Status Report

PAST AND FUTURE EMISSIONS OF AMMONIA IN EUROPE

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SR-91-01
March 1991

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Part 1 of a Report to:
Ministry for Public Housing,
Physical Planning and Environment
P.O. Box 450
Leidschendam
The Netherlands
on
Project No. 64.19.23.01

SR—91—01
March 1991

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Acknowledgements

The author would like to thank Willem Asman (National Environmental Research Institute, Roskilde), Rod Shaw and Markus Amann (IIASA), Henk Hannessen and Klaas de Winkel (VROM), Jo Wijnands (Agricultural Economics Research Institute, The Hague), Nico Hoogervorst and Klaas van der Hoek (RIVM) for their valuable comments. I am also indebted to Onno Kuik (Institute for Environmental Studies, Amsterdam) for the specification of the emission coefficients for dairy cows. I wish to acknowledge Nikolay Nikolov and various other national experts for providing their forecasts. Financial support from the Netherlands Ministry of Housing, Physical Planning and the Environment (VROM) is greatly acknowledged. The views expressed in this paper are not necessarily those of VROM.

Abstract

The ammonia emissions of the RAINS model are presented. Sources of ammonia considered are: livestock farming, fertilizers, industry, human population and other anthropogenic sources. Data on emission factors are based on recent insights in the Netherlands but are adapted to account for country-specific elements such as: stall period, N_excretion, and the age and weight distribution. Ammonia emissions in 1980 in 26 European countries and Turkey are estimated at 7960 kilotons; 10 per cent higher than Buijsman et al. (1987) estimated. Ammonia emissions in 1987 are 8143 kilotons. This is 15 per cent lower than Asman (1990) suggested but corrsonds fairly well with EMEP estimates. Country and source specific estimates, however, are more uncertain: differences between 5 and 40 per cent are possible. Estimates for cattle and fertilizer are major sources of divergencies. Based on national agricultural forecasts and trend analysis, future emissions of NH_3 are expected to increase with 8 per cent (over 1980) to 8620 kiloton in 2000.

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PAST AND FUTURE EMISSIONS OF AMMONIA IN EUROPE

Ger Klaassen[1]

> "Man is the only creature that consumes without producing. He does not give milk, he does not lay eggs, he is too weak to pull the plough, he cannot run fast enough to catch rabbits. Yet he is lord of all the animals. He sets them to work, he gives back to them the bare minimum that will prevent them from starving and the rest he keeps for himself."
> (George Orwell, *Animal Farm,* 1945)

1 Introduction

Acidification of the environment caused by atmospheric deposition is one of the serious environmental problems in Europe. In addition to sulphur compounds, nitrogen compounds contribute to acidification in the form of nitrogen oxides (NO_x) and ammonia (NH_3). Ammonia contributes more than 40 per cent to the total anthropogenic emissions of nitrogen in Europe. The share of ammonia in the total nitrogen deposition in Europe may even be higher in specific regions and varies between 30 and 90 per cent.

NH_3 can cause both direct and indirect effects on the environment. Direct effects can occur if vegetation is exposed to high concentrations in the air over long periods of time (Ministry of Housing, Physical Planning and Environment, 1986). This mainly takes place in the direct vicinity of NH_3 sources. The damage resulting from ammonia usually has an indirect cause in which four different mechanisms can play a role:

1. Acidification of soils, and eventually groundwater, through conversion of NH_3 via ammonium into nitrate.
2. Supplanting of nutrient ions such as magnesium and calcium by ammonium resulting in a shortage of these ions for the plant.

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3. Eutrophication of nutrient poor regions. Consequently, many plant species characteristic of poorly buffered environments may disappear (Roelofs et al., 1987).
4. NH_3 promotes the deposition of SO_2 because, for example, tree needles become basic due to NH_3 deposition. Because basic needles react more strongly than acid needles to SO_2, a higher SO_2 deposition takes place.

The The Regional Acidification INformation and Simulation (RAINS) model developed at IIASA combines information on several stages of the acidification processes in the environment: the sources of emissions and the potential for their abatement, the atmospheric transport and the environmental effects of acid deposition (Figure 1) (Alcamo et al., 1990). These impacts are evaluated on a regional scale for the whole of Europe for forest stands, forest soils and lakes. In doing so, the model includes the pathways of the main precursors of acidification: SO_2, NO_x and NH_3. So far, however, no explicit sub module has been incorporated into RAINS that describes the sources of ammonia emissions and their development over time.

This paper describes the NH_3 emission module as incorporated in RAINS. It is an updated and extended version of previous work (Klaassen, 1990a). In addition, the data on emission coefficients are presented and elucidated and some results are shown. The remainder of the paper is organized as follows. Section 2 describes the overall set up and algorithm. Section 3 presents the emission coefficients for livestock farming and Section 4 the coefficients of nitrogen fertilizer. Industrial emission coefficients, and the emissions of human population and other sources, are explained in Section 5. Section 6 compares RAINS estimates for 1980 and 1987 with other national and international estimates. Section 7 projects the development of ammonia emissions to the year 2000.

2 The emission module

The emission module distinguishes the following sources of ammonia emissions:

1. Livestock farming:
   - dairy cows
   - other cattle (including buffaloes)
   - pigs
   - laying hens
   - broilers (all other poultry, including turkeys and ducks)
   - sheep (including goats)
   - horses.

2. Nitrogen fertilizer consumption.
3. Industry (fertilizer and ammonia production plants).
4. Other anthropogenic sources (i.e. human respiration).

Other anthropogenic sources, of minor importance, are: human respiration, cats and dogs, sewage sludge, wild animals, traffic and coal combustion. Natural soils are an additional source. Generally NH_3 emissions are calculated as a product of the emission coefficients and the level of activity (livestock population, fertilizer consumption and production, human population). The emissions are calculated from 1960 up to the year 2000, in time steps of five years. The following description uses the indices i and l, to describe the nature of the parameters:

i	the type of animal
l	the country

Ammonia from livestock farming is released during three basic processes:

- in the stable and during storage of manure,
- during the application of manure,
- in the meadow or grazing period.

These processes are explicitly distinguished in the model since this enables the possibility to calculate the potential of emissions that can be reduced through abatement measures such as: direct application of manure into the soil, cleaning of stable air and covering of manure storage facilities. The (unabated) ammonia emissions from livestock farming ($NH_3L_{i,l}$) are therefore calculated using the following equation:

$$NH_3L_{i,l} = (nh3s_{i,l} + nh3a_{i,l} + nh3m_{i,l}) * QL_{i,l} \quad (2.1)$$

In which:

$nh3s_{i,l}$	emission coefficient of stable
$nh3a_{i,l}$	emission coefficient of application
$nh3m_{i,l}$	emission coefficient meadow
$QL_{i,l}$	animal population

This equation is used for each of the seven animal types.

Ammonia emissions resulting from the consumption of nitrogen fertilizer (NH_3F_l) depend on the amount of fertilizer used and the nitrogen loss per fertilizer:

$$NH_3F_l = nf_l * 17/14 * QF_l \qquad (2.2)$$

In which:

nf_l	the nitrogen loss per fertilizer
QF_l	the fertilizer consumption

Since the nitrogen loss is expressed as per cent of the total nitrogen in the fertilizer, the factor 17/14 is used to convert the losses expressed in nitrogen into ammonia. Note that fertilizer use and losses are country specific.

Industrial ammonia emissions are mainly related to the production of fertilizer and ammonia. The total industrial ammonia emissions (NH_3P_l) are therefore the product of the production of nitrogen fertilizer in each country and the emission coefficient:

$$NH_3P_l = nh3p * QP_l \qquad (1.3)$$

With:

nh3p	the emission coefficient for industry
QP_l	N_fertilizer production

Other sources of ammonia are: human respiration, cats and dogs, sewage sludge, wild animals, traffic, natural soils and coal combustion. Of these sources human respiration is explicitly incorporated. Remaining anthropogenic sources are included insofar as national data are available. However, emissions of natural soils are ignored in view of the large uncertainties in their order of magnitude (Buijsman et al., 1987). Buijsman et al. (1987) estimate total Europe wide ammonia emissions from natural soils at 750 kilotons of ammonia per year. This would be 10 per cent of the total ammonia emission in Europe. Other sources (NH_3O_l) are incorporated in the following manner:

$$NH_3O_l = nh3h * QH_l + Cnh3_l \qquad (2.4)$$

With:

nh3h	emission coefficient human population
QH_l	size human population
$Cnh3_l$	constant for other anthropogenic emissions

3 Emission coefficients for livestock animals

3.1 Introduction

In the past, several overviews have been made that describe ammonia emissions in Europe (Bonis, 1980; Buijsman et al., 1987; Asman, 1989; Iversen et al., 1990). However, Buijsman et al. (1987) probably underestimated their emission calculations since for most countries their results go back to research in the Netherlands on the nitrogen content of excretion carried out in 1978 (Sluijsmans et al., 1979). Country-specific data were used only for Denmark and the United Kingdom. In view of more recent information (De Winkel, 1988; Möller and Schieferdecker, 1989) on the nitrogen content of the excretion, the estimate made by Buijsman et al. (1987) needs revision. Further, estimates by EMEP (Iversen et al., 1990) are, with a few exceptions, based on Buijsman et al., (1987) multiplied by a factor of 1.2. Finally, a weak spot of the emission calculations by Asman (1990) although based on recent insights, is that they are typical for one country, the Netherlands, but are used to calculate emissions for every country. In view of the large differences in agricultural practices, this seems inappropriate.

In contrast to the detailed information available about emission factors for NH_3 in the Netherlands, data on ammonia emission factors based on country-specific elements, such as nitrogen excretion and volatilization of ammonia, is available only for a few other European countries:

- Finland (Niskanen et al., 1990; Pipatti, 1991),
- the former German Democratic Republic (Möller and Schieferdecker, 1989),
- the Netherlands (Erisman, 1989; Van der Hoek, 1989; De Winkel, 1988),
- the United Kingdom (ApSimon et al., 1989; Eggleston, 1991).

For other countries, estimates are based on general rather than country-specific emission factors:

- Czech and Slovak Federal Republic (Zavodsky and Mitosinkova, 1984),
- Denmark (Schröder, 1985; Laursen, 1989),
- Federal Republic of Germany (excluding the former GDR) (Isermann, 1990),
- Hungary (Bonis, 1981),
- Norway (Bockmann et al., 1990).

Or they are based on the same, probably outdated, estimates of the nitrogen content that were used by Buijsman (1987). Examples are: the Federal Republic of Germany (Fabry et al., 1990), France (Allemand, 1991), Italy (Gaudioso et al., 1991) and Switzerland (Stadelmann, 1988). Table 1 presents an overview of national estimates.

