under the reformed CAP, instead of having to produce particular products to obtain subsidy, farmers are able to choose what to produce. The Council of Ministers of the European Union has also recognised that farmers in receipt of subsidy have important responsibilities towards the protection of the environment, animal health and welfare, and public health. The CAP Reform Agreement (implemented in European law by Council Regulation 1782/2003) therefore requires farmers to observe certain conditions in these areas in return for receipt of this subsidy. This is known as "Cross Compliance".

These Cross Compliance conditions mean that a farmer receiving direct payments will be required to respect a number of European laws (known as the Statutory Management Requirements, SMRs) as well as maintaining the land in Good Agricultural and Environmental Condition (GAEC). These arrangements have been introduced by 1 January 2005.
There are two aspects to Cross Compliance:

- The first of these is compliance with a range of 19 European regulatory requirements covering the environment, food safety, animal and plant health and animal welfare. These Statutory Management Requirements are a set of laws which are already in force throughout the EU. Cross Compliance means that in future farmers will have to comply with these laws as a condition of receipt of subsidy. The 19 European regulatory requirements have been listed in Table 8.
- The second is compliance with a requirement that all those in receipt of the Single Area Payment have to maintain the land in Good Agricultural and Environmental Condition (GAEC). Council Regulation 1782/2003 sets out a framework of Issues and appropriate Standards which Member States must observe. Member States are permitted to define minimum requirements for

GAEC within a European framework. In general, the definition of GAECs must be in accordance with the framework set out in Table 9.

Cross Compliance aims at bridging agricultural policy, environmental policy and nature conservation policy. The CAP reform agreement requires that land in receipt of the single area payment should be kept in Good Agricultural and Environmental Condition so that land abandonment is avoided and that the positive environmental benefits of agricultural management of the land are ensured. As a condition of receipt of the single area payment, there is more flexibility for Member States in the development of Good Agricultural and Environmental Conditions which farmers must observe, than in the compliance with the Statutory Management Requirements.

The qualitative assessment presented here is conducted *ex ante*, as there is still little written information about the implementation, penetration effectiveness and efficiency of Cross Compliance measures in practice in the various Member States.

The Cross Compliance instrument ensures the implementation of existing Directives (SMRs, Table 8) and Good Agricultural and Environmental Conditions (GAECs, Table 9). A few of the SMRs and GAECs do affect the emissions of NH_3, N_2O and CH_4 and/or the leaching of NO_3, and it is likely that the Cross Compliance instrument will contribute to increased effects due to greater compliance with the SMRs and GAEC. Greater compliance to environmental Directives may magnify the effects of for example the measures of the Nitrates Directive indicated in Chapters 4.1. Greater compliance to standards and requirements for animal welfare and the housing of animals (Refs 16, 17 and 18 in Table 8) may contribute to increasing emissions. These standards and requirements fall in the category (iv) type of measures and may lead to an increase of the emissions of NH_3, N_2O and CH_4.

Linking EU support to compliance with the implementation of EU Directives ensures the implementation but may also introduce some side-effects. For example, linking the cross compliance support to the implementation of the SMRs will make farmers cautious to the risk of exceeding N application limits and environmental limits. This has as consequence that arable farmers will become more reluctant to accept animal manure from intensively managed livestock farms with excess manure, because the N content and availability of the manure is not always known well in advance. Arable farmers will prefer N fertilizers as the N availability is known, thereby cutting down the potential for recycling of nutrients from animal manure, and increasing the cost of manure disposal for intensively managed livestock farms. This situation may occur in areas with high livestock density, such as Netherlands, Flanders, Brittany in France and the Po area in Italy.

Table 8 Cross Compliance requirements according to the Statutory Management Requirements (Annex III of Regulation (EC) 1782/2003) and the assessment of their effects on pollution swapping issues (NH3, N2O and CH4 emissions and NO3 leaching).

Ref. No.	EC Directive / Regulation	What will be the Cross Compliance requirement to be met by the farmer?	What are the possible effects on NH_3, N_2O and CH_4 emissions and NO_3 leaching?
1	Council Directive 79/409/EEC of 2 April 1979 on the conservation of wild birds (OJ L 103, 25.4.1979, p. 1). Articles 3, 4 (1), (2) and (4), 5, 7 and 8.	Article 3 requires Member States to take action to secure or re-establish habitats for all naturally occurring wild birds Article 4 requires Member States to take special protection measures for certain species of bird, including the establishment of Special Protection Areas (SPAs). Appropriate steps have to be taken to avoid pollution or deterioration of habitats or disturbance of birds on these sites. There is a similar requirement for habitats outside protected sites. Article 5 prohibits the deliberate killing and significant disturbance of wild birds, deliberate destruction of, or damage to, their nests and eggs, removal of their nests or taking of their eggs except under licensed conditions e.g. for protection of crops. Article 7 permits hunting of wild birds subject to conditions. Article 8 prohibits certain means of killing wild birds.	Little or no effect on NH_3, N_2O and CH_4 emissions and NO_3 leaching;
2	Council Directive 80/68/EEC of 17 December 1979 on the protection of groundwater against pollution caused by certain dangerous substances (OJ L 20, 26.1.1980, p. 43). Articles 4 and 5.	The major consequence of this Directive is that farmers require authorisation for disposal of spent sheep dip and pesticide washings to land. Where List I and List II substances are otherwise used, manufactured, stored or handled, farmers will be expected to comply with relevant legislation, codes of practice or other relevant good practice.	Little or no effect on NH_3, N_2O and CH_4 emissions and NO_3 leaching;
3	Council Directive 86/278/EEC of 12 June 1986 on the protection of the	Use only of sludge treated in accordance with the Directive. Observation of specified harvesting intervals and other requirements to	Little or no effect on NH_3, N_2O and CH_4 emissions and NO_3 leaching;

	environment, and in particular of the soil, when sewage sludge is used in agriculture (OJ L 181, 4.7.1986, p. 6), Article 3.	prevent contaminants (e.g. heavy metals) reaching the human food chain. Farmers in NVZs will be expected to record the use of sludge in their Fertiliser and Manure Plan and to observe the relevant closed period, as necessary.	
4	Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (OJ L 375, 31.12.1991, p. 1) Articles 4 and 5.	Farmers with land in NVZs should comply with the mandatory measures contained in the Nitrate Directive, i.e. limits to the application of Nitrogen in animal manure, special measures for the storage, application methods and timing of fertilizer and animal manure.	See Chapter 4.1 for extensive description of the effects on NH_3, N_2O and CH_4 emissions and NO_3 leaching;
5	Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild flora and fauna (OJ L 206, 22.7.1992 p. 7) Articles 6, 13, 15 and 22(b).	Article 6 requires (i) Special Areas of Conservation (SACs) to be designated for habitats (listed in Annex I) and species (listed in Annex II) to be protected from damage, deterioration of habitats or disturbance of species; and (ii) the effects of plans or projects that could cause adverse effects to be considered. Article 13 requires prohibition of destroying, cutting or uprooting of protected plant species listed in Annex IV(a) of the Directive. Article 15 requires prohibition of certain methods of killing or taking wild species. Article 22 requires regulation of introduction of non-native species where prejudicial to native wildlife.	See Chapter 4.3 for a description of the likely effects on NH_3, N_2O and CH_4 emissions and NO_3 leaching;
6	Council Directive 92/102/EEC of 27 November 1992 on identification and registration of animals (OJ L 355, 5.12.1992 p. 32) Articles 3,4 and 5.	Farmers are required to comply in full with the domestic legislation which implements EU requirements governing the identification (tagging/tattooing etc), record keeping, and movement requirements for cattle, sheep, goats and pigs.	Little or no effect on NH_3, N_2O and CH_4 emissions and NO_3 leaching;
7	Commission Regulation 2629/97 of 29 December 1997 laying down detailed	Farmers are required to comply in full with the domestic legislation which implements EU requirements governing the identification	Little or no effect on NH_3, N_2O and CH_4 emissions and NO_3 leaching;

	rules for the implementation of Council Regulation 820/97 as regards eartags, holding registers and passports in the framework of the system for the identification and registration of bovine animals (OJ L 354, 30.12.1997, p. 19) Articles 6 and 8.	(tagging/tattooing etc), record keeping, and movement requirements for cattle, sheep, goats and pigs.	
8	Regulation 1760/2000 of the European Parliament and of the Council of 17 July 2000 establishing a system for the identification and registration of bovine animals and regarding the labelling of beef and beef products and repealing Council Regulation (EC) No 820/97 (OJ L 204, 11.8.2000, p.11) Article 4 and 7	Farmers are required to comply in full with the domestic legislation which implements EU requirements governing the identification (tagging/tattooing etc), record keeping, and movement requirements for cattle and pigs.	Little or no effect on NH_3, N_2O and CH_4 emissions and NO_3 leaching;
8a	Council Regulation (EC) No 21/2004 of 17 December 2003 establishing a system for the identification of ovine and caprine animals and amending Regulation (EC) No 1782/2003 and Directives 92/102/EEC and 64/432/EEC (OJ L 5, 9.1.2004, p.8) Articles 3, 4 and 5	Farmers are required to comply in full with the domestic legislation which implements EU requirements governing the identification (tagging/tattooing etc), record keeping, and movement requirements for sheep and goats.	Little or no effect on NH_3, N_2O and CH_4 emissions and NO_3 leaching;
9	Council Directive 91/414/EEC of 15 July 1991 concerning the placing of plant protection products on the market (OJ L 230, 19.8.1991, p. 1)	1. That the farmer has not retained products that are no longer approved for use. 2. That the farmer is carrying out spray operations on approved crops only, following the Green Code using the pesticide at the correct dosage levels and leaving sufficient 'buffer	Little or no effect on NH_3, N_2O and CH_4 emissions and NO_3 leaching;

	Article 3	zones' so that the spray does not enter water courses.	
10	Council Directive 96/22/EC of 29 April 1996 concerning the prohibition on the use in stockfarming of certain substances having a hormonal or thyrostaic action and of beta-agonists (OJ L 125, 23.5.1996, p. 3) Articles 3, 4, 5 and 7.	No illegal use of substances having a hormonal, thyrostatic action, or the use of beta agonists. Where confirmed residues of banned substances are found following MHS inspection the SVS will carry out an on-farm investigation, including taking extra samples.	Little or no effect on NH_3, N_2O and CH_4 emissions and NO_3 leaching;
11	Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety (OJ L 31, 1.2.2002, p. 1) Articles 14,15,17(1),18,19 and 20	(i) Ensure that the food and feed safety requirements, specified in Articles 14 and 15 of Regulation 178/2002, are met. (ii) Ensure that all stages of production, processing and distribution within the businesses under their control, satisfy the food and feed safety requirements of food law which are relevant to those activities, and verify that such requirements are met (Article 17). (iii) Maintain traceability systems (Article 18). (iv) Withdraw and/or recall food or feed from the market if this is not in compliance with food or feed safety requirements, and notify competent authorities (Articles 19/20).	Little or no effect on NH_3, N_2O and CH_4 emissions and NO_3 leaching;
12	Regulation (EC) 999/2001 of the European Parliament and of the Council of 28 January 2002 laying down rules for the prevention, control and eradication transmissible spongiform encephalopathies. (OJ L 147, 31.5.2001 p. 1) Articles 7, 11, 12, 13 and 15.	Article 7: The farmer must not feed to ruminants protein derived from mammals or feed any products of animal origin to farmed animals, in accordance with Annex IV. Further, the farmer must not export or store feed intended for farmed animals which contains protein derived from mammals or feed intended for mammals, except for the feeding to dogs and cats. Article 11: The farmer must immediately notify the DVM of any animal suspected of being infected by a TSE.	Little or no effect on NH_3, N_2O and CH_4 emissions and NO_3 leaching;
13	Council Directive 85/511/EEC of 18 November 1985 introducing	This Directive requires any person who has in his possession or under his charge an affected or suspected animal or carcass to notify the fact to the	Little or no effect on NH_3, N_2O and CH_4 emissions and NO_3 leaching;

