Trends in ammonia emissions from agriculture in Europe and in The Netherlands

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1. INTRODUCTION

The scientific and political attention for ammonia emissions originated in the 1980's when acidification and large scale forest die-back were a public concern. At first, acidification was attributed to SO_2 and NO_x, largely emitted by non-agricultural sources. Agriculture emits them in relatively small quantities, as a by-product of combustion of fossil fuels. By the end of the 1980's it became apparent that also ammonia (NH_3) contributed to acidification. For this agent the contribution from agriculture to the total emission is relatively high. In most European countries 90-100% of national NH_3-emissions originate from animal husbandry[11]. On a European scale, NH_3-emission densities are highest in The Netherlands reaching an average level of over 100 kg/ha while the average in the EC-12 and in Europe is roughly only 25 kg/ha (see table 1). The high emission levels stimulated the Dutch government to be the first to launch a national ammonia abatement program in 1990. The results of this program will be discussed in chapter 2 of this paper. Chapter 3 provides an overview of trends in ammonia emissions on a European scale.

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11 Exceptions are Sweden (60%), Luxembourg (76%), Poland (79%), Austria (81%), Slovenia (85%) and the UK (87%), according to Corinair data for 1990.

Table 1

Average NH_3 emission from agriculture in 1990 at six regional scale levels: the Northern Hemisphere, Europe, the EC-15[a] and -12, The Netherlands, and the Dutch municipality of Noordwijk.

	average (kg/ha)	lowest	highest
Northern Hemisphere	n.a.	Canada: 5	China: 50
Europe	26	USSR: 7	Netherlands: 95
EC-15	25	Spain: 10	Netherlands: 95
EC-12	25	Spain: 10	Netherlands: 95
The Netherlands	109	Almere: 20	Deurne: 340
Noordwijk municipality	48	bulbs: 5	dairy: 200

[a]) the 15 memberstates from the European Community include EC-12 and Austria, former DDR, Finland and Sweden.

Source: computed from Corinair and FAO data; Netherlands from RIVM data, N.Hemisphere from EMEP-East.

2. AMMONIA EMISSIONS IN THE NETHERLANDS

2.1. Historic development of ammonia emissions

The emissions of NH_3 from Dutch agriculture have grown exponentially since the end of the nineteenth century and reached their peek level in 1987. These emissions originate largely from animal manure (see figure 1) and for a minor share (1-5%) from the application of chemical nitrogen fertilizers.

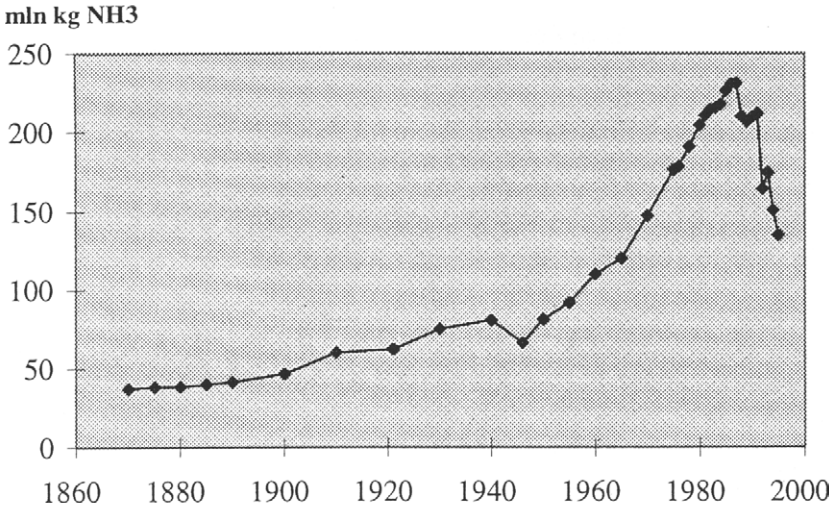

Figure 1. Ammonia emissions from livestock in The Netherlands, 1870-1995.