Therefore this study's starting point is the more recent information on emission coefficients in the Netherlands, summarized in Table 2. These emission coefficients are based on the work of a group of scientists, established in the Netherlands, to evaluate the present knowledge and to obtain more consistent and improved estimates on emission factors for NH_3 from livestock farming (De Winkel, 1988; Van der Hoek, 1989; Hannessen, 1991). For the most relevant animal categories the working group has derived average annual emission factors per animal. Emission factors for stall and storage, manure application and the meadow period were based on the application of nitrogen mass balances.

Their principle approach can be summarized in four equations:

$$N\_excretion = N\_feed - N\_retention \quad (3.1)$$

$$N\_stable = N\_excretion * volatilization\_s \quad (3.2)$$

$$N\_application = (N\_excretion - N\_stable) * volatilization\_a \quad (3.3)$$

$$N\_meadow = N\_excretion * volatilization\_m \quad (3.4)$$

The results of nutritional research were used to compute the nitrogen content of the feed per animal (N_feed) as well as the retention of nitrogen (N_retention) in various animal products such as meat and milk. As a result the nitrogen remaining in the excretion (N_excretion) could be calculated. The volatilization of ammonia in the stall and during storage of manure (volatilization_s), or in other words the loss of nitrogen, was determined by looking at the difference between the N/P ratio in excrements and in stored manure. P is regarded as a conservative component, whereas N may evaporate as NH_3. The volatilization of ammonia can then be computed from changes in the N/P ratio during storage. Where possible the average emissions factors per animal were differentiated for different housing systems using recent emission measurements (Hannessen, 1991; Van der Hoek, 1989). The volatilization coefficient of ammonia (volatilization_a) during application (N_application) and during the grazing or meadow period (volatilization_m) was based on experiments described in the literature and additional experiments carried out by various research groups. The more detailed results for the Netherlands are included in Appendix I. These results have been summarized per animal category (dairy cows, other cattle, pigs, laying hens, broilers, sheep and horses) using data for 1988 on the composition of the animal population in the Netherlands (Central Bureau of Statistics, 1989) and are presented in Table 2.

The remaining sections will explain how the emission coefficients of Table 2 were modified for several livestock categories to arrive at country-specific emission coefficients.

3.2 Emission coefficients for dairy cows

Regarding dairy cows, the major elements influencing emission factors are:

- feed composition, amount and its nitrogen content,
- retention of nitrogen in milk and meat,
- volatilization of ammonia in the stable,
- volatilization of ammonia during application,
- volatilization of ammonia in the meadow period.

Van Dijk and Hoogervorst (1984) indicate that the share of grass in the total feed consumption differs among countries. Moreover, the nitrogen content of the grass will differ since the amounts of nitrogen fertilizer applied on a pasture varies between countries (CEC, 1989). In addition, international statistics show that large differences in the annual milk production per cow exist. This suggests that the retention of nitrogen in milk might differ considerably amongst countries. As a result, the nitrogen content of the excretion is likely to vary between countries. The volume of ammonia emitted in the stall and during storage depends on the volatilization coefficient and the stall period. The number of days spent in the stall varies (Asman, 1990). In Austria, for example, the meadow period is 109 days whereas in the Netherlands it is 175 days. Method of storing manure, stable type and type of manure (liquid/solid) are other factors affecting ammonia volatilization in the stall. Although differences amongst countries do exist, lack of data (Asman, 1990) does not allow to quantify the impact of these other factors on the volatilization. Emission during application depends on factors such as the type of manure (liquid/solid), soil type, temperature, wind speed and method of applying manure (Isermann, 1990). In summary, on the one hand it does not seem appropriate to use the emission coefficients from the Netherlands for other countries. On the other hand, for only a few of the potentially large number of factors affecting emissions, data is available.

To compute country-specific emission coefficients for dairy cows in RAINS we decided to take into account differences in the level of nitrogen fertilizer application as well as differences in meadow and stall period. For both these elements data was available on a country by country basis. Moreover, the differences in meadow periods were thought to be relevant because they influenced the volume of NH_3 emissions released during stall, application and meadow period. Consequently, this affects the potential of emissions to be abated and the related abatement costs, which is the subject of another part of the RAINS model (Klaassen, 1990).

The method that has been used is the following. A recent study (Baltussen et al., 1990) indicates that there is a relationship between the nitrogen excretion of dairy cows and the nitrogen level of grassland. The nitrogen level of grassland is, to a large extent, determined by the amount of fertilizer applied. Based on data for the Netherlands the following relation has been estimated:

$$N\_excretion = 126.22252 + 0.1932 * N\_fertilizer \qquad (3.5)$$

In which N_excretion is the nitrogen excretion per animal and N_fertilizer is the fertilizer use per hectare. This relation has been used to estimate the N_excretion for other countries in Europe. The relation between the N_excretion per dairy cow in the Netherlands and the other countries is then used to correct the Netherlands emission factors. Details on the method and the data used are provided in Appendix II. For some countries national data on N_excretion (Switzerland; Menzi, 1991) or on emission coefficients (Finland; Pipatti, 1991) were used directly.

In addition, the amount of N_excretion produced in the meadow period and the stall period has been corrected using information on the meadow periods in several countries in Europe (Asman, 1990). This is based on the following equations:

$$N\_excretion\ stall = N\_excretion * st\ period/st\ period\ NL \qquad (3.6)$$

$$N\_excretion\ meadow = N\_excretion * meadow\ period/meadow\ NL \qquad (3.7)$$

where st period is the stall period in the specific country (in days) and st period NL is the stall period in the Netherlands (in days/year). Using equations (3.5) to (3.7) and data on the volatization factors based on De Winkel (1988), country-specific emission coefficients for stall, application and meadow have been calculated for dairy cows. Details are provided in Appendix II.

The resulting emission coefficients are presented in Table 3 (column 1). Total emission coefficients vary between 24.0 kg NH_3/animal per year and 35.5 kg NH_3/animal per year, mainly due to the differences in fertilizer level. The coefficients for stall, application and meadow differ roughly by a factor of two. These differences considerably influence the potential for abatement in the various countries. It is recalled however, that we were not able to take into account all the relevant factors. Differences in milk yield, for example might influence the ammonia emissions considerably (see Appendix VII). However, one should be aware that it proved impossible to take into account all the relevant circumstances that potentially influence the level of the emissions. For example, ammonia emissions in Southern European countries might be underestimated since manure is usually stored outside as solid manure. Although the nitrogen content of the excretion might be less, this method of storing manure is likely to increase the ammonia emission again.

3.3 Other cattle

For other cattle there also may be differences among countries regarding the nitrogen content of the feed, nitrogen retention in meat, and the volatilization during stall and storage, and the application of manure. Due to a lack of data, we were only able to take into the composition of the category other cattle (in young cattle, fattening calves etc.) to calculate country-specific coefficients on the basis of the emission coefficients for the Netherlands. For Finland, national data were used. The results are summarized in Table 3 (column 2). Details are supplied in Appendix III.

3.4 Pigs, laying hens, broilers and horses

For these animals, the nitrogen content of the excretion may differ among countries due to differences in the nitrogen content of the feed and nitrogen retention. In addition, the ammonia emitted from stall and manure might vary due to differences in stall type (mechanical/natural ventilation for example; Asman, 1990) and manure storage system. Differences in stable and manure handling systems are likely to cause differences in ammonia emissions from the stall, especially for laying hens. However, the stall period will not differ too much since pigs and poultry are usually inside the whole year (Asman, 1990). The losses of ammonia during application may also differ in view of differences in the usual factors affecting ammonia volatilization during application. Due to lack of data, we used the data from the Netherlands (Table 2) for each country for laying hens, broilers and horses. For pigs we took into account the weight- and age distribution to arrive at country-specific emission coefficients (see Table 3, column 3 and Appendix IV), based on the detailed emission coefficients as reported by the Netherlands. For Finland (Niskanen et al., 1990) and the United Kingdom (Eggleston, 1991) national data were used.

3.5 Sheep

For sheep, differences in meadow period and the composition of the sheep flock over sheep and goats have been taken into account to arrive at country-specific factors. The Netherlands emission factors (Table 2) were modified as follows. Ammonia losses (as kg NH_3 per animal per year) in the stall

(N_stall), during application (N_application), and in the meadow (N_meadow) are calculated as follows:

$$N\_stall = N\_excretion * stall\ period * 0.12 * 17/14 \quad (3.8)$$

$$N\_application = N\_excretion * (1-0.12) * stall\ period * 0.25 * 17/14 \quad (3.9)$$

$$N\_meadow = N\_excretion * meadow\ period * 0.12 * 17/14 \quad (3.10)$$

where N_excretion is the nitrogen content in the excretion per animal per year in the Netherlands. The stall period is expressed as part of the year. 0.12 is the part of the nitrogen in the excretion that is released as ammonia in the stall (Equation 3.9) as well as in the meadow (Equation 3.10). During application, a share of 0.25 is released of the nitrogen in excretion, taking into account the loss that already occurred in the stable (1 - 0.12). The N_excretion used is 9.8535 kg N/animal per year for sheep (including lambs) and 15.567 kg for goats. All data is based on Van der Hoek (1989). Using the above equations, data on the meadow period (derived from Asman, 1990: see Appendix V) and the number of sheep and goats in each country, the average emission coefficients for the category sheep in each country have been calculated (Table 3, column 4). For the United Kingdom we used national data (Eggleston, 1991).

Table 3 shows that emission coefficients vary between 1.7 kg NH_3 per animal per year (Belgium) and 3.0 kg NH_3 per animal per year (Finland) as a result of differences in meadow period and the ratio between sheep and goats. One should realize, however, that the data on nitrogen excretion and volatilization factors were still based on Dutch data.

3.6 A comparison with other emission coefficients

Table 4 compares the results of the emission coefficients used in RAINS with the other estimates. The RAINS emission coefficients for dairy cows are generally below the ones of Möller and Schieferdecker (1989) and the recent Dutch ones (Table 2). Neither Buijsman et al. (1987) nor Asman (1990) explicitly distinguish between dairy cows and other cattle. The emission coefficients for other cattle are somewhat lower than Möller and Schieferdecker (1989) but in line with the Netherlands. The average, country-specific emission coefficients in RAINS for cattle (dairy cows and other cattle) are difficult to compare with the other estimates since they depend on the share of dairy cows in the total cattle stock. For pigs, RAINS estimates are comparable with the ones reported in the literature. The emission coefficients for poultry (laying hens and broilers) are difficult to compare since RAINS distinguishes between laying hens and other poultry. Estimates in RAINS for sheep are below the ones provided by Buijsman et al. (1987) and Möller and Schieferdecker (1989) but comparable with Asman (1990) and the Netherlands. Emission coefficients for horses are in between both other estimates. Major differences and uncertainties appear to exist especially for cattle. For the other animals RAINS estimates are comparable with the (wide) ranges observed in the literature.