	Community measures for the control of foot-and-mouth disease (OJ L 315, 26.11.1985, p. 11) Article 3.	authorities.	
14	Council Directive 92/119/EEC of 17 December 1992 introducing general Community measures for the Control of certain animal diseases and specific measures relating to swine vesicular disease (OJ L 62, 15.3.1993, p. 69) Article 3.	The notification of this Directive requires a person who has in his possession or under his charge an animal or carcase which he knows or reasonably suspects is infected to notify the authorities.	Little or no effect on NH_3, N_2O and CH_4 emissions and NO_3 leaching;
15	Council Directive 2000/75/EC of 20 November 2000 laying down specific provisions for the control and eradication of bluetongue (OJ L 327, 22.12.2000, p. 74) Article 3.	The notification of this Directive requires any person who knows or suspects that an animal or carcass in his possession or under his charge is diseased to notify the authorities.	Little or no effect on NH_3, N_2O and CH_4 emissions and NO_3 leaching;
16	Council Directive 91/629/EEC of 19 November 1991 laying down minimum standards for the protection of calves (OJ L 340, 11.12.1991, p. 28) . Articles 3 and 4	This Directive provides Recommendations and standards for the Welfare of calf rearing. Failure to comply with the Regulations and Code may lead to loss of subsidy.	May increase the emissions of NH_3, N_2O and CH_4 from stables, because of the use of litter, increase of the surface area of fouling, and the decrease in N retention efficiency.
17	Council Directive 91/630/EEC of 19 November 1991 laying down minimum standards for the protection of pigs (OJ L 340, 11.12.1991, p. 33) Article 3 and 4 (1)	This Directive provides Recommendations and standards for the Welfare of pigs. Failure to comply with the Regulations and Code may lead to loss of subsidy.	May increase the emissions of NH_3, N_2O and CH_4 from stables, because of the use of litter, increase of the surface area of fouling, and the decrease in N retention efficiency.
18	Council Directive 98/58/EC of 20 July	This Directive provides Recommendations and standards for	May increase the emissions of NH_3,

	1998 concerning the protection of animals kept for farming purposes (OJ L 221, 8.8.1998, p. 23) Article 4	the Welfare of farmed animals. Failure to comply with the Regulations and Code may lead to loss of subsidy..	N_2O and CH_4 from stables, because of the use of litter, increase of the surface area of fouling, and the decrease in N retention efficiency.

Some of the measures of Good Agricultural and Environmental Condition Framework (GAECs) listed in Table 9 potentially may have affect on the emissions of NH_3, N_2O and CH_4 and the leaching of NO_3, but again the effects are likely small. The GAEC measures focus on maintaining an improving soil quality and minimizing soil erosion. Such measures may indirectly increase/decrease the leaching of NO_3 and increase/decrease the emission of N_2O, depending on local conditions. Currently, there is a large interest in the sequestration of carbon in the soil as mitigation measure for the emissions of greenhouse emissions. There is increasing evidence that the effects of organic carbon sequestration in the soil are off-set by increased emissions of N_2O in the long-term (Six et al., 2004). Increasing the soil organic matter content of the soil usually improves soil quality and thereby may increase crop yields and N uptake by the crop. However, organic matter rich soils usually also have a relatively high potential for nitrate leaching. Evidently, there is an optimum soil organic matter level, above which the negative side effects (increased leaching of NO_3 and increased N_2O emissions) seem to dominate.

Improving soil structure also leads to a higher soil quality and thereby likely increases crop yield and N uptake. As a result, the residual amount of N in the soil after harvest may be lower and nitrate leaching losses may also be lower. Soil structure also effects the aeration and thereby the balance between nitrification and denitrification and the N_2O/N_2 ratio during denitrification. However, it is impossible to forecast the net effect from GAEC 'soil structure', without further information about the net changes in aeration status of the soil.

Summarizing, some of the Cross Compliance measures listed in Tables 8 and 9 may have effect on NO_3 leaching and the emissions of N_2O (and NH_3), but the net effect is difficult to forecast. Overall, it is most likely that the cross compliance measures contribute to a decrease of NO_3 leaching and N_2O emissions and that effect on NH_3 and CH_4 emissions are likely to be small. More in-depth and empirical studies are needed to making the picture more quantitative.

Table 9: EU Good Agricultural and Environmental Condition Framework (GAECs) and the assessment of its effects on pollution swapping issues (NH_3, N_2O and CH_4 emissions and NO_3 leaching)

Issue	**Standards**	**Effects on NH_3, N_2O and CH_4 emissions and NO_3 leaching**
Soil erosion	• Protect soil through appropriate measures • Minimum soil cover • Minimum land management reflecting site-specific conditions • Retain terraces	• Little or no effect on NH_3, N_2O and CH_4 emissions and NO_3 leaching; • May decrease NO_3 leaching and increase N_2O emissions; little or no effect on NH_3 and CH_4 emissions; • Little or no effect on NH_3, N_2O and CH_4 emissions and NO_3 leaching; . • Little or no effect on NH_3, N_2O and CH_4 emissions and NO_3 leaching;
Soil organic matter	• Maintain soil organic matter levels through appropriate practices • Standards for crop rotations where applicable • Arable stubble management	• May increase NO_3 leaching and N_2O emissions; Little or no effect on NH_3 and CH_4 emissions; • Little or no effect on NH_3, N_2O and CH_4 emissions and NO_3 leaching; • Little or no effect on NH_3, N_2O and CH_4 emissions and NO_3 leaching;
Soil structure	• Maintain soil structure through appropriate measures • Appropriate machinery use	• May decrease NO_3 leaching and N_2O emissions; Little or no effect on NH_3 and CH_4 emissions; • Little or no effect on NH_3, N_2O and CH_4 emissions and NO_3 leaching;
Minimum level of maintenance	• Ensure a minimum level of maintenance and avoid the deterioration of habitats • Minimum livestock stocking rates or/and appropriate regimes • Protection of permanent pasture • Retention of landscape features • Avoiding the encroachment of unwanted vegetation on agricultural land	• Little or no effect on NH_3, N_2O and CH_4 emissions and NO_3 leaching; • May affect NH3 emission, if minimum grazing levels are specified. • Little or no effect on NH_3, N_2O and CH_4 emissions and NO_3 leaching; • Little or no effect on NH_3, N_2O and CH_4 emissions and NO_3 leaching; • Little or no effect on NH_3, N_2O and CH_4 emissions and NO_3 leaching

4.5 Rural Development measures

The Rural Development policy 2007-2013 focuses on three thematic axes laid down in the Rural Development Regulation (Reg. 1698/2005):

- improving competitiveness for farming and forestry;
- improving the environment and countryside; and
- improving the quality of life and diversification of the rural economy.

Within each of the three axes, various support mechanisms have been described in articles 20 to 35 for Axis 1, in articles 36 to 51 for axis 2 and in articles 52 to 59 for axis 3. At the suggestion of dr. C. Raes (DG AGRI), a selection of relevant measures was made, as regards to the scope of the current assessment, and these measures are briefly described below.

AXIS 1: Improving the competitiveness of the agricultural and forestry sector

Article 20: Measures

Support targeting the competitiveness of the agricultural and forestry sector shall concern:

(a) measures aimed at promoting knowledge and improving human potential through:

(i) vocational training and information actions, including diffusion of scientific knowledge and innovative practices, for persons engaged in the agricultural, food and forestry sectors;

(iv) use of advisory services by farmers and forest holders;

(v) setting up of farm management, farm relief and farm advisory services, as well as of forestry advisory services;

(b) measures aimed at restructuring and developing physical potential and promoting innovation through:

(i) modernisation of agricultural holdings;

(v) improving and developing infrastructure related to the development and adaptation of agriculture and forestry;

(c) measures aimed at improving the quality of agricultural production and products by:

(i) helping farmers to adapt to demanding standards based on Community legislation;

Article 24: Use of advisory services

1. Support provided for in Article 20(a)(iv) shall be granted in order to help farmers and forest holders to meet costs arising from the use of advisory services for the improvement of the overall performance of their holding.

As a minimum the advisory service to farmers shall cover:

(a) the statutory management requirements and the good agricultural and environmental conditions provided for in Articles 4 and 5 of and in Annexes III and IV to Regulation (EC) No 1782/2003;

Article 25: Setting up of management, relief and advisory services

Support provided for in Article 20(a)(v) shall be granted in order to cover costs arising from the setting up of farm management, farm relief and farm advisory services as well as forestry advisory services and shall be degressive over a maximum period of five years from setting up.

Article 26: Modernisation of agricultural holdings
1. […]
Where investments are made in order to comply with Community standards, support may be granted only to those which are made in order to comply with newly introduced Community standards. In that case, a period of grace, not exceeding 36 months from the date on which the standard becomes mandatory for the agricultural holding, may be provided to meet that standard.

Article 30: Infrastructure related to the development and adaptation of agriculture and forestry
Support provided for in Article 20(b)(v), may cover notably operations related to access to farm and forest land, land consolidation and improvement, energy supply and water management.

Article 31: Meeting standards based on Community legislation
1. Support provided for in Article 20(c)(i) shall contribute partly to costs incurred and income foregone caused to farmers who have to apply standards in the fields of the environmental protection, public health, animal and plant health, animal welfare and occupational safety.
These standards must be newly introduced in national legislation implementing Community law and impose new obligations or restrictions to farming practice which have a significant impact on typical farm operating costs and concern a significant number of farmers.

AXIS 2: Improving the environment and the countryside
Article 36: Measures
Support under this section shall concern:
(a) measures targeting the sustainable use of agricultural land through:
(iii) Natura 2000 payments and payments linked to Directive 2000/60/EC;
(iv) agri-environment payments;
(v) animal welfare payments;
(vi) support for non-productive investments;

Article 38: Natura 2000 payments and payments linked to Directive 2000/60/EC (agriculture)
1. Support provided for in Article 36(a)(iii), shall be granted annually and per hectare of utilized agricultural area (UAA) to farmers in order to compensate for costs incurred and income foregone resulting from disadvantages in the areas concerned related to the implementation of Directives 79/409/EEC, 92/43/EEC and 2000/60/EC.

Article 39: Agri-environment payments
2. Agri-environment payments shall be granted to farmers who make on a voluntary basis agri-environmental commitments. Where duly justified to achieve environmental objectives, agri-environment payments may be granted to other land managers.

3. Agri-environment payments cover only those commitments going beyond the relevant mandatory standards established pursuant to Articles 4 and 5 of and Annexes III and IV to Regulation (EC) No 1782/2003 as well as minimum requirements for fertiliser and plant protection product use and other relevant mandatory requirements established by national legislation and identified in the programme.

Article 41: Non-productive investments (agriculture)
Support provided in Article 36(a)(vi) shall be granted for:
(a) investments linked to the achievement of commitments undertaken pursuant to the measure provided for in Article 36(a)(iv) or other agri-environmental objectives;
(b) on-farm investments which enhance the public amenity value of a Natura 2000 area or other high nature value areas to be defined in the programme.