2.2. Environmental damage from ammonia deposition

The first notions about the contribution of ammonia to soil acidification in nature areas stem from 1982, when Van Breemen and his colleagues described forest soil acidification from atmospheric ammonium sulfate (Van Breemen et al., 1982). In 1984 a large coordinated research program was launched, reflecting the growing concern of policy makers with effects of air pollution, primarily on forest. The first two phases of this Dutch Priority Program on Acidification (Heij en Schneider, 1991) resulted in understanding of the causes and effects of deposition of acidifying substances on forest and heathland, which was substantial enough to implement an Acidification Policy (VROM, 1989) and an Ammonia Policy (LNV and VROM, 1990).

By then, ammonia (NH_3) was accepted to be a *potentially* acidifying substance. In the air it neutralizes acidity by transforming into ammonium (NH_4^+) but when this reaches the ground it is either taken up by plants or transformed into nitrate (NO_3^-), leaving 2 ions of H^+ for every ion of ammonium. Actual soil acidification occurs to the extend that nitrate leaches to the groundwater instead of being taken up by plants. This occurs when the potential acid and nitrogen supply is abundant, compared to the availability of other (neutralizing) minerals. Thus, acidification can be seen as a result of direct acid inputs *plus* eutrophication, an oversupply of nitrogen. This oversupply leads to rapid growth of stems and leaves but retards the development of the root system. This increases the susceptibility of trees to insects, fungi, drought, frost and storms. In addition, the diversity of (forest) ecosystems is reduced by eutrophication as grasses, stinging nettle and blackberries become dominant species in forest undergrowth and lichen disappear. Heathlands are converted into grassland and fens loose their oligotrophic conditions and associated flora and fauna. Groundwater is polluted by nitrate and aluminum, both toxic to humans (Heij and Schneider, 1991).

Dutch farmers are not as convinced as scientists and policy makers that ammonia emissions are harmful to the environment. It is very likely that the restrictions they experience from the ammonia policy and their inability to discern the visual effects from NH_3-emissions lead them to distrust the abundance of scientific evidence. They rather believe statements of Heidelberg Appeal Nederland, an organization that claims to represent Nobel laureates, publicly challenges the findings of 10 years of acidification research but avoids a scientific discussion on the issues they raise. This has increased public uncertainty about the harmfulness of ammonia emissions. Even the Minister of Environment seems to question the gravity of the ammonia problem. Despite big efforts, scientists and policy makers have not succeeded to eliminate these feelings which is a potential threat to a full implementation of the ammonia abatement policy.

2.3. The Dutch ammonia abatement policy

Setting targets

The Dutch Priority Program on Acidification provided a scientific justification for the Dutch government to develop a policy aiming to reduce ammonia emissions (LNV en VROM, 1990). The long term emission targets were derived from critical loads for various types of ecosystems and from targets for nitrate leaching in nature areas (max. 25 mg/l). It turned out that the protection of forests and heathlands required a maximum deposition of 1400 mol H^+/ha containing 1000 mol N/ha. This meant a reduction of national NH_3-emissions by 80-90%, assuming a reduction in the surrounding countries by 60% with respect to 1980 emission levels. For SO_2 and NO_x similar reductions were needed (RIVM, 1989). Protection of natural ecosystems and fens would require sharper deposition levels (down to 400 mol H^+/ha) and larger emission reductions. Calculations showed that a 70% emission reduction in The Netherlands was technically feasible but relatively costly. This was chosen as a target for the year 2000 since it was thought to be necessary to reach a minimum level of protection to national forests. The costs of a 30% emission reduction appeared to be very limited and would not create financial problems to the farming sector (Oudendag en Wijnands, 1989). This target was set for the year 1994, 5 years after the Policy Plan was put in action. Based on cost calculations, farmers didn't want to go beyond 50% reduction by the year 2000. Policy documents in the early 1990's still mentioned a target of 50-70% for 2000 but by 1995 the targets had been adjusted to 50% reduction in 2000 and 70% reduction in 2005.