4 Fertilizer use

Ammonia emissions released when nitrogen fertilizer is applied depend on elements such as: the type of fertilizer, soil pH and cation exchange capacity, drying conditions and irrigation. In this study we use the average emission coefficients for each type of fertilizer as used by Buijsman et al., (1987) and Asman (1990). Using information on the type of fertilizer for each country (Buijsman et al., 1985; FAO, 1989a), average N_losses as ammonia from fertilizer have been determined (Table 5). The emission factors that have been used per type of fertilizer are presented in Table 6. For countries where no specification was available on the type of fertilizer used, an average loss of 5 per cent was assumed. For the former GDR the average percentage loss is based on Graf (1991). Appendix VI gives details on the composition of the fertilizer use in each country upon which these average emission factors were determined.

Recently, it was suggested that the uncertainty in the ammonia losses from fertilizer is higher than previously thought (e.g. Eggleston, 1991). The losses for other nitrogen fertilizer, other complex, and not specificied N_fertilizer, vary by a factor of five (Buijsman et al., 1987; Asman., 1990). The lower values appear to be more in line with Graf (1991). Differences might be due to the local mixture applied (Table 6). The difference between calcium ammonium nitrate and ammonium nitrate might be less important (losses could be 5 per cent for both types of fertilizer). The differences between various types of ammonium phosphate, however, might be important. Because urea is an ammonium carbonate solution, it is expected to have a high loss, although it is not used very much. Summarizing, the N_loss for certain types of fertilizer (ammonium nitrate ad ammonium phosphate) is subject to discussion. Moreover, losses do not only depend on fertilizer type but also on temperature and soil type.

5 Industry and other anthropogenic sources

Ammonia production and fertilizer plants are the main sources of industrial ammonia emissions. Following Buijsman et al. (1987) we assumed the total production of ammonia plants in each country to be proportional to the fertilizer production. Emission coefficients for ammonia plants are taken as 0.8 kg NH_3 /ton fertilizer produced (Ministry of Housing, Physical Planning and Environment, 1983). According to the same source, emission factors for fertilizer plants may vary between 0.01 kg NH_3 per ton and 12.5 kg NH_3 per ton produced. As Buijsman et al., (1987) we assumed an average coefficient of 5 kg NH_3/ton fertilizer produced. As a result, the total emission coefficient used for industrial ammonia sources is 5.8 kg NH_3/ton fertilizer produced.

For human population (respiration) we use an emission coefficient of 0.3 kg NH_3/head (Buijsman et al., 1984; Erisman, 1989). For the other anthropogenic sources, different national sources have been used to estimate these (Stadelmann, 1988; Möller and Schieferdecker, 1989; Erisman, 1989; Niskanen et al., 1990). The amount of emissions as caused by the other sources included in RAINS at present are generally negligible. In all cases natural sources were excluded since the emission coefficient is very uncertain. Natural sources and sewage sludge, however, might make not insignificant contributions to the total ammonia emissions (e.g. Allemand, 1991; Eggleston, 1991). The order of magnitude of sewages sludge and natural sources is, however, believed to be too large to make a reliable estimate at this moment.

6 A comparison of past estimates

The ammonia emissions for 1980 and 1987 were calculated using the emission coefficients of Table 2 and 3, and data on livestock population, fertilizer consumption and production, as well as human population. Data on livestock population and fertilizer use is from FAO (1990a, 1990b) and national livestock statistics for Belgium, Luxembourg and the USSR (Institute Economique Agricole, 1989; Statistical Board of the USSR, 1989). Human population data are based on United Nations (1989a, 1989b) and estimates of IIASA's Population Program for the EMEP (European Monitoring and Evaluation Program) part of the USSR. The data on the USSR refer only to that part of the USSR that is within the grid used by EMEP. That is, the USSR republics Ukraine, White Russia, Georgia, Azerbajdzjan, Lithunia, Moldavia, Latvia, Armenia, Estonia and that part of the RSFSR (Russia) which is within the EMEP grid. For fertilizer use, data of the British Sulphur Corporation (1987) were used. These data is uncertain and require improvement.

Table 7 compares the estimates of various authors on a country-by-country basis. Since the authors make different assumptions on which parts of the USSR are included in their calculations, estimates for the USSR show wide differences. We compare the total estimates for Europe excluding the USSR. Table 7 shows that the RAINS estimates for 1980 are some 10 per cent higher than those of Buijsman et al.,(1987). The estimates for 1987 are comparable with the EMEP estimates (Iversen et al., 1990) but are some 15 per cent lower than those by Asman (1990). The Table also indicates that IIASA estimates for 1980 are considerably higher for some countries (for example: the Netherlands, FRG, Poland) than the Buijsman et al. (1987) computation. For several countries (Turkey e.g.) the IIASA estimate is lower. Generally, IIASA estimates for 1987 are lower than the ones by Asman (1990) (for example, Spain, France and the FRG) but are sometimes higher (for example Norway). IIASA estimates are generally in good agreement with EMEP (for example CSFR, Hungary and the United Kingdom) but differ for some countries (for example France, Italy and Turkey). Estimates for countries as given by the various authors, show considerably larger differences (up to 40 per cent, for example FRG) than the estimates for Europe as a whole.

That large uncertainties exist in country estimates can also be concluded by comparing Table 1 (national estimates) with Table 7. IIASA estimates differ generally by 10 to 20 per cent with national estimates. These differences are not only due to the fact that other emission coefficients are used for livestock animals, but are also caused by the fact that in several national estimates include other sources such as natural soils. In view of the lack of fundamental data (nitrogen content feed, volatilization factors) for most countries, the calculation of country-specific ammonia emission coefficients using nitrogen mass balance remains difficult.

Table 8 compares the estimates by source, excluding the USSR. The Table shows that our estimates are higher than Buijsman et al. (1987) for 1980 since our estimate for pigs is higher and RAINS includes other sources (human respiration) as well. In contrast, our estimates for sheep are lower. Estimates for cattle, poultry and industry have the same order of magnitude. Our overall estimate for 1987 is roughly 10 per cent lower than the one by Asman (1990). The main reason is that our estimates for cattle and for fertilizer use are lower. This being so because we use country-specific emission factors for dairy cows which are generally lower than Asman's. For fertilizer consumption our estimates are lower chiefly because we take into account the difference in nitrogen loss between calcium ammonium nitrate and ammonium nitrate (Buijsman et al., 1985) and we use lower losses for other, unspecified fertilizers. Estimates for industry are higher since we include both fertilizer and ammonia production as sources. Figures for pigs, poultry, and sheep have the same order of magnitude but are somewhat different for pigs and poultry since we used recent Dutch data on the emission coefficients.

In sum, estimates for total European NH_3 emissions (excluding the USSR), as reported in the literature, are 15 per cent higher or lower than the IIASA estimates. Estimates for specific countries, and for specific source categories, however, can show considerably greater (up to 40 per cent) or smaller divergences (smaller than 5 per cent). Estimates for specific sources also show important divergencies. This is especially the case for cattle and fertilizer, where more fundamental research seems to be necessary. In addition, including other anthropogenic sources (such as human respiration or sewage sludge) and natural soils there appears to be a source of difference between national and international estimates.

7 Future ammonia emissions

Forecasting ammonia emissions requires projections for livestock population and fertilizer use. The forecasts on livestock population and fertilizer consumption (Tables 9 and 10), as far as possible, are based on national forecasts from various agricultural research institutes or universities. Country-specific estimates were not available in international studies (Alexandratos, 1990) or were considered outdated (Politiek and Bakker, 1982). If no country-specific data were available, trends as observed in the period 1979–1988 were extrapolated. Where necessary, trends were adjusted to bring the forecasts in line with the regional forecasts of the OECD (Boonekamp, 1990) and the EC (Schäfer, 1990). Fertilizer production in 2000 was based on trend extrapolation. If necessary trends were adapted to reflect national estimates on future consumption patterns. Forecasts on human population were based on the UN medium scenario (United Nations, 1989b).

The resulting ammonia emissions for the year 2000 are shown in Table 11. They are based on the assumption that emission coefficients for ammonia remain constant over time. This may imply an underestimation of the emissions since yields/animal and consequently nitrogen excretion and ammonia emissions per animal might increase over time. According to Table 11, total ammonia emissions in Europe will increase from nearly 8000 kiloton in 1980 to more than 8600 kilotons in 2000. This implies an increase of 8 per cent.

Table 12 and Figure 2 show that the slight increase in ammonia up to the year 2000 results from two opposing trends. Emissions from cattle, notably dairy cows, will decrease considerably. In contrast, emissions from other livestock animals (pigs, poultry and sheep) and from fertilizer use, will increase if no abatement measures are taken.

The regional trend in ammonia emissions is as follows (see Figure 3). Emissions are expected to decline or stabilize in the EC-North (Belgium, Denmark, France, FRG, Ireland, Luxembourg, Netherlands and the United Kingdom), Scandinavia (Finland, Norway, Sweden) and Alpine countries (Austria, Switzerland). Mediterranean countries show a diffuse picture (Albania, Yugoslavia and Turkey). An increase is generally expected in EC-South (Greece, Italy, Portugal, Spain) and in Eastern Europe (Bulgaria, Czechoslovakia, GDR, Hungary, Poland, Rumania and the USSR).

There exists uncertainty in these estimates. Not only because differences exist between the estimates of emissions coefficients, but also because there is uncertainty in the forecasts. This is not only due to major uncertainties on the continuation of EC-policy (especially regarding dairy cows and potential new member states) but is also due to the structural changes in Eastern Europe. For the former GDR, for example, the national expert projection shows a drastic reduction in the number of livestock animals and fertilizer use. Using the estimates of Nikolov (1990) for livestock population, based on long term trend extrapolation, would generally show that ammonia emissions in Eastern Europe would rise even more. Emissions in Mediterranean countries (especially Turkey) might even increase. In summary, the results of the projections suggest that ammonia will continue to be an important source of acidification in Europe.