AXIS 3 The quality of life in rural areas and diversification of the rural economy
Article 52: Measures
Support under this section shall involve:
(b) measures to improve the quality of life in the rural areas,
comprising:
(iii) conservation and upgrading of the rural heritage;

Article 57: Conservation and upgrading of the rural heritage
The support referred to in Article 52(b)(iii) shall cover:
(a) the drawing-up of protection and management plans relating to Natura 2000 sites and other places of high natural value, environmental awareness actions and investments associated with maintenance, restoration and upgrading of the natural heritage and with the development of high natural value sites;

4.5.1. Assessment of the Rural Development Regulation measures and supporting
The qualitative assessment presented here is conducted ex ante, as there is still little written information about the implementation and penetration of Rural Development measures in practice in the various Member States, and its effectiveness and efficiency in terms of the competitiveness of agriculture (axis 1), improving the environment and the countryside (axis 2) and the quality of life in rural areas and the diversification of the rural economy (axis 3). Written information about the effects on NH_3 emission, NO_3 leaching and N_2O and CH_4 emissions are also lacking.

The incentives (support, subsidies) provided to improve the competitiveness of agriculture (axis 1) are through:
a) improving the advisory services (extension services) in agriculture and forestry;
b) promoting innovations (investments) in agricultural holdings and infrastructure (including land improvement and water management); and

c) implementing new standards in the field of environmental protection, animal and plant health, and animal health.

Promoting extension services and advisory services commonly has a positive effect on the agronomic and economic performances of farms, though the precise effects are difficult to forecast and often diverse. (see McCown, 2005, in Hatfield, 2005). The changes in environmental performance of the farm, and the possible changes in NH_3 emission, NO_3 leaching and N_2O and CH_4 emissions highly depend on the type of advisory work is being done. When the emphasis is on a balance improvement of both the economic and environmental performances, it is likely that emissions per unit produce will decrease (Table 8).

Promoting innovations (investments) in agricultural holdings and infrastructure (including land improvement and water management) may have rather similar effects. Through investments in land improvement and water management (irrigation and drainage), the production potential may likely increase. By doing so, emissions per unit produce may decrease but per unit surface area increase (Table 10). But again, it largely depends on the type of investments and innovations. When payments of the Rural Development are targeted to investments in low-emission animal housing and animal manure storage systems, as indicated by the Thematic Strategy on Air Pollution (see section 2.4), and if these investments are combined with the implementation of integrated N management as suggested by BAT 8, synergistic effects on decreasing $NH_{3,}$ N_2O and CH_4 emissions are possible.

Implementing new standards in the field of environmental protection, animal and plant health, and animal health, in general will contribute to improving the environmental performance of farms. When the new standards relate to N use and water use efficiencies, the support for implementing new standards will likely contribute to decreases in NH_3 emission, and N_2O and CH_4 emissions, both per unit surface area and produce. Providing incentives via Rural Development measures to the N use efficiency for specified farming systems provides opportunities for rewarding those farmers that go beyond certain standard criteria and thereby decreasing N losses in an integrated way. However, if the new standards mainly focus on animal welfare and on the surface area and bedding material of the animal housing systems, emissions of NH_3 N_2O and CH_4 may increase considerably. This occurs because the emissions of NH_3 are proportional to the surface area that animals foul, while emissions of N_2O and CH_4 tend to be higher in (deep) litter stables than in stables with slattened floors and or sloping floors (Sommer et al., 2006). When the new standards relate to improving plant and animal health, emissions of NH_3, N_2O and CH_4 and the leaching of NO_3 would most likely decrease, because of the more vigorous growth and higher resource (N) utilization.

The incentives (support, subsidies) provided to improve the environment and the countryside (axis 2) are through payments and subsidies for specific commitments, investments and activities. This support is meant to compensate farmers

- for disadvantages related to measures of the Birds and Habitat Directives implemented in Natura 2000 areas:
- who make agri-environmental commitments on a voluntary basis
- that go beyond mandatory standards on a voluntary basis
- for non-productive investments in agriculture so as to enhance the public amenity value of a Natura 2000 area.

Table 10. Support measures within the three thematic axes as defined in the Rural Development Regulation (Reg. 1698/2005) and the assessment of their effects on pollution swapping issues (NH_3, N_2O and CH_4 emissions and NO_3 leaching). See also text.

Axis	Art. No.	What will be the measure / requirement supported by the Regulation?	What are the possible effects on NH_3, N_2O and CH_4 emissions and NO_3 leaching?
1	20	*Measures aimed at promoting knowledge and improving human potential through:* • vocational training and information actions, including diffusion of scientific knowledge and innovative practices, for persons engaged in the agricultural, food and forestry sectors; • use of advisory services by farmers and forest holders; • setting up of farm management, farm relief and farm advisory services, as well as of forestry advisory services;	Likely neutral effects on NH_3, N_2O and CH_4 emissions and NO_3 leaching. However, if the increased knowledge leads to improved N management, emissions may decrease.
1	20	*Measures aimed at restructuring and developing physical potential and promoting innovation through*: • modernisation of agricultural holdings; • improving and developing infrastructure related to the development and adaptation of agriculture and forestry;	Likely neutral effects on NH_3, N_2O and CH_4 emissions and NO_3 leaching. However, if innovations and the increased knowledge leads to improved N management, emissions may decrease.
1	20	*Measures aimed at improving the quality of agricultural production and products by*: • helping farmers to adapt to demanding standards based on Community legislation	Neutral effects to decreasing/or increasing NH_3, N_2O and CH_4 emissions and NO_3 leaching;
2	36	Support under this section shall concern measures targeting the sustainable use of agricultural land through: • Natura 2000 payments and payments linked to Directive 2000/60/EC; • agri-environment payments; • animal welfare payments; • support for non-productive investments	Likely a decreasing effect on NH_3, N_2O and CH_4 emissions and NO_3 leaching. But effects can be diverse; for example animal welfare payments may lead to increased emissions of NH_3, N_2O and CH_4. Conversely, Natura 2000 payments may lead to decreases in emissions.

3	52	Support under this section shall involve: measures to improve the quality of life in the rural areas, comprising conservation and upgrading of the rural heritage;	Neutral effects to decreasing / increasing NH_3, N_2O and CH_4 emissions and NO_3 leaching;

Commonly, measures in Natura 2000 areas and agri-environment measures are associated with a decrease in the non-factor inputs, leading to extensification of agricultural production and likely also to decreases in the emissions of NH_3, N_2O and CH_4 and the leaching of NO_3 per unit surface area. Such measures usually lead also to increased environmental awareness and thereby also may contribute to decreasing NH_3, N_2O and CH_4 emissions and NO_3 leaching. However, extensification not necessarily leads to a decrease in the emissions per unit of agricultural produce. Other measures involved under axis 2 likely have little or no effect on the emissions of NH_3, N_2O and CH_4 and the leaching of NO_3. However, it depends also on the Member States, as there is some flexibility to adjust and modify possible measures towards decreasing NH_3 emissions.

Promoting the quality of life in rural areas and the diversification of the rural economy (axis 3) likely will increase the income from non-agricultural activities in the rural areas relative to that from agricultural activities. As a result, the non-factor input and the production potential of that area may tend to decrease, as will the emissions of NH_3, N_2O and CH_4 and the leaching of NO_3.

Summarizing, the Rural Development Regulation 1698/2005 will have diverse effects on the emissions of NH_3, N_2O and CH_4 and the leaching of NO_3. Axis 1 support may lead to decreased emissions when the emphasis is on implementing new standards for environmental protection and on compliance to Community standards (category iii), while Axis 2 support will lead to decreasing emissions when the emphasis is on extensification and decreasing non-factor inputs (like fertilizer inputs, and specific measures are taken for environmental protection, such as NH_3 emission abatement, if Member States decide to set this as a priority). However, when the emphasis is on animal welfare support (category (iv)), gaseous emissions may increase, as the animal housing requirements for animal welfare may lead to increasing emissions of NH_3, N_2O and CH_4. Axis 3 support may lead to a slight decrease in emissions of NH_3, N_2O and CH_4 and the leaching of NO_3 (category (iii)).

The amount of financial support that is actually available under the Rural Development Programme is limited and there is competition between farmers (and the different issues) for the funds. Therefore, there is by definition a limited scope for a European wide reduction in N emissions/leaching through the Rural Development Programme. By contrast, since governments can define their local priorities, there may be more potential for achieving local benefits in specific situations (e.g. adjacent to priority habitats like Natura 2000).

4.6 National Policy instruments

Bos et al. (2005) discuss the results of a workshop for 8 member states within the EU the national policy instruments for the mitigation of N (and P) losses from dairy farming systems. One of the findings of the workshop was the lack of uniformity in calculation methods between countries. This relates especially to the characterization and number of farm animals, the amounts of animal manure applied to farmland, and N balances. Despite the lack of accuracy in the N balance statistics, N balances at farm level were considered a useful integrated indicator for the environmental impact of N losses from dairy farming systems. An N balance approach has been used as policy instrument in the Netherlands from 1998-2006 (Van Grinsven et al., 2005)

4.6.1. The Netherlands

From 1998 to 2006, the Netherlands had implemented the so-called Mineral Accounting System (MINAS) as policy instrument to reducing N and P losses from agriculture, in addition to a specific ammonia abatement policy (which mainly focussed on low-emission manure application, covered manure storages and spatial zoning of intensive livestock farms near Nature 2000 areas) (Van Grinsven et al., 2005).

The N and P accounting system MINAS was implemented at farm level. MINAS involved registration of all N and P inputs and output at farm level, using a farm-gate balance sheet approach, which is an integral approach to regulating N and P. Inputs of N and P via fertilizers (except for P fertilizers), animal feed, animal manure, compost and other sources, as well as the N and P output (export at farm level) in harvested products, including any animal manure had to be recorded accurately, using official documents for sales and purchases from accredited firms only. The difference between total N and P inputs and outputs should not exceed certain 'acceptable' (levy-free) surpluses for N and P. When N and/or P inputs exceeded the N and/or P outputs plus the levy-free surpluses for N and P, farmers had to pay a levy which was proportional to the exceedance to the levy-free N and/or P surpluses. Levies provided the incentive to both lower the import of N and P in fertilizers, animal feed and/or animal manure, and to increase the export from the farm of harvested products and animal manure. Levy-free surpluses were differentiated according to soil type and land-use, and have been lowered step-wise between 1998 and 2003. Surpluses at farm level that exceed levy-free surpluses were charged.

The basic reasons for implementing a farm-gate balance approach for nutrient accounting (MINAS) was the need to regulate N and P from both fertilizers and animal manure. Further, there was need for an instrument that provided an incentive for good nutrient management at farm level. MINAS was seen as both a management instrument for farmers to improve nutrient management at farm level and as a regulatory instrument for the government to regulate N and P losses from agriculture to the wider environment, i.e. to groundwater, surface waters and atmosphere (Van Grinsven et al., 2005; Oenema and Berentsen, 2004)

The manure policy provided strong incentives to utilize N and P in crop and animal production better so as to decrease N and P surpluses. Better utilization of N and P from animal manure involved manure transport from areas with excess amounts to areas with little manure, next to improvement of nutrient management in crop and animal production. MINAS has been the core instrument behind the improvement of nutrient management and the better utilization of N and P in crop and animal production from 1998 onwards. The effectiveness of MINAS follows from the estimation that 80% of the decreases in N and P surpluses during the period 1998-2003 is the result of the manure policy and 20% of other polices and autonomous developments. In summary, the manure policy led to the following changes in N losses (Van Grinsven et al., 2005):

- Decrease of mineral nitrogen fertilizer by 29% over the period 1998-2002
- Decrease of total nitrogen excretion by livestock by 22% over the period 1998-2002
- Nitrogen surplus of soils decreased by 35% in 2002 in comparison to 1997
- Nitrogen load of surface waters from agriculture decreased 10% in 2002 in comparison to 1997
- Dairy farming systems on sandy soils with groundwater in which nitrate concentration exceeds 50 mg per liter decreased from 75% to 60%
- Ammonia emission decreased by 31% in 2002 in comparison to 1995
- Nitrous oxide emission decreased by 18% in 2002 in comparison to 1995

In conclusion, the MINAS approach is an integral approach with synergistic effects on decreasing N leaching to groundwater and surface waters, ammonia emissions to the atmosphere and also on decreasing nitrous oxide emissions to the atmosphere (Category (ii) combined with some category (i) type of measures).