Instruments

On the national level, policy instruments include mandatory coverage of manure storage and mandatory incorporation of slurries into the soil. Policy makers are preparing legislation which prescribes that new stables and major stable adaptations meet certain emission requirements (Green Lable stables). On the local level, farmers have to comply to production permits, based on calculated ammonia deposition on acid-sensitive areas. In addition to the nationally prescribed measures for emission reduction, farmers can invest in low ammonia housing systems to meet the requirements for a production permit or move the location of their stables away from the sensitive areas.

2.4. Effects of the Dutch ammonia policy

Without the ammonia policy, NH_3 emissions from livestock would have stabilized roughly at the 1986 level. This stabilization was due to other policies such as the national manure policy from 1986 (which put a hold to the systematic expansion of the pig and poultry industry) and the EU dairy policy from 1984 (which put a maximum on the national milk production and thus results in annual reductions of the number of dairy cows). Although the manure production per animal continued to grow, the net result was a stabilization of the national manure production (measured in nitrogen) since 1986.

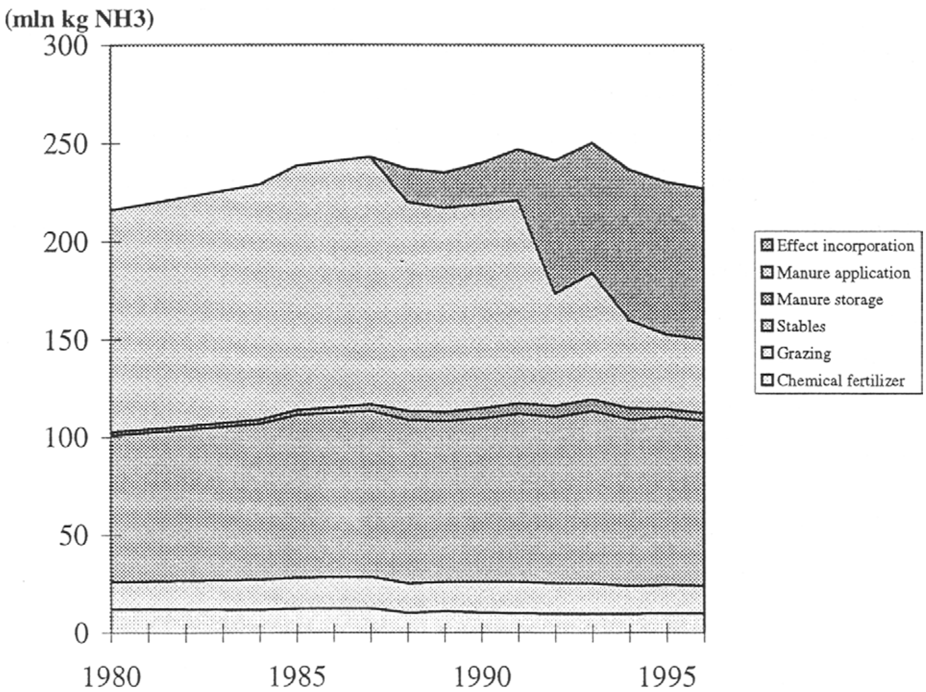

Figure 2. Effects of incorporating manure on NH_3-emissions between 1980 and 1996.

The largest contribution to NH_3 reduction came from incorporation of manure into the soil, which was made compulsory in a stepwise fashion between 1987 and 1995, see figure 2. This effect may be overestimated since we observe a growing gap between measured and calculated ammonia concentrations in ambient air since 1992. The emission from storage facilities grew slightly but would have grown substantially if they had not been covered. That is because the manure policy prescribed a restricted period for manure spreading in order to reduce nitrate leaching. This meant that more manure was stored for a longer period of time before spreading on the fields.