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Figures

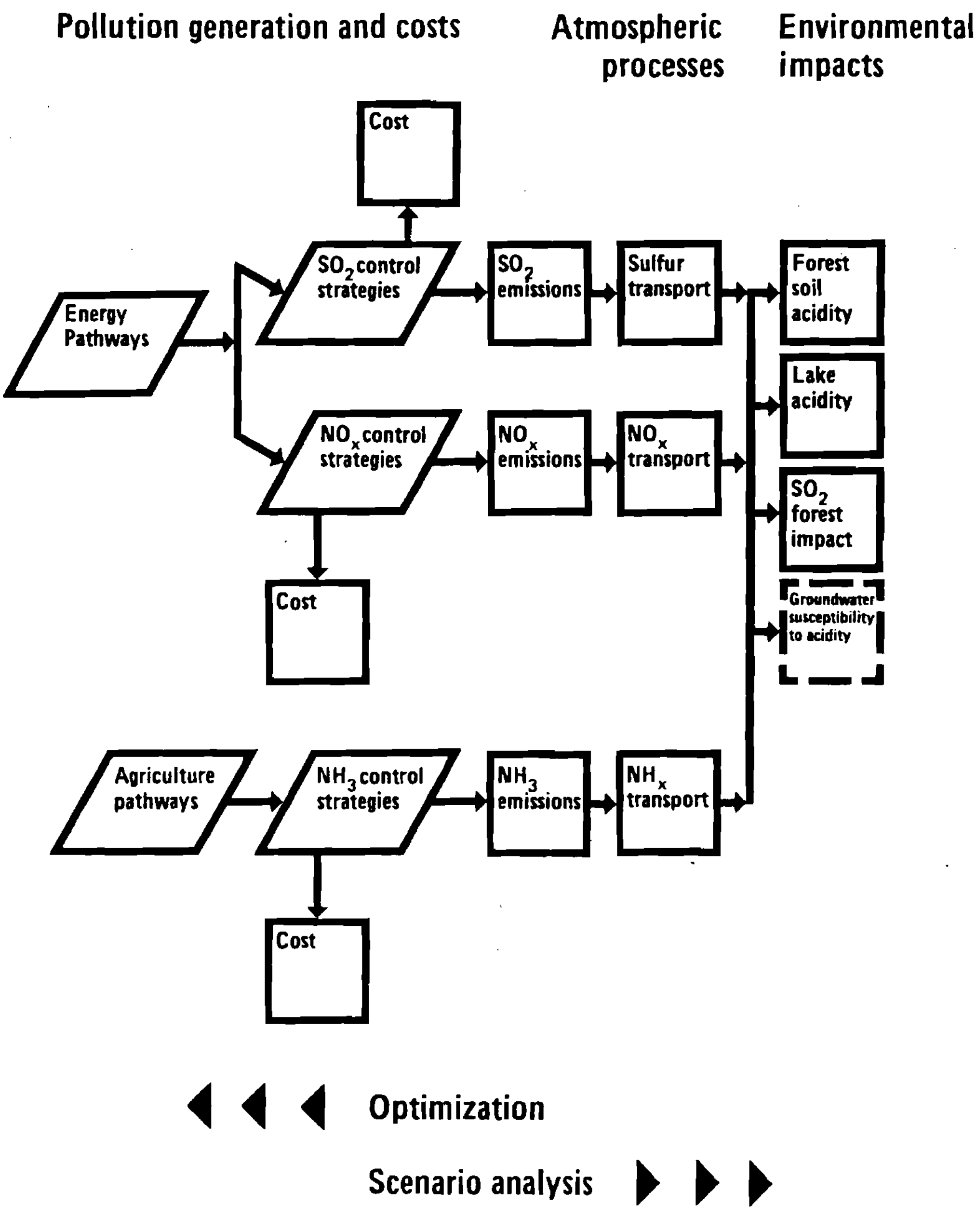


Figure 1 Flowchart of the RAINS Model.

FIG 2. NH3 BY SOURCE AND YEAR

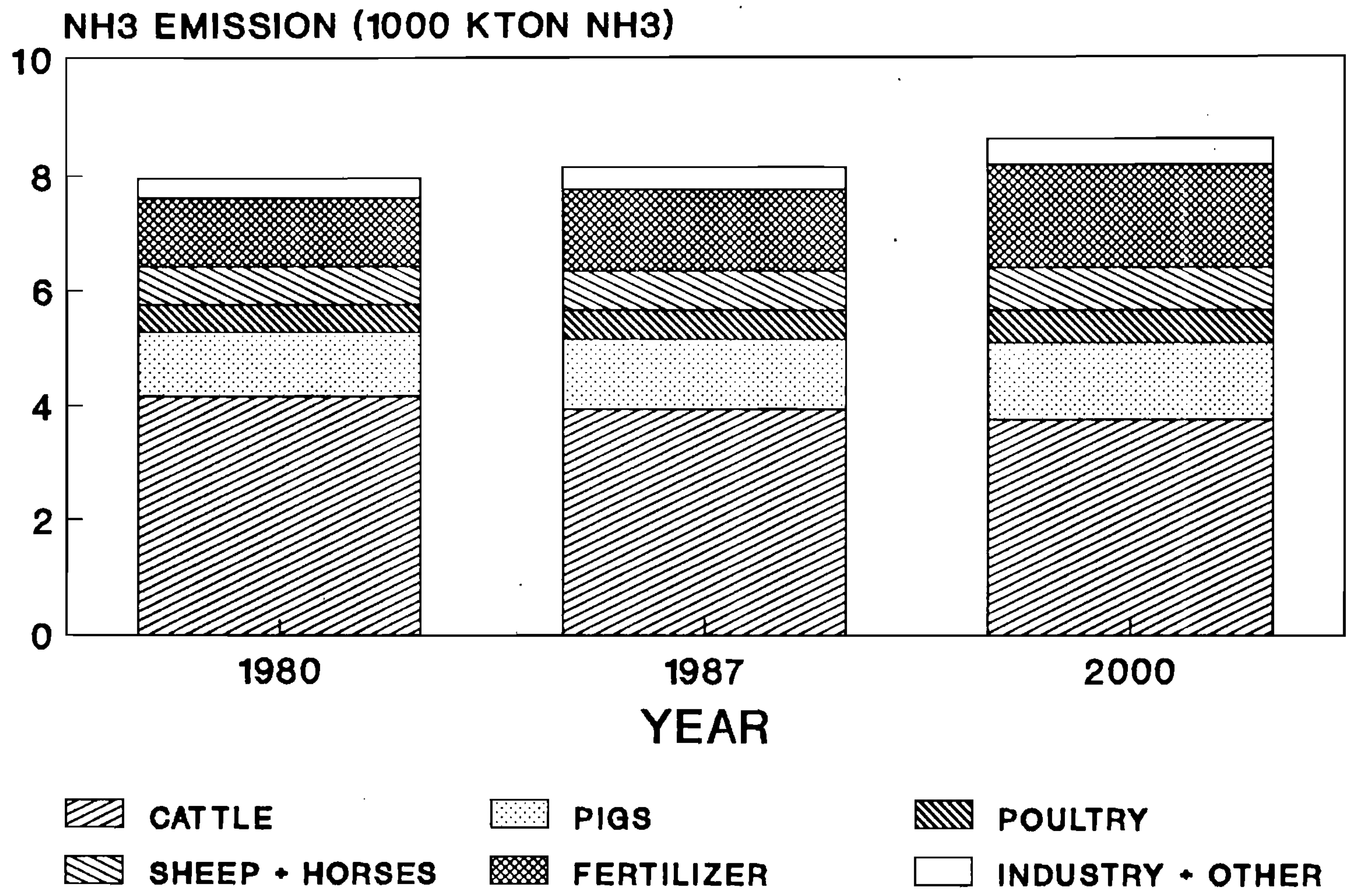
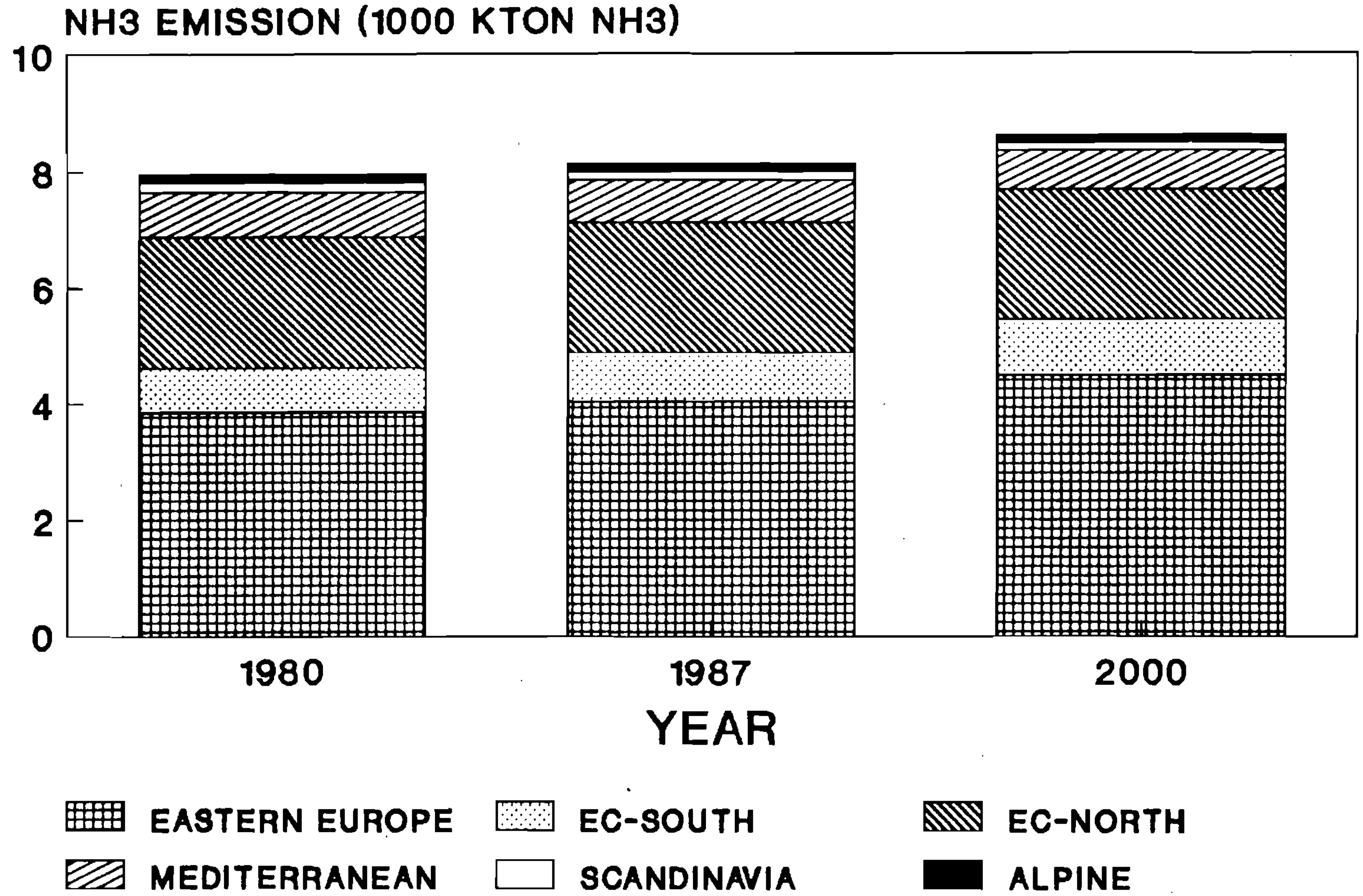


FIG 3. REGIONAL DEVELOPMENT



Tables

Table 1. National NH_3 estimates

ESTIMATE COUNTRY	NH_3 EMISSION (KTON NH_3)		YEAR	REFERENCE
CSFR	128–222	3)	1981	Zavodsky et al. (1984)
Denmark	106–138	2)	78/82	Sommer et al. (1984)
	196	1)	85/86	Schröder (1985)
	155	1)	1980	Laursen (1989)
Finland	52		84/86	Niskanen et al. (1990)
France	782	3)	1985	Allemand (1991)
FRG	348–360		1988	Fabry et al. (1990)
	641	1)	1986	Isermann (1990)
GDR	345–355	3)	80/85	Möller et al. (1989)
Hungary	90–157		1976	Bonis (1981)
	150	3)	80/87	Fekete (1991)
Italy	422		1987	Gaudioso et al. (1991)
Netherlands	258		1987	Erisman (1989)
	154		1982	Buijsman et al. (1984)
Norway	57	1)	80/89	Bockmann et al. (1990)
Switzerland	64	3)	1987	Stadelmann (1988)
UK	451	1)	83/84	ApSimon et al. (1989)
	560	3)	1987	Eggleston (1991)

1) Only agricultural sources.
2) Livestock manure only.
3) Includes emissions from natural sources.