The ammonia emission abatement policy was implemented from the early 1990s. It mainly focussed on low-emission manure application, covered manure storages and spatial zoning of intensive livestock farms and of zones with ammonia emission limits around and near Nature 2000 areas. These measures (category (i)) decreased the emissions of NH_3 significantly. Initially, these measures probably increased the leaching of NO_3, as farmers did not correct N fertilizer applications for the increased NH_4 contents in the animal manure, until the total N input was limited following the implementation of MINAS (category (ii)). The increased extension and set-up of demonstration farms in practice also had a positive effect on the fine-tuning of the N fertilizer application to the increased NH_4 contents in the animal manure. The spatial zoning near Nature 2000 farms limited animal husbandry and the application of animal manure in these zones. However, the total milk quota and the pig and poultry production rights were not decreased, and as a consequence, areas elsewhere felt increasing environmental pressure from the animal manure that could not applied anymore in the zones in and around the Nature 2000 zones. This may be considered beneficial, if the losses in other areas were not considered as important to society as protection of the Natura 2000 sites.

4.6.2.Germany

An overview of policy instruments implemented in Germany can be found in Bos et al. (2005), and references therein. Due to the federal system in Germany, a broad spectrum of policy instruments has been implemented. Apart from the EU policy instruments discussed before, albeit with modifications, Germany has extensive experience with cooperative and voluntary agreements at the local scale. The voluntary co-operative agreements usually include restrictions in mineral fertilization, on-farm advice, and compensation payments to farmers ('water protection contracts'). More than 1000 co-operative agreements currently exist. Some Länder give absolute priority to such co-operative agreements, as significant decreases in N surpluses, residual soil mineral N and nitrates in groundwater have frequently obtained. Furthermore, local co-operative agreements provide scope for site-specific conditions and are widely accepted by farmers.

Finally, there seem to be no or little antagonistic activities involved between these co-operative agreements and other policy instruments.

4.6.3. Austria

The Nitrates Directive and Habitats Directive have been controlled under the cross compliance regime since 2005.

- Nitrates Directive, Habitat Directive and Cross Cross Compliance Requirements (VO (EG) Nr. 1782/2003, Vo (EG) Nr. 795/2003, Vo(EG) Nr. 796/2003).
- Nitrates Directive and Rural Development:

Austria has designated the whole national territory as a "vulnerable zone" with respect to nitrates, with reference to Article 3, no. 5. The action programme for the whole territory includes manure application limits (175 kg N/ha on arable land, 210 kg N/ha on grassland), permitted time periods of fertilization, guidelines for fertilization at steep slopes and on snow covered areas as well as next to watercourses and minimal limits for volumetric capacity of manure storages (see also Table 3).

The Austrian Agri-environmental Programme ÖPUL 2000 is part of the Austrian Programme for Rural Development. ÖPUL 2000 has so far (for the years 2000-2006) supported the aim of the nitrate directive because of the "Grundförderung" (basic subsidy) which has included:

- the maximal limit of 2,0 Livestock units/ha (that is e.g. 2 cattle > 2 years /ha)
- fertilizer reduction
- abdication measures including organic farming
- measures of greening of arable land during winter
- measures to prevent erosion on arable land and in vine yards.

The agri-environmental programme ÖPUL 2000 pursues a horizontal approach which aims at making agriculture more environmentally compatible in the entire federal territory. The participation is on a voluntary basis. The farmers have to fulfill contractual obligations which are compensated annually by means of subsidies.

The new agri environmental programme 2007-2013 intents to implement manure export contracts in case that the maximum N manure amount of the Nitrate Directive is exceeded.

- Habitat Directive (Natura 2000: RL 79/409/EWG , RL 92/43/EWG), Water Framework Directive and Rural Development Regulation (Council Regulation (EC) No 1698/2005)

One of the measures supported under the new rural development program 2007-2013 in Austria is according to Art. 38 of the Rur.Dev.Reg. "Natura 2000 payments" Payments in Natura 2000 areas will be paid for agricultural measures to enforce the favorable conservation status of the Natura 2000 conservation objectives withinin Natura 2000 areas and support biodiversity within these areas. Discontinuation of mineral fertilizer might be one of the management restrictions.

Payments linked to Directive 2000/60/EC for costs and loss of income are not taken into account within the Article 38 payments of the Austrian Rural Development programme, because the WFD-river management plans are not yet available. They will be in force in 2009 and have to be implemented by 2012. They should be supported by the agri-environmental measures according to Article 39 of the rural development regulation.

- NEC-Directive and Rural Development

One of the agri-environmental measures according to the new Austrian Programme for Rural Development 2007-2013 (acc. to Art. 39 of the Rural Dev. Reg) is to reduce ammonia emissions via spreading of manure or fermented slurry close to soil (injection, trail tube, trail shoe). Payments: € $1/m^3$. Other measures of the agri-environmental programme to reduce ammonia emissions are in general measures of fertiliser reduction and abdication, including organic farming. Also investment aid has become more important in the new Austrian Programme for Rural development

Two antagonisms in these policies have been defined:

- Reduction of ammonia emissions via spreading of manure close to soil (injection) may increase nitrate leaching in the soil;
- Stables systems supporting animal welfare (deep litter-loose housing) can increase ammonia and nitrous oxide emissions into the atmosphere.

4.7 Greenhouse gas abatement measures

The EU-25 has approved the Kyoto Protocol and has committed itself to decrease the greenhouse gas emissions by 6 % in 2010/2012 relative to the reference year 1990. Agriculture is a major source of methane and nitrous oxide and as a whole contributes about 10% to the overall greenhouse gas budget of the EU-25. However, there is as yet no specific EU policy for agriculture to decreasing the emissions of methane and nitrous oxide from agriculture, though most member states have identified and examined various possible measures. Tables 11, 12 and 13 list such possible measures for methane and nitrous oxide respectively (adapted from Oenema et al., 2001; Hatch et al., 2004; Soliva et al., 2006).

The qualitative assessments indicate that there are a number of synergies between measures aimed at decreasing N_2O emissions and nitrate leaching (Tables 11 and 12). The effects on NH_3 emissions are less evident. In a few cases, some antagonisms may be observed with ammonia or the others gases.

Table 11. Overview of possible measures to reduce CH_4 emission from livestock farms

Measure	**Aim**	**Side effects on nitrate leaching?**	**Side effects on NH_3 emissions?**
Improved feeding of animal	Increasing animal productivity, decreasing CH_4 emission from enteric fermentation, and decreasing CH_4 emission from manure	Likely a decreased leaching, because of improved N use efficiency	Likely a decreased NH_3 emission, because of improved N use efficiency
Additives in feed	Decreasing CH_4 emission from enteric fermentation and from manure	No or little effect	No or little effect
Reduction of the number of livestock	Decreasing CH_4 emission from enteric fermentation and from manure	Likely a decreased leaching	Likely a decreased NH_3 emission
Type of manure storage	Decreasing CH_4 emission from stored manure by better aeration and/or lowering temperature	No or little effect	Effect depends on change in storage system
Time of storage of manure	Preventing the development of anaerobic conditions in the manure by regular emptying of the storage	No or little effect	Effect depends on change
Additives to manure, e.g. acid	Inhibition of methanogenesis in stored animal manure	No or little effect	Effect depends on additive, but acid will reduce emissions
Anaerobic digestion of manure and collecting of CH_4	Use CH_4 for production of electricity and reduce CH_4 emission	Likely an increased leaching because of more N in manure	Likely a decreased NH_3 emission

Table 12. Overview of possible measures to decrease N_2O emission from agriculture via increasing N use efficiency of the whole farming system.

Measure	**Aim**	**Side effects on nitrate leaching?**	**Side effects on NH_3 emissions?**
Changing crops in rotation	Use of more N efficient crops in the rotation	Likely a decreased leaching	Likely no or little effect on NH_3 emission
Animal nutrition	Increase animal productivity and decrease N contents in urine and dung	Likely a decreased leaching	Likely a decreased NH_3 emission
Restricted grazing	Decrease urine/dung excretions in the field	Likely a decreased leaching	Increased NH_3 emission
Adjustment of N application rate and time to crop demand	Increase N use efficiency of applied fertilizer N	Likely a decreased leaching	Likely a decreased NH_3 emission
Efficient application of fertilizer: placement, row application	Increase N use efficiency of applied fertilizer N	Likely a decreased leaching	Likely no or little effect on NH_3 emission
Soil and plant testing as basis for N fertilization	Increase N use efficiency of applied fertilizer N	Likely a decreased leaching	May decrease NH_3 emission
Accounting for mineralization of organic N	Decrease amount of required fertilizer N	Likely a decreased leaching	May decrease NH_3 emission
Winter crops	Decrease amount of required fertilizer N	Likely a decreased leaching	Likely no or little effect on NH_3 emission, but could decrease NH_3 emissions if manure is spread under a canopy
No manure application in autumn and winter	Higher N use efficiency of manure N	Likely a decreased leaching	Likely an increase in NH3 emission
Application technique with low NH_3 emission	Higher N use efficiency of manure N	Likely a decreased leaching	Decrease in NH_3 emission
Storage of manure with low NH_3 emission	Higher N use efficiency of manure N	Likely an increase in leaching	Decrease in NH3 emission
Application of other nutrients	Optimize growth conditions and N uptake of the crop	Likely a decreased leaching	Likely no or little effect on NH_3 emission
Soil cultivation	Optimize growth conditions and N uptake of the crop	Likely a decreased leaching	Likely no or little effect on NH_3 emission
Liming	Optimize growth conditions and N uptake of the crop	Likely a decreased leaching	Likely no or little effect on NH_3 emission
Application of water/irrigation	Optimize growth conditions and N uptake of the crop	Likely a decreased leaching	May decrease NH_3 emission if coupled with manure spreading timing and to encourage infiltration

Table 13. Overview of possible measures to decrease N_2O production during nitrification and denitrification.