2.5. Projections of NH_3-emissions from Dutch agriculture

Dutch scientists are developing a tradition of scenario studies on pollution from Dutch agriculture. These studies are used in ex-ante policy evaluations and provide a basis for discussion on policy adaptations. The first scenario study was carried out in 1989, as part of the 'Concern for Tomorrow' study (RIVM, 1989). It predicted that the acidification policy from 1989 would reduce NH_3-emissions between 1980 and 2000 by 33%, mainly by adapting housing systems and by incorporating and injecting animal manure. With additional effort a reduction of 70% was thought to be achievable, basically by applying stronger versions of the same kind of measures but than on a larger scale. The study also mentioned the alternative of large scale processing of animal manure to a full substitute of chemical fertilizer, reflecting the believes of optimists about the potentials of technological innovation. Five years and 50 million guilders later (FOMA, 1995) it was concluded that that option might have been technically feasible but not compatible with the rules of a free market economy.

Table 2

Overview of RIVM scenario studies on NH_3-emissions from Dutch agriculture: application rates of measures and overall emission reduction in 2010 compared to the 1980 level.

Emission reducing measures	Concern for Tomorrow (1989)	2nd National Environmental Outlook (1991)	3rd National Environmental Outlook (1993)	4th National Environmental Outlook (1997)
	(%)			
Change N% in feed				
- cattle	+25	+10	+ 4	+5 / - 0
- pigs	- 1	- 10	- 20	- 10 / -20
- poultry	- 1	- 10	- 7	+ 22
Low NH_3 housing				
- cattle	0	0	0	25
- pigs	53	100	100	75
- poultry	72	100	100	70-90
Cover manure storage	0	100	100	100
Incorporate slurry on grassland	60	100	100	100
Incorporate slurry on arable crops	100	100	100	100
Manure processing	25-100	11-18	26/187	5
% Emission reduction 1980-2010	70	63	74	60

Subsequent scenario studies (see table 2) all came to the conclusion that all available technical measures need to be applied in order to reach emission levels that are compatible with targets for ecosystem protection. As more field data became available on the effectiveness of emission abatement techniques, the scenario studies became less optimistic about the actual emission reductions that each technique could achieve. This implies that larger cuts in the livestock production sector are needed to reach the emission targets. This means that farmers' resistance will grow and that the likelihood of reaching the targets diminishes as time goes by. The long term target, 80-90% emission reduction or a return to 1920 emission levels, seems to be out of reach forever.

2.6. Scientific developments in The Netherlands

Dutch policy makers have a number of concerns with respect to the ammonia problem, some of which can be dealt with by conducting more research. Policy makers are looking for new approaches to the ammonia problem, which is more attuned to region specific circumstances, such as the type of nature that is to be protected and the types of farming that are regionally dominant. A regional approach requires accurate region specific data on emissions, atmospheric transport, deposition and dose-effect-relations on vegetation. This means that research should pay more attention to uncertainty analysis, and verification of emission factors. For this a two year Nitrogen research program (STOP, Erisman et al., 1996) was financed. It addresses two main topics: (1) improvement of source-receptor relations on a local and regional scale, and (2) better understanding of causal ecological relations to improve critical load estimates for different ecosystems. Furthermore, RIVM currently runs a research project in which measured NH_3 concentrations in ambient air are compared to calculated concentrations based on estimated NH_3-emissions. Our uncertainty analysis seems to indicate that emission estimates are highly sensible to variations in emission factors of cattle stables. To establish better emission factors we need new and more accurate measuring techniques for stable emissions. A second area of research deals with the regional distribution of sources and receptors of ammonia. Since emission targets, which were derived from the present regional distribution patterns, seem unattainable in the next decades, it becomes interesting to examine alternative distribution patterns of the two which require less ambitious emission targets to protect ecosystems. These alternative patterns may become interesting policy options, especially when the public costs of relocating nature areas and/or farms are lower than the costs of increasing national emission reductions from 80 to 90%.

3. AMMONIA EMISSIONS IN EUROPE

Ammonia emission levels in Europe are generally much lower than in The Netherlands. But emission levels per hectare in the Po-valley (Italy), Brittany (France), Sleeswijk-Holstein (Germany) and Flanders (Belgium) are also far above the European average. The high concentration of animals in these regions is accountable for this situation.