Table 2. Emission coefficients for livestock animals in the Netherlands (per animal in kg NH_3/annum)

Subcategory	Emission coefficient			
	Stall/Storage	Application	Meadow period	Total
DAIRY AND CALF COWS	8.79	14.40	12.34	35.53
OTHER CATTLE	3.61	6.14	2.74	12.49
PIGS	2.27	2.85	0.00	5.12
LAYING HENS	0.14	0.18	0.00	0.32
BROILERS	0.07	0.11	0.00	0.18
SHEEP	0.39	0.71	0.96	2.06
HORSES	5.00	4.00	3.50	12.50

Data based on De Winkel (1988), Van der Hoek (1989) and Hannessen (1991). Horses based on Asman (1990). Detailed data have been aggregated using national livestock data for the Netherlands in 1988 (see Appendix I.) Other cattle are total cattle minus dairy cows. Sheep include goats. Broilers are total poultry minus laying hens and include turkeys and ducks.

Table 3. Emission coefficients RAINS (kg NH_3 per animal per year)				
COUNTRY	DAIRY COWS	OTHER CATTLE	PIGS	SHEEP AND GOATS
Albania	27.3	12.5	5.1	2.5
Austria	27.9	12.5	5.2	1.9
Belgium	26.4	14.1	5.3	1.7
Bulgaria	27.3	12.5	5.1	2.0
CSFR	32.0	12.5	5.1	2.0
Denmark	31.3	12.6	4.6	1.9
Finland	33.2	11.4	5.1	3.0
France	24.6	14.2	5.0	2.0
FRG	32.6	12.4	5.0	2.4
GDR	30.3	12.5	5.1	1.9
Greece	25.6	11.9	4.8	2.2
Hungary	24.6	12.5	5.1	1.9
Ireland	24.9	13.9	5.1	1.9
Italy	26.0	13.8	4.9	2.0
Luxembourg	29.9	14.5	5.0	2.5
Netherlands	35.5	12.5	5.1	2.0
Norway	33.7	12.5	5.1	2.9
Poland	27.8	12.5	5.1	1.9
Portugal	26.3	12.5	5.1	2.1
Romania	27.4	12.5	5.1	2.0
Spain	25.4	12.3	5.0	2.1
Sweden	30.2	12.5	5.1	2.9
Switzerland	32.9	13.3	4.2	2.1
Turkey	24.0	12.5	5.1	2.2
UK	26.5	14.8	5.1	2.7
USSR	24.3	12.5	5.1	2.0
Yugoslavia	25.2	12.5	5.1	1.9

Table 4. Comparison of emission coefficients (In kg NH_3 per animal per year)					
LIVESTOCK CATEGORY	RAINS (1991)	Buijsman et al. (1987)	Möller et al. (1989)	Netherlands (1988/1991)	Asman (1990)
DAIRY COWS	24.0–35.5	18.4	42.5	35.5	25.1
OTHER CATTLE	11.4–14.8	18.4	18.7	12.5	25.1
PIGS	4.2–5.3	2.8	6.3	5.1	4.8
LAYING HENS	0.32	0.26	0.27	0.32	0.32
BROILERS	0.18	0.26	0.27	0.18	0.32
SHEEP	1.7–3.0	3.1	3.6	2.1	1.9
HORSES	12.5	9.4	18.2	12.5	12.5

Table 5.	Average N_losses of fertilizers
COUNTRY	(% LOSS OF N_CONTENT)
Albania	6.0
Austria	1.7
Belgium	2.0
Bulgaria	5.0
CSFR	5.0
Denmark	1.7
Finland	1.3
France	2.7
FRG	3.4
GDR	3.3
Greece	5.8
Hungary	7.0
Ireland	3.8
Italy	5.8
Luxembourg	2.0
Netherlands	1.9
Norway	1.1
Poland	9.8
Portugal	4.2
Romania	5.0
Spain	4.6
Sweden	2.2
Switzerland	4.1
Turkey	6.5
UK	5.4
USSR	5.0
Yugoslavia	5.0

Table 6. Emission Factors for N_fertilizer (% loss of N_content)	
ammoniumsulphate	15
ammoniumnitrate	10
ammoniumsulphate nitrate	12.5
calcium ammonium nitrate	2
urea	10
ammoniumphosphate	5
other nitrogen fertilizer	1
other complex fertilizer	1
other not specified	1
Source: Buijsman et al. (1987) and Asman (1990).	

Table 7. NH_3 emission estimates per country (kton NH_3)

ESTIMATE	Buijsman et al.	IIASA	IIASA	Asman	EMEP
COUNTRY	(1987) 1980/83	1980	1987	(1990) 1987	(1990) 1988
Albania	21	25	27	32	24
Austria	72	79	79	107	85
Belgium	82	102	105	123	94
Bulgaria	126	122	120	123	147
CSFR	170	200	197	219	200
Denmark	111	116	103	144	129
Finland	44	56	49	61	43
France	709	679	650	974	841
FRG	371	529	533	718	380
GDR	207	228	239	274	242
Greece	95	88	100	111	112
Hungary	130	156	155	179	151
Ireland	117	128	128	188	139
Italy	361	359	366	435	426
Luxembourg	5	5	5	7	6
Netherlands	150	224	239	276	218
Norway	36	37	47	38	41
Poland	405	570	528	561	478
Portugal	47	66	65	76	55
Romania	301	297	340	387	350
Spain	232	251	317	365	273
Sweden	52	66	59	74	62
Switzerland	53	64	60	68	61
Turkey	683	532	476	573	699
UK	405	482	492	548	478
USSR	1256	2288	2446	1543	3182
Yugoslavia	198	214	217	235	235
EUROPE	6434	7961	8143	8439	9129
Europe minus USSR	5178	5676	5696	6903	5969

Note: Due to rounding total might differ from the sum.

Table 8. NH_3 estimates according to source (kton NH_3)

ESTIMATE	Buijsman et al. (1987)	IIASA	IIASA	Asman (1990)
SOURCE	early 80	1980	1987	1987
Cattle	2749	2813	2624	3560
Pigs	422	868	949	897
Poultry	325	339	344	436
Sheep	640	441	468	395
Horses	58	72	63	64
Fertilizer	881	867	959	1538
Industry	102	104	101	13
Other	0	172	188	0
Total	5178	5676	5696	6903

Note: excluding the USSR.
Due to rounding, total might differ from sum.

Table 9. Livestock population in 2000 (National reference pathway)
(In 1000 heads)

SECTOR COUNTRY		DAIRY COWS	OTHER CATTLE	PIGS	LAYING HENS	BROILERS	SHEEP	HORSES
Albania		288	503	269	3094	5330	3325	41
Austria	1)	905	1641	4545	8708	8558	231	46
Belgium	11)	600	1227	6829	5879	36681	287	10
Bulgaria	2)	654	1111	5214	15838	30005	9968	120
CSFR		1703	3656	5551	26353	23616	1500	31
Denmark		534	1011	8208	2639	10917	83	10
Finland	3)	363	711	1212	3379	6307	68	29
France		6079	14522	13448	67764	177367	10648	175
FRG		4645	11186	26975	37959	20933	1838	344
GDR	4)	1100	3750	10500	20141	19859	3200	170
Greece		271	224	1402	18280	31222	23976	20
Hungary	5)	585	1115	9960	25500	22560	3080	100
Ireland	6)	1400	5920	975	3763	9836	4896	35
Italy		2677	6710	9965	47792	100468	17344	209
Luxembourg		49	193	92	27	147	12	0
Netherlands	7)	1607	2663	12034	34695	39277	2199	59
Norway	8)	310	590	650	3600	1700	980	18
Poland		3801	3828	15127	35582	3775	5747	539
Portugal		394	850	1484	7518	19322	7355	20
Rumania		1982	6616	22446	57928	162810	26190	898
Spain		1428	4477	24922	44818	11287	34140	262
Sweden	9)	500	660	4100	6400	7382	427	60
Switzerland	10)	750	600	1700	2700	4600	480	55
Turkey		4207	3675	7	54838	17930	40049	380
UK		2935	7678	7944	40290	95023	34255	228
USSR		31405	54149	59459	263624	679061	52541	4891
Yugoslavia		2397	1692	9587	2352	103144	8563	147
TOTAL		73569	140958	264605	841461	1649117	293382	8897

1) Fischer (1990), except horses which is based on trend extrapolation. Dairy cows adjusted to reflect yield increase.
2) Nikolov (1990), horses based on trend extrapolation.
3) Kettunen (1990).
4) Münch (1990).
5) Csaki (1990).
6) Reidy (1990), horses based on trend extrapolation.
7) Hoogervorst (1991), horses follow trend.
8) Riseth (1990).
9) Bolin/Wahlgren (1990), horses based on trend extrapolation.
10) Schnetti (1990), horses based on trend extrapolation.
11) Kelchtermans (1989). Laying hens, horses follow trend.
12) All other countries based on trend extrapolation. However, the number of dairy cows in those EC-countries, for which no national forecast was available was corrected. This was in order to reflect the EC milk quota arrangements and to bring the projection for the total EC-12 in line with EC forecasts (Schäfer,1990).

Table 10. Fertilizer use in 2000 (National reference pathway) (In kton)

COUNTRY		CONSUMPTION	PRODUCTION
Albania		71	66
Austria		121	134
Belgium		189	739
Bulgaria	1)	665	1344
CSFR		623	574
Denmark		363	238
Finland	2)	180	277
France		3309	1195
FRG		1730	359
GDR	3)	360	792
Greece		530	581
Hungary	4)	650	595
Ireland	5)	380	397
Italy		917	1113
Luxembourg		12	0
Netherlands		444	2079
Norway	6)	110	373
Poland		1614	1855
Portugal		157	136
Romania		632	2369
Spain		1489	1052
Sweden		209	151
Switzerland	7)	70	34
Turkey		1598	968
UK		1966	989
USSR		11129	15482
Yugoslavia		608	913
EUROPE		30126	34805

1) Nikolov (1990).
2) Kettunen (1990).
3) Münch (1990).
4) Csaki (1990).
5) Reidy (1990).
6) Riseth (1990).
7) Schnetti (1990).
8) All other countries based on trend extrapolation of the period 1979–1988.