Measure	Aim	Side effects on nitrate leaching?	Side effects on NH_3 emissions?
No simultaneous application of NO_3 and easily available C	Decrease denitrification	Likely an increased leaching	Likely no or little effect on NH_3 emission
No NO_3 fertilizer during wet conditions	Decrease denitrification	Likely a decreased leaching	Likely no or little effect on NH_3 emission
No urea and anhydrous ammonia during dry conditions	Decrease N_2O production during nitrification	Likely no or little effect on leaching	Likely a decrease in NH_3 emission
Proper drainage and irrigation	Avoid wet conditions; decrease denitrification	Likely no or little effect on leaching	Likely no or little effect on NH_3 emission
Nitrification inhibitor	Inhibit nitrification	Likely a decreased leaching	Likely no or little effect on NH_3 emission
Winter crops	Decrease denitrification in off-season	Likely a decreased leaching	Likely no or little effect on NH_3 emission could decrease NH_3 emission if slurry applied under canopy
Removing crop residues	Decrease denitrification in off-season	Likely a decreased leaching	Likely no or little effect on NH_3 emission
Soil cultivation	Increase aeration and decrease denitrification	Likely an increased leaching	Likely no or little effect on NH_3 emission
Anaerobic storage of manure	Decrease nitrification and denitrification	Likely no or little effect on leaching	Likely no or little effect on NH_3 emission

5 DISCUSSION AND CONCLUSIONS

5.1 Some introductory remarks

The assessments of the main environmental policy instruments made in this study are rather global and qualitative. The assessments are based on literature study and expert judgement. However, the number of studies that specifically address the effectiveness and pollution swapping potential of the policy instruments is still limited and therefore only very limited use could be made of literature data, especially at the scale of EU-25+ level.

The incidence of (unwanted) trade-offs or side-effects of implementing environmental policies and measures to decrease the emissions of ammonia to the atmosphere and the leaching of nitrate to surface waters and groundwater, is more than an academic issue. There is reluctance among groups of farmers to implement specific measures in some regions on the grounds that these measures contribute to side-effects. This relates especially to obligations in some member states to using low-emission techniques for the application of animal manures to grassland. Though the ammonia abatement potential is acknowledged, the farmers argue that these techniques contribute to increased nitrate leaching and N_2O emissions, while bird nests and soil fauna are destroyed by the equipment used to apply the manure. Such possible side-effects and such views hamper the acceptance and implementation of environmental policies and measures in practice. The most significant side-effects in practice of policies to decrease the emissions of ammonia and the leaching of nitrate seem to be:

- the prescriptive nature of the measures that some view as oppressing entrepreneurship,
- the increased administrative burden, and
- the agronomic / economic consequences.

Pollution swapping is a special case of trade-offs; it refers to the unintentional increase in emission of an environmental pollutant (pollutant 'B') following the implementation of policies and measures to decrease the emission of a target pollutant (pollutant 'A'). This type of pollution swapping is called type 1 pollution swapping in the current study. Type 2 pollution swapping refers to the unintentional increase in emission of an environmental pollutant (pollutant 'A') in an area (area 'Z') following the implementation of policies and measures to decrease the emission of a pollutant 'A') in area 'Y'. The mechanism of pollution swapping has always occurred, but the term and the interest in pollution swapping in relation to the effects of environmental policies is of recent date. The mechanism is often overlooked when suggesting and implementing environmental policies and measures (see Box 1 below). It should be noted that, once recognized, measures involving pollution swapping may still be accepted following the setting of priorities, which may vary locally and regionally (e.g. Angus et al. 2003). However, this requires that policy makers reach consensus on the priorities between pollutant forms (Type 1 swapping) and between different locations (Type 2 swapping). Given that it is not currently feasible to avoid all environmental impacts of ammonia and other nitrogen forms, such priority setting is essential.

Box 1. Fertilizer 'solution' could turn local problem global
David S. Reay. 2004 (Nature 427, 485)

It was gratifying to see the range of well-argued responses in Correspondence (Nature 427, 99; 2004) to your News Feature "Fertilized to death" (Nature 425, 894–895; 2003). All the correspondents put forward valid points regarding the pros and cons of nitrogen fertilizer use. However, a key issue was overlooked, that of 'pollution swapping'.
Pollution of our ground and surface waters by nitrogen fertilizers poses a host of potential environmental problems, including toxic algal blooms and fish kills. Preventing nitrogen fertilizer from leaching into drainage waters, as may be achieved by no-till practices, would therefore seem to be an obvious goal.
Here, though, we run into a real danger of what has become known as 'pollution swapping'. If the added nitrogen fertilizer is neither taken up by plants nor lost via leaching, then more of it is likely to end up as the powerful greenhouse gas nitrous oxide (A. Mosier *et al. Nutr. Cyc. Agroecosyst.* **52,** 225–248; 1998), through the process of denitrification.
By limiting the pollution of water by nitrogen fertilizers, using so-called 'buffer strips' or strategies such as no-till farming, we may simply be swapping a relatively local pollution problem for the global problem of climate change (M. Hefting *et al. J. Environ. Qual.* **32,** 1194–1203; 2003).
Which of these is the more important problem depends on your perspective, and there may be other land-use strategies through which we can limit nitrogen leaching without bumping up emissions of nitrous oxide.
In the end, though, the answer for much of the developed world is likely to be a familiar one — use less fertilizer, but more efficiently.

Environmental policy in agriculture is a relatively new policy field; the first policies in the environmental policies in EU agriculture originate from the second half of the 1980s. Considering this relative young history, the huge diversity in EU agriculture with many farmers, and the complexity of the nitrogen cycle with many opportunities for losses and many controlling factors, it is not surprising that side-effects of environmental policies and measures occur. It has been suggested that pollution swapping originates from single-issue (single-species) policies and from a too disciplinary approach (see section 2.5) and that pollution swapping can be circumvented by an 'integrated approach' (e.g., Erisman et al., 2005). Clearly, integrated approaches can greatly contribute to minimizing pollution swapping and maximizing synergistic effects, but it would be naïve to believe that any side-effect can be precluded. Side – effects are part of the game of environmental policies. Especially economic side – effects, and administrative side - effects, but also type 1 and type 2 pollution swapping likely will occur following the implementation of any environmental policy. The focus should be on understanding the cause – effect relationship and on minimizing the side – effects. Evidently, if pollution swapping can not be avoided, integrated assessments should be made on the various loss routes and subsequent impacts.

5.2 The changing policy context.

Agriculture in EU-25+ is extremely diverse. Agriculture is also dynamic and changing, due to for example changes in (world) market conditions, increased knowledge, technological developments, urbanization and (changes in) governmental policies and measures. Structural changes in agriculture will require policy reform and adjustment (e.g., Blandford and Hill, 2006). Following the reform and adjustments of agricultural policies, structural changes in agriculture may go faster. The CAP reform has and will contribute to major changes in agriculture in coming years. Also the expected revision or abolishment of the milk quota system in the EU by 2015 may have major consequences on the regional distribution and total number of dairy farms and hence dairy cattle and NH_3 emissions.

Following the further liberalization of markets and the decreasing influence of the CAP on EU agriculture, changes in agriculture will be mainly driven by economical principles and consumer concern. Changes in agriculture will be increasingly driven by the 'economics of scale', the 'economics of specialization' and the 'economics of intensification'. These trends make farms larger, specialized and intensive (whenever possible). It will also lead to regional conglomerations of intensive and specialized farming systems near markets and large cities, because of location specific cost advantages (e.g. Steinfeld et al., 2006). This holds especially for intensively managed livestock farms, and vegetable production, horticulture, floriculture, etc. The question then is whether the current environmental policy instruments like the Nitrate Directive, Water Framework Directive, IPPC and NEC Directives, and Birds and Habitats Directives are sufficiently robust, coherent and effective 'to shape these trends within environmental acceptable limits'.

In some sectors, there has been a strong trend towards vertical integration of activities, in the so-called agro-complex. The interdependency in this agro-complex (suppliers, farmers, processing industry and retailers) is large, and retailers and super markets increasingly dominate the price and quality of the product and the way it is produced. So far, little or no attention has been paid to optimize the N use efficiency in the whole food processing chain. All measures specified in, for example, the Nitrates Directive and in the guidelines of the UNECE working group on the abatement of ammonia emissions focus solely on the primary producers, on the farmers. There has been very little involvement of retailers and supermarkets in the enforcement of EU environmental policy. This is surprising, as the agro-complex and especially suppliers, processing industry and retailers play a dominant role in (the development of) agriculture. Also the possible role of the consumer in enforcing environmental policy and increasing N use efficiency could be explored further.

The dominant current trends of specialization, up-scaling and conglomeration will complicate the integration of crop production and animal production, which seems necessary for more effective and efficient recycling of nutrients from livestock manure. The recycling and efficient use of nutrients from animal manure on large intensive farms is also energy-intensive, and with the likely increasing energy prices in the near future will make it less cost-effective. The likely increase in the price of (fossil) energy will hit especially intensively managed livestock farms, vegetable, horticulture, floriculture, because these sectors are energy intensive. Such possible trends may lead to the development of high-tech, integrated crop and animal production systems, opposite to the current trend of specialization.

During the last decade, there has been a trend towards integration of agricultural and environmental policy. This trend is expected to continue. There is scope for exploring the potential for further integration of NH_3 emission abatement concerns into the CAP and particularly through the Rural Development Policy discussed in chapter 4. Apart from the UK, which seems to be ambitious in implementing cross compliance measures, there seems room for greater integration of agricultural and environmental policy. The Rural Development Programme holds the prospect of effective supporting measures to reduce adverse impacts of nitrogen (e.g., Austria), within the available funds, but it remains a matter for the Member States to set their own priorities.

Next to the likely trends in mainstream agriculture, there will be increasing areas in EU under agri-evironmental regulations and nature legislation (Natura 2000 areas). This will be in part the consequence of stabilizing or even decreasing human population in EU-25, simultaneous to increases in agricultural productivity; less land will be needed for agricultural production, while more land will be needed to halt biodiversity loss, to grow forests and for amenity and recreational purposes. This trend will probably increase the need for zoning of agricultural activities requiring priority setting in relation to type 2 pollution swapping. (e.g. accepting some nitrogen pollution in certain areas may become inevitable in order to protect priority areas, such as the Natura 2000 network).

The European Commission has increasing ambition as regards the decrease of the emission of greenhouse gases and the replacement of fossil fuel by bio fuels and other more sustainable sources of energy. Growing energy crops will be at the expense of other agricultural crops and/or natural land. It will also require nitrogen and other nutrients, and although the N requirements may be modest (because of the high C to N ratio of some energy crops), the growth of energy crops will without doubt lead to a further intensification of agricultural production, including bio fuel production. This may also lead to further increases in the emissions of greenhouse gases by exacerbating N_2O emissions (Crutzen et al., in press), which will necessitate further actions.

Land is scarce in the world, while both the human and animal populations in the world are growing (Bruinsma, 2003; Smil, 2000). Hence, globally there will be an increasing pressure to produce more per unit land surface, especially in the continents of the world where the increases in humans and animals are largest (Asia, Africa). Although these underlying trends do not apply to Europe, this pressure will be felt also in the EU, because of the effects of globalization and open markets. As N has been a key tool to intensify agricultural production in the past decades, there will be increasing need to increase the N use efficiency in agriculture and to minimize N losses from agriculture.

5.3 Policy instruments and its effects

Apart from the trend towards integration of agricultural and environmental policy, there is also a trend towards using a mixture of policy instruments. It is now commonly accepted that a combination of policy instruments is most effective and efficient in achieving the policy targets (Verbruggen, 1994; Romstad, et al, 1997; OECD, 2003). To further elucidate this statement, we include a short discussion about the nature of policy instruments.

Agricultural and environmental policy instruments can be divided into three main categories (Verbruggen, 1994): (i) direct regulation or command-and-control instruments, (ii) economic or market-based instruments and (iii) communicative or persuasive instruments. Table 14 shows some examples of the three types of policy instruments affecting the agronomic, economic and environmental performances of farms.

Table 14: Categories of policy instruments.