3.1. Historic development of ammonia emissions in Europe

Historic data on NH_3-emissions in Europe are hard to come by and they show a large variation in accuracy, both over time and between countries. EMEP has compiled timeseries for all European countries from 1980. These data show that total European NH_3-emissions have remained stable around 5.6 billion kg NH_3 until 1989 and have then dropped 0.9 billion kg until 1994 (see table 3). Part of this reduction can probably be ascribed to improved estimation procedures but a substantial part is caused by reductions in the number of animals. In the EC the quotation of milk production led to a downward trend in cattle numbers. In former East-European countries animal numbers diminished as a result of the decay of the communist system. In both parts of Europe emission levels dropped by roughly equal amounts between 1989 and 1994.

Table 3

Development of NH_3-emissions in Europe between 1980 and 1994.

	1980	1985	1990	1994	'94-'80
	(mln kg NH_3)				
Netherlands	234	256	236	172	-62
EC-12	3217	3254	3031	2819	-398
EC-15	3683	3726	3475	3212	-471
Europe	5894	5936	5621	4936	-958

Source: EMEP/MSC-W, 1996.

3.2. Ammonia deposition and public awareness in Europe

The public awareness of the ammonia problem is probably highest in The Netherlands but even there it is not overwhelming. Most European countries have been reluctant to take action against ammonia emissions, simply because they are not aware of the problem. Research over the past five years, however, has led to new combinations of existing knowledge which gives a better view on the nature and size of the ammonia problem. This is related to the development of the concept of critical loads, which are indications for the maximum annual deposition of a certain agent that will not harm a chosen ecosystem. These critical N loads take account of physical and chemical conditions of soils, regionally specified targets for protected ecosystems and depositions from other acidifying (and atrophying) agents such as SO_2. The environmental damage from ammonia can be derived from critical loads for nitrogen, derived simultaneously from critical loads for acidification and eutrophication. Generally, the critical N load for eutrophication is lower than the one for acidification (Hettelingh et al., 1995). In the largest part of Europe (with the exception of Scandinavia, Italy and the east coast of the UK) ammonia depositions take more than 50% of total nitrogen deposition. In high emitting regions this share exceeds even 70%. This means that in large parts of Europe ammonia deposition contributes significantly to the excedence of critical nitrogen loads. Presently, total nitrogen depositions exceed critical N loads all over Europe, except in Ireland, the northern part of Scandinavia, southern Italy and the largest part of Greece. In the EC-15 more than 34% of the ecosystems (38 million hectares) were unprotected against eutrophication in 1990 (IIASA, 1996). The exceedence is highest in the centralwestern part of Europe (Germany, Denmark, Poland, Czech Republic, Austria, Switzerland, Luxembourg, Belgium, The Netherlands, and central England), with levels of more than 10 kg/ha (or 1 g/m^2) per year (Posch et al., 1997). More than half of this can be attributed to ammonia. This means that ammonia deposition is a substantial threat to endangered ecosystems all over Europe.

3.3. Ammonia policies in Europe

Emission abatement policies are always a response to a widely established public concern about possible harmful effects of emissions. Since ammonia emissions are generally low in Europe and people are generally unaware of its harmful effects, NH_3 abatement policies are rare in Europe. At present, only Flanders (Belgium), Denmark and The Netherlands have a national policy aiming to reduce NH_3 emissions. All countries prescribe special manure application methods which reduce volatilization of reduced nitrogen in manure. In The Netherlands this is supplemented by obligations to cover outside manure storage facilities and subsidies to built low emitting housing systems (see par. 2.3).

The effects of these measures are not clearly visible in reductions of NH_3 emissions because simultaneous changes in the number of livestock occurred. In Flanders livestock expansion outweighed the effect of low emission manure application. This increased average NH_3 emission from 70 to 80 kg/ha between 1985 and 1994. In Denmark the abatement measures were only partly counteracted by a 30% increase in pig and poultry numbers, resulting in a net reduction from 55 to 45 kg/ha in the same period (RIVM, 1996).