Table 11. Future NH_3 emission estimates per country (kton NH_3)				
YEAR COUNTRY	1980	1987	2000	Index 2000/1980
Albania	25	27	33	134
Austria	79	79	80	101
Belgium	102	105	90	89
Bulgaria	122	120	141	115
CSFR	200	197	191	95
Denmark	116	103	81	70
Finland	56	49	39	70
France	679	650	637	94
FRG	529	533	541	102
GDR	228	239	176	77
Greece	88	100	125	143
Hungary	156	155	161	103
Ireland	128	128	156	122
Italy	359	366	371	103
Luxembourg	5	5	5	100
Netherlands	224	239	209	93
Norway	37	47	31	83
Poland	570	528	476	84
Portugal	66	65	62	94
Romania	297	340	422	142
Spain	251	317	409	163
Sweden	66	59	59	89
Switzerland	64	60	52	81
Turkey	532	476	414	78
UK	482	492	509	105
USSR	2288	2446	2935	128
Yugoslavia	214	217	218	202
EUROPE	7961	8143	8620	108

Note: Due to rounding, totals might differ from the sum.

Table 12. Future NH_3 emissions by source (kton NH_3)

SOURCE	1980	1987	2000
Dairy cows	2373	2228	1928
Cattle	1783	1703	1825
Pigs	1125	1223	1338
Laying hens	270	272	270
Other Poultry	212	237	293
Sheep	545	571	629
Horses	127	120	110
Fertilizer	1170	1393	1781
Industry	140	156	202
Other	219	240	240
Total	7961	8143	8620

Note: Due to rounding, total might differ from sum.

Appendix I. Detailed Emission Coefficients

Table I.1	Detailed emission coefficients in The Netherlands. (Per animal in kg NH_3/annum)				
CBS No.	Subcategory	Emission Factor			
		Stable	Application	Meadow	Total
211	DAIRY AND CALF COWS	8.789	14.398	12.336	35.523
201–109	Youg cattle	3.869	6.339	4.253	14.461
213	Breeding bulls > 2 yr	10.579	17.391	0.000	27.970
215	Fattening calves	1.602	3.631	0.000	5.233
217–227	Young cattle for fattening	5.759	9.435	0.000	15.194
229	Fattening/grazing catle > 2 yr	0.000	0.000	12.336	12.336
Subtotal	OTHER CATTLE	3.609	6.140	2.741	12.489
235–237	Piglets < 20 kg (included in	0.000	0.000	0.000	0.000
239–241	239)	2.767	3.920	0.000	6.687
243	Fattening Pigs	1.604	3.006	0.000	4.610
245	Breeding pigs 20–50 kg	5.442	4.500	0.000	9.942
247–251	Breeding sows> 50 kg	8.094	8.036	0.000	16.130
253	Other sows	2.767	3.920	0.000	6.687
255	Boars > 50 kg	5.517	5.478	0.000	10.995
	Mature boars				
Subtotal	PIGS	2.269	2.852	0.000	5.121
265	Lambs (included in 266)	0.000	0.000	0.000	0.000
266	Ewes	0.700	1.280	2.090	4.070
268	Rams (included in 266)	0.000	0.000	0.000	0.000
282	Milch goats	2.300	4.100	0.000	6.400
284	Other goats (included in 268)	0.000	0.000	0.000	0.000
Subtotal	SHEEP	0.389	0.709	0.961	2.058
275	Laying hens < 18 weeks	0.55	0.126	0.000	0.181
276–277	Laying hens > 18 weeks	0.171	0.194	0.000	0.365
Subtotal	LAYING HENS	0.142	0.177	0.000	0.320
269	Slaughter chickens	0.065	0.104	0.000	0.169
271	Mother animals < 5 months	0.142	0.128	0.000	0.270
273	Mother animals > 5 months	0.314	0.283	0.000	0.597
287	Ducks	0.117	0.000	0.000	0.117
291	Turkeys for slaughter	0.429	0.429	0.000	0.858
293	Turkeys < 7 months	0.445	0.445	0.000	0.890
295	Turkeys > 7 months	0.639	0.639	0.000	1.278
Subtotal	OTHER POULTRY	0.069	0.107	0.000	0.176
260–263	HORSES (includes ponies)	5.000	4.000	3.500	12.500

CBS refers to the Netherlands Central Bureau of Statistics division Data based on de Winkel (1988), Van der Hoek (1989), Asman (1990) and Hannessen (1991).

Note: Due to rounding, total might differ from sum.

Appendix II. Emission coefficients dairy cows

A. N_Excretion and N_Fertilizer level

A recent study (Baltussen et al. 1990) shows that there is a relation between the nitrogen excretion of dairy cows and the nitrogen level of grassland. The nitrogen level of grassland is, to a great extent, determined by the application of artificial fertilizer. Table II.1 shows the relation for the Netherlands.

Table II.1 Relation N_fertilizer and N_excretion.

N_fertilizer (kg/ha)	N_excretion (kg/cow)
168	158
264	176
359	200
457	212

This table is derived using a number of assumptions in Baltussen (1990) on the number of calves per dairy cow, the stall type, the size of the farm (26 ha), the milk yield per cow (6000 kg/year), the fodder composition, the number of animals per hectare (2.4/ha) and the pasture time. The relation between the total N_level grassland and the N_excretion is shown in Table II.2.

Table II.2 N_excretion and total N_grassland.

N_level grassland (kg/ha)	N_excretion (kg/ha)
200	130
300	145
400	165
500	175

Part of the excretion is applied as manure on grassland (excretion in the stall period; 50 per cent of the N is effectively applied). The N_excretion per dairy cow (including young cattle) is around 200 kg N, of which 82 kg in the stall period. Effectively 41 kg N (50%) is applied as excretion on grassland. Since the average N_application of fertilizer is 346 kg/ha the total N_application in the Netherlands is some 400 kg/ha (346 + 41). Table II.3 shows the relation between N_level, N-excretion, N_organic effective and the N_fertilizer level.

Table II.3 N_level, N_excretion, N_organic and N_fertilizer.

N_level (kg/ha)	N_excretion (kg/ha)	N_organic effect (kg/ha)	N_fertilizer (kg/ha)
200	130	130/165*41 = 32	200–32 = 168
300	145	145/165*41 = 36	300–36 = 264
400	165	41	400–41 = 359
500	175	175/165*41 = 43	500–43 = 457

From Table II.3, Table II.1 can be derived. Of course one should note that the relation in Table II.1 is a specific one based on specific assumptions for the Netherlands.

From Table II.1 we can estimate the following function:

$$N\_excretion = 126.22252 + 0.1932 * N\_fertilizer \quad (1.1)$$

This function has been used to estimate the N_excretion of dairy cows in other countries. The ratio between the N_excretion per dairy cow in the Netherlands and the other countries has been used to arrive at country-specific emission coefficients for other countries.

The level of N_fertilizer use per hectare grassland in other European countries is based on data for the EC-9 countries (Van Dijk and Hoogervorst, 1982) and estimated for other countries as follows. The total N_fertilizer consumption per country is distributed over arable land and grassland as 2:1. This ratio was based on the fertilizer levels advised in various countries (see Table II.4) (CEC, 1989).

Table II.4 Maximum advised N_fertilizer levels (kg N/ha/year)(1988).

	Meadow		Arable land	
	Grass	Silage	Barley	Winter Wheat
Denmark	250	350	130	180
FRG	380	300	170	210
Ireland	390	325	140	210
Netherlands	400	400	–	200
United Kingdom	275	330	125	200

Taking the Netherlands as an example, we obtain the following. The N_fertilizer level was 240 kg N/ha. The area of grassland was 45 per cent, the area of arable land 55 per cent of total agricultural land. This gives the formula:

$$0.45 * N/grass + 0.55 * N/arable = 240 \quad (1.2)$$
$$N/grass = 2 * N/arable \quad (1.3)$$

With:

N/grass being the N_fertilizer level of grassland.
N/arable being the N_fertilizer level of arable land.

For the Netherlands, this implies that N/grass is 330 kg/ha and N/arable land is 165 kg/ha. This corresponds quite well with the real N_fertilizer level on grassland of specialized dairy farms; their fertilizer level on grassland was 346 kg/ha in 1986/87 (Baltussen, 1990). For Hungry it was taken into account that the N_fertilizer level of grassland is only 40 per cent of that of arbale land (Mészáros, 1991. Table II.5 (next page) shows the N_fertilizer levels that have been calculated using FAO statistics (FAO, 1989a; FAO, 1989b), Van Dijk and Hoogervorst (1982) and Mészáros (1991).

Using formula (1.1) the N_excretion per dairy cow in other countries has been estimated (see Table II.5, column 2). Table II.5 also shows an index used to correct the ammonia emission coefficients for dairy cows in the Netherlands (column 3). In calculating the ammonia emissions (see also Section B) an N_excretion per cow of 138.56 kg N/year was used for the Netherlands since this is the official figure (De Winkel, 1988) used to calculate the Netherlands emission coefficients. Hence the index in column 3 of Table II.5 relates to the 138.56 kg N. For Switzerland, however, data from Menzi et al. (1991) on the N_excretion per dairy cow were used directly.

B. Meadow periods and emission coefficients

The second change that has been made was to take account of the differences in meadow periods in various countries. Using the information on the nitrogen balance for dairy cows in the Netherlands (De Winkel, 1988), in combination with data on the meadow period (Asman 1989; Menzi et al., 1991) country-specific emission coefficients were derived. For this purpose we used the following specification of the equations (see main text equations (2.1 to 2.4)) that relate the NH_3 emission coefficients to the N_excretion:

$$N\_stable = 0.1324 * 17/14 * 54.44 * stall\ period/190 * N\_excretion/100 \quad (1.4)$$

$$N\_application = 0.25 * 17/14 * (1 - 0.1324) * 54.44 * stall\ period/190 * N\_excretion/100 \quad (1.5)$$

$$N\_meadow = 0.12 * 17/14 * 84.52 * meadow\ period/175 * N\_excretion/100 \quad (1.6)$$

In which:

N_stable	NH_3 emission coefficient stable
N_application	NH_3 emission coefficient application
N_meadow	NH_3 emission coefficient meadow
N_excretion	N in excretion in country i (index)

Stall period and meadow period are the periods in each country. N_excretion/100 refers to the index used to estimate N_excretion in other countries with the Netherlands being 100. 0.1324, 0.25 and 0.12 are the coefficients for volatilization. 54.44 is the N_excretion in the stall in the Netherlands. 84.52 is the N_excretion in the meadow in the Netherlands. The resulting emission coefficients, as well as the length of the meadow period in each country, are presented in Table II.5. In cases where no data on the stall period was available, the length was assumed to be 50 per cent of the year (compare Buijsman et al., 1987).