Regulatory measures	Economic instruments	Communicative instruments
- public land use planning (zoning/spatial planning) - pollution standards - prohibition of particular agricultural production methods	- taxes - subsidies - price support - import/export tarifs - tradable rights and quotas	- agricultural extension service - education and persuasion - co-operative approaches

Regulatory measures involve a restriction on the choice of agents, methods and actions. Regulations are compulsory measures imposing requirements on producers to achieve specific levels of environmental quality, including environmental restrictions, bans, permit requirements, maximum rights or minimum obligations. They are the most common policy measure used in EU-environmental policies, as for example in the IPPC and Nitrates Directives.

Economic instruments are common in agricultural policy, in the CAP, but are not common in environmental policy (yet). Environmental taxes and tradable rights/quotas have only been implemented in a few countries, like the pig and poultry production rights in the Netherlands. Subsidies are increasingly used as a policy instrument to promote environmentally friendly practices in agriculture (OECD, 2003); they are part of the CAP reform (and Agri-Environmental Regulations and the Rural Development Regulations). Payments based on farm fixed assets are policy measures granting a monetary transfer to farmers to offset the investment cost of adjusting farm buildings or equipment to adopt more environmentally friendly farming practices. Support has been and can be provided to livestock farmers to assist them in meeting the requirements of regulations, particularly in response to animal housing and manure storage and manure application requirements, for example under the Rural Development Regulation.

Potentially, a tax on N fertilizer (or on fossil energy sources) and / or on protein-rich animal feed stuffs may greatly contribute to N input control and to increasing N use efficiency, and thereby on decreasing N losses in an integrated way. A tax on N fertilizer seems a simple measure to lower excess N input, depending on the tax rate, although there may be also side-effects involved. We recommend to exploring the effectiveness and efficiency of a tax on N fertilizer as a measure to improve the N use efficiency in agriculture.

Communicative instruments include collective projects to address environmental issues and measure to improve information flows to promote good agricultural practices and environmental objectives. This information can be provided to both producers, in the form of technical assistance and extension, and to consumers, via labelling. Technical assistance and extension are policy measures providing farmers with on-farm information and technical assistance to plan and implement environmentally friendly farming practices. This assistance can take a variety of forms including: technical advice regarding the construction of manure storage facilities; practical advice on the spreading of manure; the development of nutrient management plans; and the monitoring of environmental impacts. Technical assistance has been provided also to assist the implementation of the Codes of good agricultural practice required by the Nitrate Directive (Zwart et al., 2006; OECD, 2003).

Currently, most of the current EU Environmental Directives are mostly based on regulatory instruments, and only to a small extent on economic and communicative instruments. Following the CAP reform and the trends towards integration of agriculture and environmental policies, economic instruments are increasingly used to achieve environmental targets. The mix of policy instruments will depend on the policy target but also on the farmers, on their capability, ability and willingness to implement the policy and measures. When the farmers lack the competency, it is clear that training, education and extension would be the main instrument. When farmers lack the tools and instruments, they will be unable to implement the policy and measures. Hence, efforts should be made to provide farmers with these tools. When farmers are unwilling to implement policies and measures, it will be clear that regulatory instruments and communicative instruments alone will meet with resistance. In this case, incentives via economic instruments will be needed. In practice, there can be a variable combination of incapability, inability and unwillingness (as defined above), suggesting indeed that a combination of policy instruments would be most effective and efficient.

Table 15: Categories of effects following the implementation of policies and measures

Technological changes	Managerial changes	Structural changes
animal housing systems	allocation of manure and	farming system
manure storage systems	fertilizer applications	farm size
low-emission application	animal feeding	specialization vs. diversification
techniques	crop care and management	integration with processing
fertilizer spreading techniques	grazing management	industry and markets

Policies and measures aim at changing farmers' behaviour and thereby aim at improving the economic and environmental performance of the farms. The changes brought about by the change in farmers' behaviour can be categorized in three types of effects, namely (i) technological changes, (ii) managerial changes and (iii) structural changes. Table 15 shows some examples of the three types of changes. The distinction between these types of changes is important as it will contribute to increased understanding of the unintentional pollution swapping through policies and measures.

Technological changes involve investments in the '*hardware'* of the farm, in the buildings, machines, and equipment. These investments are often costly, and usually are only made when combined with up-scaling (enlargement of the farm) to make the investment cost-effective, or following suitable incentives (subsidies, tax reduction, fines). Changes in the technology, the hardware of the farm, may lead to managerial and structural changes (see below), but not necessarily. The latter, often unintentional, changes will depend on the local farm situation. The ammonia abatement measures and especially the BREFs (Reference documents of best available techniques) are examples of policies and measures with emphasis on technological change.

Managerial changes involve investments in the '*software'* of the farm, in the capability, ability and willingness of the farmer. These changes require training, education, demonstration and persuasion activities. And they require suitable instruction, guidelines and managing tools. Managerial changes greatly influence resource use efficiency, i.e., the use efficiency of nutrients (N, P and other nutrients), water, energy, etc., through the controlled purchase and allocation of inputs, and the management of the land, soil, crop, animal, and machines. The measures of the Nitrates Directive and a few ammonia abatement measures of the UNECE-working group and the IPPC Directive (animal feeding, integral N management) are examples of policies and measures focused on changes in the management and resource use efficiency of farms.

Structural changes concern changes in the *orgware* of agriculture, in the type (cropping systems, animal systems, mixed systems), size and location of farming systems, in the vertical (from suppliers to consumers) and horizontal (co-operation among farmers) organisation. Structural changes involve changes in the relative importance of production factors and resources (land, labor, capital, energy and management), and may involve changes in ownership of farms and farm land, and in the organization of farmers and the institutionalization of farmers' organizations. It may change total employability and gross domestic production, and competitiveness of agriculture may involve changes in social integration of the agricultural community within the society. Hence, structural changes can be dramatic. Typical examples of policies and measures (directly and/or indirectly) focused on structural change are the CAP and Rural Development Regulations. Also the Habitats Directive may lead to structural change in regions.

In practice, achieving policy targets often requires a combination of managerial, technological, and structural changes, depending also on the local situation in the Member States. Agriculture is highly diverse and this makes generalization somewhat a perilous undertaking. Managerial changes are often most easy to realize, as they require little investments, while the effect and impact is often very large ('picking the low-hanging fruits'). However, benefiting from improved management requires that the proper technology is there. Conversely, policies and measures focused on technological change, like many of the ammonia abatement measures, presume that the management skills to handle these technologies and their effects are present. Structural changes are often most complicated; they are often very costly and take a long time, especially when the needed change is in the opposite direction of current autonomous trends (up-scaling, specializing, intensifying and conglomerating). Hence, measures aimed at technological and managerial changes should go hand in hand, and in terms of ease of implementation, the order is managerial changes > technological changes > structural changes.

5.4 Pollution swapping through abatement measures of NH_3 and NO_3 losses

Volatilization of NH_3 occurs at an early stage in the sequence of processes following the excretion of faeces and urine by animals and or the application of urea and ammonium-based fertilizers (Fig. 6). The emission of N_2O and the leaching of NO_3 occur at later stages. From this sequence of processes, it will become clear that measures that effect the emission of NH_3 will change the total amount of N at an early stage and thereby likely have an effect on the emission of N_2O and the leaching of NO_3 too. Conversely, it is less likely that measures that effect the leaching of NO_3 will *greatly and directly* effect the emission of NH_3 (although the obligation to spread manure in the growing season only, to prevent nitrate leaching, may lead to higher NH_3 compared to manure spreading in winter).

The sequence of processes shown in Figure 7 explains to some extent why the ammonia abatement measures described in chapter 4.2 will frequently affect nitrate leaching, and why the nitrate leaching abatement measures described in chapter 4.1 generally have little effect on emission of NH_3, unless the total N input is controlled too. The reason for the swap between nitrate and ammonia related to avoidance of winter spreading is that spring/ summer conditions promote partitioning of nitrogen to the air (as NH_3), reducing losses to water (as NO_3), while wet winter conditions minimize losses of NH_3 to air, and promote leaching losses, especially when coupled with differences in plant uptake of $NO_{3.}$

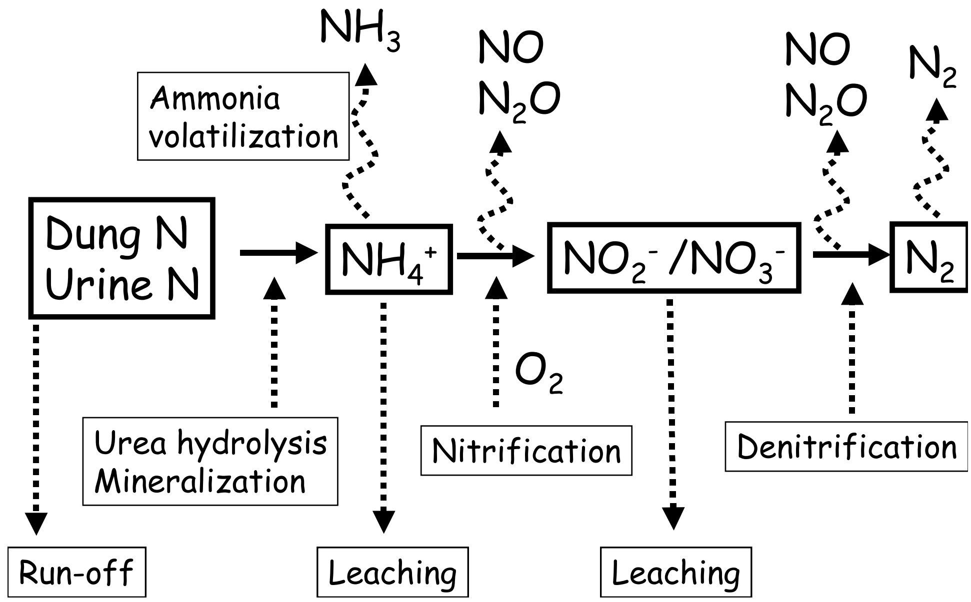

Figure 7. Sequence of N transformation processes, and the release and loss of various N compounds from dung and urine. Note that the uptake by the crop of NH_4^+ and NO_3^- is not included in this conceptual framework.

A second reason that may explain why the NH_3 emission abatement measures likely have more effect on NO_3 leaching than the NO_3 leaching abatement measures have on NH_3 emission is the fact that the current NH_3 abatement measures are more focused on technological changes and the NO_3 leaching abatement measures more on managerial changes (chapter 5.2). The technological measures to abate NH_3 emission are focussed on preventing the escape of NH_3 emission (trapping), while the managerial changes tend to be focussed more on improving N utilization, i.e., preventing the leaching of NO_3 combined with balanced fertilization (fine-tuning of supply to demand by the crop).

The measures of the Nitrates Directive can be classified in three groups, based on their synergistic and antagonistic effects on the emissions of NH_3, N_2O and CH_4. Similarly, the measures of CLRTAP and IPPC on ammonia emission abatement can be categorized in two, based on their synergistic and antagonistic effects on the emissions of N_2O and CH_4 and the leaching of NO_3. However, the effects are not straightforward or linearly, and this makes the assessment of the overall result complicated. Site-specific conditions and the farm management do have a great effect on the overall net effect. That is also the reason why the results of field experiments are sometimes diverse and even conflicting as regards the quantitative aspects of Type 1 pollution swapping. There is a large number of controls on the emissions of NH_3, N_2O and CH_4 from manures in storage and following application to land, and our quantitative understanding of these controls is still limiting.