The lack of national ammonia policies in Europe does not imply that there is no political attention for the ammonia problem. The UN-ECE currently facilitates negotiations for a new Nitrogen Protocol, covering emissions from both oxidized (NO_x) and reduced nitrogen (NH_3) to the air. Information on critical nitrogen loads (see par. 3.2) and on technical potentials and costs of emission reductions for NO_x and NH_3 (see par. 3.5) provides the basis for these negotiations, which are expected to be completed in 1998.

3.4. Future trends in European ammonia emissions

Future developments of ammonia emissions are dependent on developments in livestock production and in application of emission control measures. Table 4 gives an overview of current reduction plans in the EC-15 countries and in non-EC Europe. These data have been derived from an inventory of officially declared national emission ceilings, collected on a routine basis by the Secretariat of the Convention on Long-range Transboundary Air Pollution (UN-ECE, 1995). In cases where no projection was supplied by a country for the target year 2010, emission ceilings were derived in accordance with the practice used for modeling work under the Convention. This means that target levels were derived from projections of livestock numbers and control measures.

Compared to the base year 1990, ammonia emissions in the EC-15 would be lower by about 15% and by 17% in the non-EC countries, see table 4. Reductions in Denmark (26%), Finland (27%), Germany (29%), and The Netherlands (66%) are far above the EC average. The reductions in Finland and (East) Germany, as in many other countries, are based on expected reductions in animal numbers only. Realization of these CRP's will increase the protection of ecosystems against eutrophication. The combined effect of the CRP's for NO_x and NH_3 are estimated to reduce the unprotected area of ecosystems in Europe from 18% in 1990 to 11% in 2010 (IIASA, 1996). Within Europe large regional differences will remain, however, with unprotected area of ecosystems ranging from more than 80% in Belgium, The Netherlands, West Germany, Belarus, Czech Republic, Lithuania, and Poland to less than 20% in, Ireland, UK, Norway, Sweden, Finland, Albania, Greece, Romania and Russia.

Table 4

Current reduction plans for ammonia emissions in EC-15 countries and in non-EC Europe in 2010, compared to emissions in 1990[a]).

Country	base year	target 2010	Change	Index	control
	(mln kg NH_3)			(index)	
Austria	91	93	2	102	
Belgium	95	106	11	112	yes[b])
Denmark	140	103	-37	74	yes
Finland	41	30	-11	73	
France	700	669	-31	96	
Germany(incl.DDR)	759	539	-220	71	
Greece	78	76	-2	97	
Ireland	126	126	0	100	yes
Italy	416	391	-25	94	
Luxembourg	7	6	-1	86	yes
Netherlands	236	81	-155	34	yes
Portugal	93	84	-9	90	
Spain	353	373	20	106	
Sweden	61	53	-8	87	yes
United Kingdom	320	270	-50	84	
EC-15	3516	3000	-516	85	
non-EC	4213	3484	-729	83	
EUROPE	7729	6484	-1245	84	

[a]) base year data, collected by UN-ECE, differ from EMEP data as presented in previous tables.

[b]) not mentioned in the IIASA study.