Table II.5	Dairy cows emission coefficients							
	KG N per ha pasture	N_excretion per cow	N_excretion index	Stall period	Emission Coefficients (kg/NH$_3$/animal per year)			
SECTOR COUNTRY	(kg/ha)	(kg N/year)	(NL = 100)	(days)	Stable	Applica-tion	Meadow	Total
Albania	108	147	78	183	6.6	10.7	10.0	27.3
Austria	50	136	72	255	8.5	13.9	5.6	27.9
Belgium	120	149	79	150	5.5	9.0	12.0	26.4
Bulgaria	107	147	78	183	6.6	10.8	10.0	27.3
CSFR	153	156	82	255	9.7	15.9	6.4	32.0
Denmark	150	155	82	241	9.1	15.0	7.2	31.3
Finland	164	158	84	240	9.3	15.2	7.3	31.8
France	32	132	70	183	5.9	9.7	9.0	24.6
FRG	130	151	80	292	10.8	17.7	4.1	32.6
GDR	191	163	86	183	7.3	11.9	11.1	30.3
Greece	60	138	73	183	6.2	10.1	9.3	25.6
Hungary	34	133	70	180	5.8	9.6	9.1	24.6
Ireland	40	134	71	183	6.0	9.8	9.1	24.9
Italy	70	140	74	183	6.2	10.2	9.5	26.0
Luxembourg	185	162	86	180	7.1	11.7	11.2	29.9
Netherlands	325	189	100	190	8.8	14.4	12.3	35.5
Norway	208	166	88	245	10.0	16.3	7.4	33.7
Poland	122	150	79	183	6.7	11.0	10.1	27.8
Portugal	79	141	75	183	6.3	10.4	9.6	26.3
Romania	109	147	78	183	6.6	10.8	10.0	27.4
Spain	54	137	72	183	6.1	10.0	9.3	25.4
Sweden	118	149	79	245	8.9	14.6	6.7	30.2
Switzerland	39	110	79	310	11.3	18.6	3.1	32.9
Turkey	50	136	72	150	5.0	8.2	10.9	24.0
UK	88	143	76	180	6.3	10.3	9.9	26.5
USSR	24	131	69	183	5.9	9.6	8.9	24.3
Yugoslavia	49	136	72	183	6.1	9.9	9.2	25.2

Note: Due to rounding, total might differ from sum.

C. Emission coefficients used

For all countries the data in Table II.5 were used in the calculations. For Finland, however, national data on the emission coefficients were used (Pipatti, 1991) since they reflect national agricultural practice better. Table II.6 summarizes the emission coefficients for dairy cows as they were used in this paper to calculate emissions.

Table II.6 Dairy cows emission coefficients ($KG\ NH_3$ per animal per year)

	PROCESS			
COUNTRY	Stall/Storage	Application	Meadow	Total
Albania	6.56	10.74	9.99	27.29
Austria	8.47	13.88	5.57	27.92
Belgium	5.47	8.97	11.96	26.41
Bulgaria	6.57	10.76	9.96	27.29
CSFR	9.71	15.91	6.39	32.00
Denmark	9.14	14.97	7.17	31.27
Finland	13.80	11.50	7.90	33.20
France	5.92	9.70	8.98	24.59
FRG	10.79	17.68	4.11	32.59
GDR	7.29	11.94	11.05	30.28
Greece	6.16	10.09	9.34	25.59
Hungary	5.84	9.56	9.15	24.55
Ireland	5.99	9.81	9.08	24.88
Italy	6.25	10.23	9.47	25.95
Luxembourg	7.12	11.66	11.15	29.93
Netherlands	8.77	14.37	12.32	35.45
Norway	9.93	16.31	7.44	33.70
Poland	6.69	10.93	10.15	27.80
Portugal	6.32	10.35	9.58	26.26
Romania	6.58	10.79	9.98	27.35
Spain	6.11	10.01	9.26	25.37
Sweden	8.92	14.61	6.66	30.19
Switzerland	11.32	18.55	3.06	32.94
Turkey	4.98	8.15	10.88	24.01
UK	6.30	10.32	9.87	26.48
USSR	5.85	9.59	8.87	24.31
Yugoslavia	6.07	9.94	9.20	25.22

Reference: Appendix II. Except Finland based on Pipatti (1991).
Note: Due to rounding, total might differ from sum.

Appendix III. Emission coefficients – other cattle

Table III.1 presents the emission coefficients for other cattle. They were derived from the Netherlands coefficients taking into account, however age and weight distribution, within the category pigs. For Finland national data were used (Pipatti, 1991).

Table III.1 Emission coefficients – other cattle (In kg NH_3 per animal per year)

	PROCESS			
COUNTRY	Stall/Storage	Application	Meadow	Total
Albania	3.61	6.14	2.74	12.49
Austria	3.32	5.66	3.47	12.45
Belgium	3.74	6.18	4.15	14.07
Bulgaria	3.61	6.14	2.74	12.49
CSFR	3.61	6.14	2.74	12.49
Denmark	3.44	5.79	3.38	12.61
Finland	4.80	3.90	2.70	11.40
France	3.48	5.71	5.01	14.20
FRG	3.41	5.82	3.21	12.44
GDR	3.61	6.14	2.74	12.49
Greece	2.53	4.38	4.99	11.90
Hungary	3.61	6.14	2.74	12.49
Ireland	2.93	4.80	6.15	13.88
Italy	3.50	5.83	4.42	13.75
Luxembourg	3.42	5.62	5.46	14.50
Netherlands	3.61	6.14	2.74	12.49
Norway	3.61	6.14	2.74	12.49
Poland	3.61	6.14	2.74	12.49
Portugal	3.61	6.14	2.74	12.49
Romania	3.61	6.14	2.74	12.49
Spain	2.57	4.42	5.27	12.26
Sweden	3.61	6.14	2.74	12.49
Switzerland	3.59	6.01	3.71	13.31
Turkey	3.61	6.14	2.74	12.49
UK	3.73	6.12	4.91	14.76
USSR	3.61	6.14	2.74	12.49
Yugoslavia	3.61	6.14	2.74	12.49

Appendix IV. Emission coefficients – pigs

Table IV.1 presents the emission coefficients for pigs. They were derived from the Netherlands coefficients taking into account, however age and weight distribution, within the category of pigs. For Finland and the United Kingdom national data were used (Niskanen et al., 1990; Eggleston, 1991).

Table IV.1 Emission coefficients – pigs
(In kg NH_3 per animal per year)

	PROCESS			
COUNTRY	Stall/Storage	Application	Meadow	Total
Albania	2.27	2.85	0.00	5.12
Austria	2.26	2.89	0.00	5.15
Belgium	2.32	2.99	0.00	5.31
Bulgaria	2.27	2.85	0.00	5.12
CSFR	2.27	2.85	0.00	5.12
Denmark	1.95	2.62	0.00	4.57
Finland	2.36	2.72	0.00	5.08
France	2.12	2.88	0.00	5.00
FRG	2.12	2.83	0.00	4.95
GDR	2.27	2.85	0.00	5.12
Greece	2.12	2.65	0.00	4.77
Hungary	2.27	2.85	0.00	5.12
Ireland	2.19	2.93	0.00	5.12
Italy	2.26	2.65	0.00	4.91
Luxembourg	2.03	2.96	0.00	4.99
Netherlands	2.27	2.85	0.00	5.12
Norway	2.27	2.85	0.00	5.12
Poland	2.27	2.85	0.00	5.12
Portugal	2.27	2.85	0.00	5.12
Romania	2.27	2.85	0.00	5.12
Spain	2.13	2.86	0.00	4.99
Sweden	2.27	2.85	0.00	5.12
Switzerland	1.81	2.38	0.00	4.19
Turkey	2.27	2.85	0.00	5.12
UK	1.34	3.76	0.00	5.10
USSR	2.27	2.85	0.00	5.12
Yugoslavia	2.27	2.85	0.00	5.12

Appendix V. Emission coefficients – sheep (and goats)

Table V.1 Sheep

SECTOR COUNTRY	Stall period (days)	Meadow period (days)	Emission Coefficients ($Kg\ NH_3$/animal per year)			
			Stable	Application	Meadow	Total
Albania	91	274	0.33	0.60	0.98	1.9
Austria	0	365	0.00	0.00	1.30	1.3
Belgium	0	365	0.00	0.00	1.30	1.3
Bulgaria	91	274	0.33	0.60	0.98	1.9
CSFR	91	274	0.33	0.60	0.98	1.9
Denmark	91	274	0.33	0.60	0.98	1.9
Finland	243	122	0.87	1.59	0.43	2.9
France	91	274	0.33	0.60	0.98	1.9
FRG	152	213	0.54	1.00	0.76	2.3
GDR	91	274	0.33	0.60	0.98	1.9
Greece	91	274	0.33	0.60	0.98	1.9
Hungary	91	274	0.33	0.60	0.98	1.9
Ireland	91	274	0.33	0.60	0.98	1.9
Italy	91	274	0.33	0.60	0.98	1.9
Luxembourg	91	274	0.33	0.60	0.98	1.9
Netherlands	91	274	0.33	0.60	0.98	1.9
Norway	243	122	0.87	1.59	0.43	2.9
Poland	91	274	0.33	0.60	0.98	1.9
Portugal	91	274	0.33	0.60	0.98	1.9
Romania	91	274	0.33	0.60	0.98	1.9
Spain	91	274	0.33	0.60	0.98	1.9
Sweden	243	122	0.87	1.59	0.43	2.9
Switzerland	91	274	0.33	0.60	0.98	1.9
Turkey	91	274	0.33	0.60	0.98	1.9
UK	0	365	0.00	0.00	1.30	1.3
USSR	91	274	0.33	0.60	0.98	1.9
Yugoslavia	91	274	0.33	0.60	0.98	1.9
EUROPE						

Source: Van der Hoek for the N_excretion, N_retention and volatization for sheep. Stall period is assumed 1/4 year (91 days) unless data (Asman, 1990) for other countries were available.