Provisional results presented by Velthof et al (2007) provide quantitative underpinning for the necessarily qualitative assessments made in this study. They estimated that full implementation of the measures of CLRTAP in the EU-25 to achieve the objectives of the NEC Directive has the potential to decrease the emissions of NH_3 by 49% relative to a reference situation without NH_3 emission abatement measures (Table 16). However, these measures increase the leaching of NO_3 by 11% and the emissions of N_2O by 7% in the EU-15. Conversely, full implementation of the measures of Nitrates Directive has the potential to decrease the leaching of NO_3 by 65% relative to a reference situation without NO_3 leaching abatement measures. Moreover, these measures are estimated to decrease the emissions of NH_3 by 10% and the emissions of N_2O by 23% in the EU-25. These results indicate indeed that the NH_3 emission abatement measures likely have antagonistic effects on NO_3 leaching, while NO_3 leaching abatement measures overall have synergistic effects on the emissions of NH_3 and N_2O in the EU-15. Although it must be recognized that these initial model results do not include all the possible trade offs, such as the effect that avoidance of winter spreading in nitrates policy may increase ammonia emission. The results presented in Table 16 however, clearly show that the measures with the largest synergistic effects are related to N input control (i.e. balanced fertilization), and that the measures with the largest antagonistic effects are related to technological measures aimed at preventing the emissions of NH_3, without N input control. Further sensitivity analyses and assessments are needed to be able analyze the effects to the various assumptions made in this quantitative assessment.

It should also be emphasized that the trade-offs shown in Table 16 represent the consequence of separate application of these policy measures directed at ammonia or nitrate mitigation. Many of the pollutant swapping effects from ammonia mitigation result from the simple fact that more nitrogen is saved in the farming systems. Therefore integrated packages considering ammonia, nitrate and nitrous oxide mitigation, and entailing better use of the nitrogen saved, have the prospect of avoiding much or all of the Type 1 pollution swapping indicated in Table 16.

Table 16. Results of the assessment of the implementation of NH_3 emission abatement measures of CLRTAP and the NO_3 leaching abatement measures of the Nitrates Directive on the ***potential relative changes (in percent)*** *in the emission of NH_3 and N_2O to the atmosphere and the leaching of NO_3 to groundwater and surface waters in the EU-25*). The reference situation is for the year 2000, without the implementation of any of these measures (Velthof et al., 2007).*

Code	measures	NH_3 emission, change in %	N leaching, change in %	N_2O emission, change in %
A1	Low Nitrogen Fodder	-4.1	-2.3	-1.7
A2	Stable Adaptation	-5.4	1.0	8.3
A3	Covered Manure Storage	-1.1	0.4	0.1
A4	Biofiltration (air purification)	-2.7	0.7	0.3
A5	Low Ammonia Application of Manure	-18.1	2.9	12.1
A6	Urea substitution	-5.2	0.5	-0.6
A7	Incineration of poultry manure	-0.4	-0.3	-0.1
N1	balanced N fertilizer application	-8.9	-28.0	-14.0
N2	Maximum manure N application standard	-0.9	-2.7	-0.4
N3	Limitation to N application in winter and wet periods	-0.9	-4.6	-2.3
N4	Limitation to N application on sloping grounds	-0.8	-2.4	-1.6
N5	Manure storage with minimum risk on leaching	1.1	-5.2	0.3
N6	Appropiate pplication techniques	0.0	-6.3	-0.4
N7	Riparian zones	0.0	-0.4	0.3
N8	Growing winter crops	0.0	-3.0	-0.2
P1	Equilibrium fertilization of P	-8.2	-7.8	-4.4
A1 + N1	Low Nitrogen Fodder + balanced N application	-12.4	-29.1	-15.1
A2 + N1	Stable Adaptation + balanced N application	-14.6	-27.2	-5.9
A3 + N1	Covered Manure Storage + balanced N application	-10.1	-27.7	-14.0
A5 + N1	Low Ammonia Application + balanced N application	-24.4	-26.3	-4.2
N1 + P1	Balanced N and P fertilization	-12.9	-31.5	-16.1
A1-A7	Package of ammonia measures	-35.9	2.8	17.9
N1-N8	Package of nitrate measures	-8.7	-41.5	-15.3
A1-A7 + N1-N8	All ammonia and nitrate measures	-40.7	-40.8	0.3

**) While the model addresses many of the underlying type 1 pollutant trade offs, not all process interactions are considered. Hence avoiding winter application is estimated by the model to reduce ammonia emission, when in fact seasonal interactions can cause a net increase in ammonia emission due to spreading in warmer conditions which favour ammonia emission.*

Results of the assessments of the Birds and Habitats Directives also have a qualitative and tentative character, as the Natura 2000 management plans and special action plans are still being elaborated. In general, the management plans of these Directives have regional effects, i.e. within and around the Natura 2000 areas. The management plans measures may contribute to decreasing emissions NH_3, N_2O and CH_4 and the leaching of NO_3 as most of these measures put restrictions on agricultural activities. However, some measures may contribute to increasing the emissions of NH_3, N_2O and CH_4 and the leaching of NO_3 elsewhere (type 2 pollution swapping), as some farming activities may be transferred from around the Natura 2000 areas to elsewhere. There are no quantitative assessments about the scale and extent of this type of pollution swapping. As the area involved in Natura 2000 in EU-25 is between 10 to 20%, the overall effect can be significant. The important point to consider from these interactions is that European policy makers need to agree the spatial priorities for environmental protection. Having set these priorities, the benefits of policies should not just be measured as reductions in total European emissions, but also in terms of improving condition of the priority habitats and species (cf. Sutton et al. 2004). The spatial strategies related to Natura 2000 thus hold the prospect of maximizing the environmental benefit (by focusing on Natura 2000 sites as priority areas) for a given amount of overall reduction in nitrogen emissions.

Cross Compliance is meant to ensure respect of the Statutory Management Requirements, SMRs) and the maintenance of the land in Good Agricultural and Environmental Condition (GAEC) in response to area payments. So far, Member States differ in the ambition and the procedures of implementation of cross compliance (see also http://www.ewindows.eu.org/cifas). It seems that UK is ambitious (see also http://www.defra.gov.uk/farm/capreform/singlepay/crosscomply/index.htm), while the Netherlands and Flanders seem less ambitious (http://landbouw.dotnet15.hostbasket.com/mtr/controle.html#wat4) and http://www2.vlaanderen.be/ned/sites/landbouw/publicaties/volt/19.html.
The 'Environmental' Directives and the 'Animal Welfare' Directives may have the largest effects on the emissions of NH_3, N_2O and CH_4 and the leaching of NO_3. The enforcement of the cross compliance with 'Environmental' Directives (Birds Directive 79/409/EC; Groundwater Directive 80/68/EC; Sludge Directive 86/278/EC; Nitrates Directive 91/676/EC and the Habitats Directive 92/43/EC) is from 2005 onwards, and that of the 'Animal Welfare' Directives (91/629; 91/630/EC and 98/58/EC) is from 2007 onwards. The enforcement of the 'Animal Welfare' Directives may have side-effects. Commonly, measures to establish animal welfare in animal housing contribute to increases in the emissions of NH_3, N_2O and CH_4 from animal housing systems. This follows from various assessments on the effects of housing systems on NH_3, N_2O and CH_4 emissions (Poulsen et al., 2003; Oenema et al., 2001). Quantitative assessments of the effects of such measures for the EU-25 have not been made yet.

The assessment of the Rural Development Regulation 1698/2005 suggests that this regulation will have diverse effects on the emissions of NH_3, N_2O and CH_4 and the leaching of NO_3, depending on the relative importance of the axes. Axis 1 support may lead to decreasing emissions when the emphasis is on implementing new standards for environmental protection. Axis 2 support will lead to decreases in the emissions when the emphasis is on extensification and decreases in fertilizer use and livestock density. In Austria, Axis 2 has also been used to set reduction in ammonia emissions as a national priority under the RDP. However, when the emphasis is on animal welfare support in animal housing, gaseous emissions may increase as the animal housing requirements for animal welfare lead to increasing emissions of NH_3, N_2O and CH_4. Axis 3 support likely leads to a modest decrease in emissions of NH_3, N_2O and CH_4 and the leaching of NO_3.

Evidently, the new agricultural and environmental policies in EU tend to be more integrated than older ones, and less focused on specific measures. This holds especially for the CAP reform, Cross Compliance and Rural Development

Regulations, but also for Environmental Directives. For example, the Water Framework, Birds and Habitats Directives are typical (ecological) target oriented directives, while the Nitrate directive is more oriented towards specific measures. The focus of targets of new directives is shifting somewhat from the front side of the DPSIR scheme (Driving Forces – Pressure – State – Impact - Response) to the backside. This change in focus provides Member States the opportunity to make site and region-specific management plans including guidelines and possible input restrictions for the front side of the DPSIR scheme, and thereby improves the precision of the policy. However, it makes control and enforcement in practices of the implementation much more complex. The change in focus likely has no effects on pollution swapping, i.e., synergism and antagonism can occur irrespective of where policies and measures latch on to the DPSIR scheme.

Targets for nitrogen are formulated at the level of Pressures (fertilizer and animal manure inputs via the Nitrates Directive), Environmental State (NH_3 emission ceilings, via the NEC Directive, NO_x and PM_{10} via the Air Quality Directive, NO_3 concentrations in groundwater and surface waters via the Nitrates Directive), and the Impact level (ecological status, and health status via the Water Framework Directive, Birds and Habitat Directives, and Thematic Strategy). Although this diversity of targets likely has no effect on the mechanisms of pollution swapping, there is the risk of sub-optimal measures, seen from the point of view of effectiveness and implementation and enforcement costs (efficiency). Ideally, investments (both public and private) of Member State resources in (both mandatory and voluntary) measures to satisfy EU requirement should lead to solving the most urgent ecological and human health related problems.

There are various measures, associated with EU directives, which can be very expensive per kg of prevented emission or per unit surface area of protected habitat (for example, certain buffer strips, some low-emission animal housing systems and manure processing techniques). Additionally, ecological benefits can be very uncertain, especially when pollution swapping may occur. The current national policy evaluation procedures do not exclude low cost-efficiency (meaning high costs and low benefits), because they tend to focus on single environmental issues. This increases the risk that economic costs associated with the implementation of Directive will be (politically) qualified as disproportional. In the Water Framework Directive, disproportional economic effects of required measures may be used as argument (is a valid reason) to relax in the implementation of EU requirements.

So far, EU directives have led to a less polluting agricultural sector, while maintaining economic vitality. However, production costs on a farm level have increased due to higher environmental requirements, and have changed economical competition both between member states and also between the EU and agricultural production outside the EU. An unintentional possible side-effect of Environmental Directives can be relocation of polluting sectors (pigs, dairy, horticulture) to regions where legal protection so far is less strict than elsewhere, inside or outside the EU. This type 2 pollution swapping is apparent in some new Member States, where it appears that some foreign companies may have ceased intensive livestock operations to due concerns over increased environmental regulation. Recently, NGO's like Polish Green Network and the Animal Welfare Institute have raised concern about the establishment of large foreign pig farms in central European countries (e.g., Poland and Romania). These organizations blame especially the internationals 'Smithfield Food Company' from the US, which took over Animex S.A., the second largest Polish state-owned meat processor and producer in 1999, and the Danish company 'Poldanor', for buying out bankrupt local farms, for shifting the cost of industrial hog-raising onto the environment and small farms, for poor animal welfare, and for disturbing local markets through over-production. Type 2 pollution swapping is also the consequence of location specific cost advantages, which leads to conglomerations of specialized agricultural sectors in some regions.