Source: IIASA, 1996

Table 4 also shows that very few countries are expected to take control measures to realize their reduction plans. According to a IIASA study all countries mentioned will apply more efficient application techniques for most types of manure, see table 5. This is a logical choice since it is the most cost-effective way to reduce NH_3 emissions. Stable adaptations are expected for laying hens in all countries and for other poultry and dairy cattle in Ireland, Luxembourg and The Netherlands. It is remarkable that no stable adaptations are foreseen for pigs. These stables are presently being built in The Netherlands and they prove to be a fairly cost-effective way to reduce NH_3 emissions. Biofiltration of stable air, on the other hand (and envisioned for The Netherlands), is still relatively expensive and might sooner be applied in cattle stables than for pigs. Covers on manure storages are applied to all manure types in The Netherlands but only to cattle and pig manure in Ireland and Sweden and to pig manure in Luxembourg. This might also be an interesting measure for countries which have limited time periods for manure spreading and thus need substantial manure storages. It is also seen as an appropriate (and thus not necessarily cost-effective) measure to offset potential acidifying side-effects of a eutrophication abatement measure. Given the overview of table 5 we see a large variation in control measures between the countries listed. This might suggest that there is no standard best approach to reducing ammonia emissions and that each country (andregion) needs to find its own appropriate measure mix.

Table 5

Ammonia emission control measures by country, assumed to realize the CRP's for 2010.

CONTROL MEASURES	Dairy cows	Other cattle	Pigs	Laying hens	Other poultry
Low Nitrogen Feed			Ireland		
			Luxembourg		
	Netherlands		Netherlands	Netherlands	Netherlands
Stable adaptation				Denmark	
	Ireland			Ireland	Ireland
	Luxembourg			Luxembourg	Luxembourg
	Netherlands		Netherl.[a])	Netherlands	Netherlands
				Sweden	
Biofiltration			Netherl.[b])		
Coverings for manure storage		Ireland	Ireland		
			Luxembourg		
	Netherl.[a])	Netherlands	Netherlands	Netherlands[a])	Netherlands[a])
	Sweden	Sweden	Sweden		
Low emission manure application	Belgium[a])	Belgium[a])	Belgium[a])	Belgium[a])	Belgium[a])
		Denmark	Denmark	Denmark	Denmark
	Ireland	Ireland	Ireland	Ireland	Ireland
	Luxembourg	Luxembourg	Luxembourg	Luxembourg	Luxembourg
	Netherlands	Netherlands	Netherlands	Netherlands	Netherlands
				Sweden	Sweden

[a]) my addition; not mentioned in the IIASA study.

[b]) considering technical circumstances I question this assumption.

[c]) the source also mentions application to sheep manure in Luxembourg, The Netherlands and Sweden but I question the applicability of this technique to this manure type.

Source: IIASA, 1996.

3.5. Scientific developments

Recently, new protocols have been developed to arrive at uniform NH_3-emission estimates throughout Europe (EEA, 1996) but the results still have to find their way to the various emission databases. It is clear that the availability of statistical data form the largest obstacle to more adequate emission estimates, not insufficient knowledge of underlying chemical and physical processes.

Accurate data bases on current ammonia emissions in European countries are needed as a starting point for multilateral negotiations on emission reductions. Corinair provides such a data base but harmonization is still needed to attain comparable data. Countries apply different estimation procedures to arrive at national emission estimates. The simplest procedure uses fixed emission factors (obtained from literature) per animal, distinguishing only between crude categories such as cattle, sheep, horses, pigs and poultry. The second stage procedure uses nation specific emission factors, and possibly increasing the number of animal categories. In the third stage emission factors are applied to a mathematical description of the nitrogen flow in farming systems. This allows calculation of the effects of applied emission abatement techniques. As application of these techniques increases over time, average emission factors will also differ between years. In a fourth stage, emission factors take account of the N composition of feed rations or excreta. Most European countries currently apply first or second stage estimating procedures for NH_3-emissions. Some countries, like Belgium (Flanders), The Netherlands, and the UK use third stage procedures. The fourth stage procedure is still only being developed at research stations in The Netherlands and it may take several years before we will see field application.

Table 6

Application of estimating procedures for NH_3 emissions in Europe since 1980.

Estimating procedure	before 1985	1985 -1990	1990 - 2000	after 2000
1. general emission factor, few animal categories	Netherlands		most European countries	
2. nation specific emission factors		Netherlands		
3. time specific emission factors			Belgium Netherlands United Kingdom	
4. feed ration specific emission factors			research stations	Netherlands ?