Table V.2 Goats						
SECTOR COUNTRY	Stall period (days)	Meadow period (days)	Emission Coefficients (Kg NH_3/animal per year)			
			Stable	Application	Meadow	Total
Albania	91	274	0.56	1.03	1.69	3.3
Austria	0	365	0.00	0.00	2.25	2.3
Belgium	0	365	0.00	0.00	2.25	2.3
Bulgaria	91	274	0.56	1.03	1.69	3.3
CSFR	91	274	0.56	1.03	1.69	3.3
Denmark	91	274	0.56	1.03	1.69	3.3
Finland	243	122	1.50	2.75	0.75	5.0
France	91	274	0.56	1.03	1.69	3.3
FRG	152	213	0.94	1.72	1.31	4.0
GDR	91	274	0.56	1.03	1.69	3.3
Greece	91	274	0.56	1.03	1.69	3.3
Hungary	91	274	0.56	1.03	1.69	3.3
Ireland	91	274	0.56	1.03	1.69	3.3
Italy	91	274	0.56	1.03	1.69	3.3
Luxembourg	91	274	0.56	1.03	1.69	3.3
Netherlands	365	0	2.25	4.13	0.00	6.4
Norway	122	243	0.75	1.38	1.50	3.6
Poland	91	274	0.56	1.03	1.69	3.3
Portugal	91	274	0.56	1.03	1.69	3.3
Romania	91	274	0.56	1.03	1.69	3.3
Spain	91	274	0.56	1.03	1.69	3.3
Sweden	122	243	0.75	1.38	1.50	3.6
Switzerland	91	274	0.56	1.03	1.69	3.3
Turkey	91	274	0.56	1.03	1.69	3.3
UK	0	365	0.00	0.00	2.25	2.3
USSR	91	274	0.56	1.03	1.69	3.3
Yugoslavia	91	274	0.56	1.03	1.69	3.3

Source: Van der Hoek for the N_excretion, N_retention and volatization for sheep. Stall period is assumed 1/4 year (91 days) unless data (Asman, 1990) for other countries were available.

Table V.3 Emission coefficients – sheep and goats (In kg NH_3 per animal per year)

	PROCESS			
COUNTRY	Stall/Storage	Application	Meadow	Total
Albania	0.42	0.77	1.27	2.46
Austria	0.00	0.00	1.86	1.86
Belgium	0.00	0.00	1.71	1.71
Bulgaria	0.34	0.62	1.01	1.97
CSFR	0.34	0.60	1.01	1.96
Denmark	0.33	0.60	0.98	1.90
Finland	0.90	1.65	0.45	3.00
France	0.35	0.64	1.05	2.04
FRG	0.56	1.02	0.78	2.35
GDR	0.33	0.60	0.98	1.91
Greece	0.38	0.70	1.15	2.24
Hungary	0.33	0.60	0.98	1.91
Ireland	0.33	0.60	0.98	1.91
Italy	0.35	0.64	1.05	2.03
Luxembourg	0.43	0.78	1.28	2.50
Netherlands	0.38	0.70	0.95	2.04
Norway	0.87	1.59	0.48	2.93
Poland	0.33	0.60	0.98	1.91
Portugal	0.36	0.65	1.07	2.08
Romania	0.34	0.62	0.01	1.97
Spain	0.36	0.66	1.08	2.10
Sweden	0.87	1.59	0.43	2.90
Switzerland	0.37	0.67	1.10	2.13
Turkey	0.38	0.71	1.15	2.24
UK	0.00	0.00	2.68	2.68
USSR	0.34	0.62	1.01	1.96
Yugoslavia	0.33	0.60	0.99	1.92

Note: Due to rounding, total might differ from sum.

Table V.3 summarizes the average emission coefficients for sheep that have been used in the computations. They were based on Tables V.1 and V.2 and the ratio between sheep and goats in the various countries. For the United Kingdom data from Eggleston (1991) were used.

Appendix VI. Consumption of N_Fertilizer types

Table VI.1 Consumption of N_fertilizer types

SECTOR COUNTRY	QUANTITIES Total Fertilizer (TON)	ammonium sulphate	ammonium nitrate	ammonium sul nitrate	calcium ammonium nitrate	urea	ammonium phosphate	other nitrogen fertilizer	other complex fertilizer	other not specific
Albania	66100		33050		33050					
Austria	165072	308			93924	1275		6043	63522	
Belgium	197758	4778		155	123511	698		5720	62896	
Bulgaria	418000									418000
CSFR	589000									589000
Denmark	381263	380	17333		82041	4432		90416	186661	
Finland	214353	5			21156	4442		6615	182135	
France	2568400	40900			1111900	287500		544700	583400	
FRG	1601435	116686		81261	1009775		84573	10709	298431	
GDR	773900	193475			286343	247648				46434
Greece	425000	56443	127466		53050	6610			181431	
Hungary	613827	296	224143		120743	171087		14682	82876	
Ireland	343000	3963	2403		130457	84690			121487	
Italy	1059044	67699	10517		195607	430506		26192	328523	
Luxembourg	197758	4778		155	123511	698		5720	62896	
Netherlands	458210	1394	0		364608	2467	1037	13558	75146	
Norway	113600					1300		15200	97100	
Poland	1335421	88885	787312		0	349279	71699	494	37752	
Portugal	148489	21844	0	3132	70474	6071	3372	853	42743	
Romania	720000								720000	
Spain	1147800	105006	38230	31004	311606	185332		72340	404282	
Sweden	240866	46	21974		51176	5126		66639	95905	
Switzerland	72600	1800	0		39900	17400	1600	400	11500	
Turkey	1110732	97263	217152		217152	246340	84376		248450	
UK	1314000		642260		33740			54000	584000	
USSR	11787000									11787000
Yugoslavia	52100								521000	
	8375981	560953	6061603	117487	94794	1505299				

Source: FAO (1989, p 89). GDR based on Möller et al. (1989).
Quantities for 1987/88. If no data available, then data of previous years were used. Data of Buijsman (1985) were used to determine the distribution between ammonium nitrate and calcium ammoniumnitrate. If no data were available, a 50/50 split was assumed (ALB,TUR).

Appendix VII. Emission coefficients dairy cows in relation to milk yield

A seperate analysis was carried out to investigate the relation between milk yield, N_excretion and emission coefficients for ammonia. The results are displayed in Table VII.1. The following method was employed.

First of all, the fodder demand per cow in fodder units per cow per day (VEM) was related to the standard milk yield (kg/cow per year, using equations 7.1 and 7.2).

$$M = (0.4 + 0.15V) * m \qquad (7.1)$$

With:
M: Standard Milk yield (standardized to a 4 per cent fat content) (kg/year)
m: real milk yield (kg/year)
V: fat content of the milk (%)

$$VEM = 5013 + 440 * M + 0.7293 * M^2 \qquad (7.2)$$

VEM: Fodder Units Dairy Cows (Kg/day)

Secondly, N_intake via fodder in the meadow period and stall period were related to the Fodder demand in VEM units per day, the length of the stall and meadow period and the N_intake per VEM unit for the Netherlands.

N_intake stall = VEM * stall period * 0.00003082 (7.3)

N_intake meadow = VEM * meadow period * 0.0000482862 (7.4)

Both stall period and meadow period are in days.

Thirdly, the N_retention in milk, meat and calf were calculated:

N_retention stall = N_content milk * M * stall period/365 + C-stall (7.5)

With:
N_content milk: 0.0054 (kg N/kg milk)
C-stall : 0.95 (kg N retained in calf)

N_retention meadow = N_content milk * M * meadow period/365 + C-meadow (7.6)

With:
N_content milk: 0.0054 (kg N/kg milk)
C-meadow : 0.75 (kg N retained in meat)

Fourthly, the N_content of the excretion was calcluated. For both the meadow and the stall period the following equation was used:

N_excretion = N_intake – N_retention (7.7)

Finally, using the calculated N_excretion in the meadow and stall period (see column 5 and 6 in Table VII.1) the emission coefficients for ammonia can be calculated.

$$N\_stable = 0.1324 * 17/14 * N\_excretion\ stall \quad (7.8)$$

$$N\_application = 0.25 * 17/14 * (1 - 0.1324) * N\_excretion\ stall \quad (7.9)$$

$$N\_meadow = 0.12 * 17/14 * N\_excretion\ meadow \quad (7.10)$$

In which:

N_stable	NH_3 emission coefficient stable
N_application	NH_3 emission coefficient application
N_meadow	NH_3 emission coefficient meadow
N_excretion	N in excretion in country i

The results are given in Table VII.1. One should note that the following, simplifying assumptions were made:

- N_ content of the fodder (kg N/kg) for all countries is equal to that of the Netherlands.
- ratio summer/winter production of milk per day is equal to the Netherlands.
- the fat content of the milk is based on EUROSTAT (1990) for the EC-12 countries; for all other countries the fat content is 3.75 per cent.
- the volatilization coefficients are equal to those of the Netherlands.
- ratio VEM/ real fodder demand is equal.

Table VII.1 Emission coefficients in relation to milk yield.										
SECTOR	Milk yield per cow	Fat content	Standard milk yield	VEM/ cow/day	N_excretion stall	N_excretion meadow	NH_3 stall/cow	NH_3 meadow/ cow	NH_3 application/ cow	NH_3 total/ cow
COUNTRY	(kg/cow)	(%)	(kg/cow)	(kg/cow)	(kg/cow)	(kg/cow)	(kg/cow)	(kg/cow)	(kg/cow)	(kg/cow)
Albania	1412	3.75	1359	6661	33	54	5	8	9	21.8
Austria	3818	3.75	3675	9517	59	44	10	6	16	31.6
Belgium	4122	3.74	3961	9874	36	89	6	13	9	28.0
Bulgaria	3488	3.75	3357	9122	41	70	7	10	11	27.6
CSFR	3857	3.75	3712	9564	60	44	10	6	16	31.7
Denmark	5992	4.31	6271	12787	73	65	12	9	19	40.3
Finland	5062	3.75	4872	11016	63	56	10	8	16	34.7
France	3011	3.87	2952	8620	40	67	6	10	10	26.5
FRG	4816	3.97	4794	10918	77	33	12	5	20	37.2
GDR	4566	3.75	4395	10417	45	78	7	11	12	30.7
Greece	1794	3.51	1662	70320	34	56	5	8	9	22.5
Hungary	4822	3.75	4641	10726	46	82	7	12	12	31.3
Ireland	3859	3.53	3587	9407	42	72	7	10	11	28.1
Italy	3600	3.55	3357	9121	41	70	7	10	11	27.4
Luxembourg	4122	3.98	4110	10060	44	78	7	11	12	29.9
Netherlands	5733	4.29	5982	12421	56	89	9	13	15	36.6
Norway	5716	3.75	5502	11811	68	58	11	8	18	37.0
Poland	3154	3.75	3036	8723	40	67	6	10	10	26.7
Portugal	2597	3.40	2363	7892	37	62	6	9	10	24.5
Romania	2026	3.75	1950	7385	35	59	6	9	9	23.5
Spain	3353	3.45	3076	8773	39	67	6	10	10	26.5
Sweden	6010	3.75	5785	12168	69	59	11	9	18	37.9
Switzerland	4773	3.75	4594	10667	79	24	13	3	21	37.0
Turkey	596	3.75	574	5706	24	57	4	8	6	18.5
UK	4737	3.92	4680	10775	46	83	7	12	12	31.6
USSR	2426	3.75	2335	7858	37	62	6	9	10	24.6
Yugoslavia	1781	3.75	1714	7096	34	57	6	8	9	22.8