Another complication when striving to ensure synergism and preventing antagonism are climate policies. Almost by definition, technical measures (end of pipe) to reduce specific emissions of nitrogen (air purification, sub-surface application of manure) will increase energy demand, while reduction of N-losses to natural ecosystems may reduce C-sequestration or C-storage in some systems. For atmospheric deposition, the use of critical loads based on critical limits for indicators relevant to environmental and public health, to some extent tackles the problem of dealing with different ecological effects (plant diversity, fauna) in different ecosystem types. However, the UNECE convention on LRTAP focuses on atmospheric input, and therefore on ecosystems that are considered sensitive to atmospheric deposition.

5.5 Conclusions and recommendations

The loss of N from agriculture via the volatilization of NH_3 and N_2O to the atmosphere and the leaching of NO_3 to groundwater and surface waters are related to the amount of N within the system and to the N surplus. The volatilization of NH_3 is linearly related to the amount of ammoniacal – N in the system (Monteny and Erisman, 1998; Sommer et al., 2006). The leaching of NO_3 from soils and manure storage systems to groundwater and surface waters is most directly related to the amounts of mineral N in soil (Schröder et al. 2003). Environmental conditions and management activities do have large and complicated effects on the relationships between amounts of N in the system and the losses via volatilization of NH_3 and N_2O and the leaching of NO_3 from the system, but the first-order kinetics of the N loss processes provide a sound basis for the guiding principle of N loss control via N input control.

The NO_3 leaching abatement measures of the Nitrates Directive and the NH_3 emission abatement measures of the UNECE – CLRTAP, the IPPC and NEC Directives and the Thematic Strategy on Air pollution do include N input control as one of the measures, but not as a guiding principle. Moreover, there is little or no reference in the Nitrates Directive to creating synergistic effects on the abatement of NO_3 leaching and NH_3 emission. Conversely, there is little or no reference in the UNECE – CLRTAP, the IPPC and NEC Directives and the Thematic Strategy on Air pollution to creating synergistic effects on the abatement of NH_3 emission and NO_3 leaching. Both set of policies and measures have a strong single N species focus, although both mention integrated N management. For effective and efficient policy on the abatement of NO_3 leaching and NH_3 emissions (and other N species), N input control should be the guiding and overall arching principle. This guiding principle creates synergistic effects on the abatement of NO_3 leaching and NH_3 emissions (and the emission of other N species) and circumvents antagonistic effects of the single species abatement measures mentioned in the Nitrates Directive and the UNECE – CLRTAP and the IPPC and NEC Directives. This also in line with the recommendations of the Nanjing Declaration (see Erisman et al., 2005).

Nitrogen input control in EU agriculture mainly means N fertilizer input control and animal feed input control. The total N input of N fertilizer in EU-25+ has been estimated at about 12 Tg, the import of food and feed at about 7.6 Tg and the inputs via biological N fixation at 2.2 Tg (Van Egmond et al. (2002). There are additional N inputs via atmospheric deposition (7.3 Tg), but these inputs roughly balance the losses via the emission of NH_3 and NO_x (7.8 Tg). The inputs of N fertilizer and imports of N via feed and food and to a lesser extent via biological N fixation fuel the N cycle of the European agriculture and thereby make agriculture conducive to N losses via the volatilization of NH_3 and N_2O and the leaching of NO_3. Naturally, the N inputs via N fertilizer and animal feed have greatly contributed to the increased productivity of the European agriculture, but the question is whether all the N is really needed. The price of N fertilizer is strongly related to the price of fossil energy, but both the energy cost and the absolute monetary costs of fertilizer production have gone down significantly during the 20th century (Smil, 2001), and have made N fertilizer relatively cheap. As a consequence, there has been relatively little economic incentive during the second half of the 20th century to save on N fertilizer use.

5.5.1 Conclusions

- The NH_3 emission abatement measures of the UNECE – CLRTAP and the IPPC and NEC Directives do have the potential of type 1 pollution swapping because of the emphasis on technology and the early incidence of NH_3 emission early in the sequence of N cycling processes. To minimize type 1 pollution swapping, the NH_3 emission abatement measures have to be combined simultaneously with the NO_3 leaching abatement measures of the Nitrates Directive and with a strong emphasis on N input control.
- Greater emphasis on low-protein feeding within the context of NH_3 emission abatement measures does have the potential of synergistic effects on decreasing the emissions of NH_3 and N_2O and the leaching of NO_3.
- The NO_3 leaching abatement measures of the Nitrates Directive have the potential of both synergistic and antagonistic effects on decreasing the emission of NH_3 and N_2O. The synergistic effects seem to dominate, because of the emphasis on balanced N fertilization and N input control. Type 1 pollution swapping to increased NH_3 emission may occur following the tendency in cattle farming systems to move to zero-grazing systems (to circumvent the leaching of NO_3 from animal droppings in pastures, but NH_3 emissions are larger from housing systems than from grazing systems). Type 1 pollution swapping to

increased NH_3 emission may also occur following a ban on the application of animal manure off the growing season; this ban contributes to a higher utilization of nutrients from manure by the crop and to less NO_3 leaching losses, but at the same time may contribute to increased emissions of NH_3 (and N_2O), because of higher temperature and possible lower incidence of rainfall during the growing season. The pollution swapping potential of the NO_3 leaching abatement measures of the Nitrates Directive to increased NH_3 emissions can be minimized through implementation of NH_3 emission abatement measures of the UNECE – CLRTAP. This indicates again that NH_3 emission abatement measures have to be combined simultaneously with the NO_3 leaching abatement measures of the Nitrates Directive and vice versa to be able to effectively and efficiently decrease N losses from agriculture.

- Designation of Nitrate Vulnerable Zones and areas of special protection (Natura 2000) within the context of the Birds and Habitats Directives do have the potential of type 2 pollution swapping, i.e., transferring the environmental pressures resulting from agricultural activities from within and around the designated zones to elsewhere, outside the designated zones. This type of pollution swapping can only be circumvented or minimized by removing the agricultural productivity or by the implementation of N loss abatement measures. However, transferring hot spots of N emissions (e.g. intensive livestock operations) from areas sensitive to N deposition to areas that are much less sensitive to N deposition can greatly decrease the ecological impact of the N losses, depending in part on the background deposition and the critical load.
- All measures that lead to increased N-use efficiency at the system level decrease the N losses via the emission of NH_3 and N_2O and the leaching of NO_3 per unit of agricultural produce, but not necessarily the emissions per unit of surface area. Decreasing the losses per unit of surface area requires that increases in N-use efficiency are not counterbalanced by increases in production capacity, which may occur in Member States following, for example, the abolishment of the milk quota system.
- Cross Compliance measures, introduced following the CAP reform, ensures respect in practice of 19 Statutory Management Requirements (SMRs) and Good Agricultural and Environmental Condition (GAEC). Thereby, Cross Compliance measures have the potential to exacerbate synergistic and antagonistic effects on the abatement of N loss pathways. The SMRs include the Nitrates Directive and the Birds and Habitats Directives, with their potentials of creating synergistic and antagonistic (type 1 and type 2 pollution swapping) effects. The SMRs also include animal welfare regulations which may contribute to an increase of the emission of NH_3 and N_2O and the leaching of NO_3 because of the regulations on the area and bedding material of animal housing systems, and the requirements on outside free-walk. Further, such animal welfare regulations may increase the animal feed conversion ratio (more feed is needed to produce 1 unit of animal produce) and thereby also increase emissions.
- The effects of the Rural Development Regulation on the emission of NH_3 and N_2O and the leaching of NO_3 from agriculture are diverse and complex. They have the potential of decreasing N losses and of creating synergistic effects on

the emission of NH_3 and N_2O and the leaching of NO_3, depending on the measures that are being supported.

- In its present form the IPPC Directive has the potential, by the requirement for using Best Available Techniques (BAT), to reduce European ammonia emissions from pig and poultry emissions. However, the environmental benefits of IPPC are wider than a simple contribution to European scale emission reduction. The permitting and review requirements provide a link to other Directives, notably the Habitats Directive, so that IPPC provides a key tool for ensuring local protection of priority sites, such as the Natura 2000 network.
- Trends in agricultural development suggest that more livestock will fall under the regime of the IPPC Directive in near future, because of the effects of up-scaling in agriculture. This will make the impact of the IPPC directive for agriculture larger and calls for an increasing need of joint implementation of IPPC and Nitrates Directive measures. However, if the obligations of the IPPC are too strict from a farmers' point of view, there is the possibility that farm size will remain just under the threshold levels, depending also on the competitivess of larger-scale farms.

5.5.2 Recommendations

- The measures dealing with N input control in the Nitrates Directive (Balanced N fertilization) and the UNECE – CLRTAP and the IPPC and NEC Directives (protein content of the animal, integrated N management) should be the guiding and overall arching principle of the NH_3 and N_2O emission and NO_3 leaching control.
- The implementation and enforcement of the measures of the Nitrates Directive must be jointly with those of UNECE – CLRTAP and the IPPC and NEC Directives, so as to circumvent type 1 pollution swapping.
- In addition to NH_3 emission ceilings and limits, input limits for N from animal manure and NO_3 concentration in groundwater and surface waters, there is scope for formulating targets for N use efficiency for specified farming systems. Such targets for N use efficiency have the advantage of providing a measure for an integrated N input control and for the N loss to the environment.
- There is scope for introducing effective and efficient economic incentives to abate NH_3 and N_2O emissions and NO_3 leaching simultaneously, provided that N input control is the guiding and overall arching principle and that there is a well-balanced and joint implementation.
- Providing incentives via Rural Development measures to the N use efficiency for specified farming systems provides opportunities for rewarding those farmers that go beyond certain standard criteria and thereby decreasing N losses in an integrated way.
- A tax on N fertilizer (or on fossil energy sources) and / or on protein-rich animal feed stuffs may also contribute to N input control and to increasing N use efficiency, and thereby on decreasing N losses in an integrated way. However, a tax on N fertilizer and/or protein-rich animal feed will also penalise farmers that use N fertilizer and protein-rich animal feed judiciously, and was therefore

considered unfeasible in the recent past. With a greater priority in EU policy on climate change, fossil energy use and N emission control, new perspectives may emerge.

- Animal welfare regulations for animal housing should be combined with NH_3 and N_2O abatement measures and NO_3 leaching abatement measures
- In addition to spatial *zoning* of areas with high nature values and/or vulnerable to NO_3 leaching (within the context of the Nitrates Directive and the Birds and Habitats Directives), there is scope for spatial *planning* of N polluting agricultural activities in areas that are less vulnerable. This can be relevant also given the trends towards conglomerating large, specialized and intensive farms in areas with cost-specific advantages (which do not have necessarily nature or N cycling specific advantages).
- The role of the agro-complex (suppliers, farmers, processing industry and retailers) has so far received little or no attention in decreasing N losses from agriculture. This is surprising, as the agro-complex and especially suppliers, processing industry and retailers play a dominant role in (the development of) agriculture. It is suggested to explore the potentials of the agro-complex in improving N use efficiency and decreasing N losses from agriculture.
- So far, the leakages of the N species from the holes in the pipe have been considered equally (damaging). We recommend examining the potential ecological damage of each of the N species involved so as to making a rating among the N species. The resulting prioritization will depend on the quantitative relationships between nitrogen forms, and may be expected to vary spatially depending on local and regional priority concerns.

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