Various research centers in Europe study emission processes of ammonia, especially in the United Kingdom, Denmark, Germany and The Netherlands. There is more than average attention in The Netherlands and the UK for new techniques to measure NH_3-emissions from naturally ventilated stables. Scientists in the UK specialize in modeling evaporation of NH_3 after manure spreading in the field. German researchers seem more interested in measurements of NH_3 emissions from pig and poultry stables. Actually, scientists all over Europe continue to improve their techniques to better measure ammonia volatilization at each stage of the nitrogen cycle. This provides the basis for improved emission inventories in the (near) future.

REFERENCES

1. Breemen, N. van, P.A. Burrough, E.J. Velthorst, H.F. Dobben, T. de Wit, T.B. Ridder, H.F.R. Reinders (1982) 'Soil acidification from atmospheric ammonium sulfate in forest canopy throughfall', in: *Nature*, 299: 548-550.
2. EEA (1996) Joint EMEP/CORINAIR Atmospheric Emission Inventory

Guidebook, first edition. Vol. 1-2. Copenhagen, Denmark.

3. Erisman, Jan-Willem, Roland Bobbink and Ludger van der Eerden, eds. (1996) Nitrogen pollution in the local and regional scale; the present state of knowledge and research needs. Bilthoven: RIVM, report no. 722108010.
4. FOMA (1995) Jaarverslag 1994 [Annual Report]. Wageningen: Financierings-Overleg Mest- en Ammoniakonderzoek.
5. Heij, G.J. and T. Schneider (eds.) (1991) Dutch Priority Program on Acidification. Eindrapport tweede fase additioneel programma verzuringsonderzoek. Bilthoven: RIVM, report no. 200-09.
6. Hettelingh, J-P, M. Posch, P. de Smet and R.J. Downing (1995) *The use of critical loads for emission reduction agreements in Europe*, in: Water, Air and Soil Pollution **85:2381-2388**.
7. IIASA (1996) Cost-effective Control of Acidification and Ground-Level Ozone, Second Interim Report to the European Commission, DG-XI. Working Document, December 1996.
8. LNV en VROM (1990) Plan van Aanpak Beperking Ammoniak Emissies van de landbouw [Ammonia Policy]. Tweede Kamer, vergaderjaar 1990-1991, 18225, nr.42 en 43. Den Haag: SDU-uitgeverij.
9. MSC-W (1996) MSC-W Status Report 1996, part One; Estimated dispersion of acidi- fying agents and of near surface ozone. EMEP/MSC-W Report 1/96, Oslo: MSC-W.
10. Oudendag, D.A. en J.H.M Wijnands (1989) Beperking van de ammoniak-emissie uit dierlijke mest; een verkenning van mogelijkheden en kosten. [Reducing ammonia emissions from manure; an exploration of possibilities and costs] Den Haag: LEI, Onderzoeksverslag 56.
11. Posch, M, J-P. Hettelingh, P.A.M. de Smet, R.J. Downing (eds.) (1997) Calculation and mapping of critical thresholds in Europe; status report 1997. Bilthoven, The Netherlands: RIVM-CCE (in preparation).
12. RIVM (1989) Concern for Tomorrow, National Environmental Outlook 1985-2010. Bilthoven: RIVM, pp.456.
13. RIVM (1991) Second National Environmental Outlook 1990-2010. Alphen a/d Rijn: Samsom H.D. Tjeenk Willink, pp.550.
14. RIVM (1993) Nationale Milieuverkenning 3, 1993-2015. Alphen a/d Rijn: Samsom H.D. Tjeenk Willink, pp.167.
15. RIVM (1996) Milieubalans 96, Het Nederlandse milieu verklaard [Environmental

Balance 1996, explaining the Dutch environment] Alphen a/d Rijn: Samsom H.D. Tjeenk Willink, pp.142.

16. VROM (1989) Bestrijdingsplan Verzuring [Acidification Policy] Tweede Kamer, vergaderjaar 1988-89, 18225, nr.31. Den Haag: SDU-uitgeverij.