Working Paper

COST FUNCTIONS FOR CONTROLLING AMMONIA EMISSIONS IN EUROPE

Ger Klaassen

WP–90–71
November 1990

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Foreword

Strategies to reduce regional acidification in Europe will require reductions in emissions of sulphur, nitrogen oxides and ammonia. The Transboundary Air Pollution Project (TAP) has been expanding the Regional Acidification Simulation and Information (RAINS) model to include nitrogen compounds. Ger Klaassen from the Free University of Amsterdam has joined TAP to incorporate emissions and control costs for ammonia compounds into the RAINS model. This working paper, and his companion paper on ammonia emissions in Europe, represent the preliminary results in this very important step in our work.

Bo R. Döös
Leader, Environment Program

Roderick W. Shaw
Leader, Transboundary Air Pollution Project

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Abstract

This paper presents a submodule which computes the costs of controlling ammonia emissions in 27 European countries. The submodule will be incorporated into the RAINS (Regional Acidification INformation and Simulation) model. Abatement options included are low nitrogen feed, stable adaptations, covering manure storage, biofiltration and low nitrogen applications of manure. Cost estimates are based on country-, animal-, and technology specific data such as the stable size and fertilizer price, manure production per animal and the investments per animal place. Results are shown as costs functions for the year 2000 for Finland and the Netherlands. They suggest that ammonia emissions in Finland could be reduced by 30% over the 1980 level at costs of 3 million DM per year only. Associated marginal costs would be 2300 DM/ton abated ammonia. A similar reduction in the Netherlands would cost 130 million DM per year. Marginal costs would be 4400 DM/ton ammonia abated. Using best available technologies, ammonia emissions in Finland could be reduced by nearly 55%, and in the Netherlands by 65% over the 1980 level. The cost functions show that up to a 50% reduction over the 1980 level, marginal costs are relatively low. For further reductions, costs are expected to increase sharply since more expensive techniques have to be applied.

Contents

I. INTRODUCTION . . . 1

II. OPTIONS TO CONTROL AMMONIA EMISSIONS . . . 2
- A. Introduction . . . 2
- B. Livestock farming . . . 2
- C. Industrial emissions . . . 4

III. LOW NITROGEN FEED AND ADAPTATIONS OF STABLE AND STORAGE . . . 4
- A. Introduction . . . 4
- B. The algorithm . . . 5
  - Investment costs . . . 5
  - Fixed operating costs . . . 5
  - Variable operating costs . . . 6
  - Unit costs of NH_3 control . . . 6
- C. Low nitrogen feed . . . 7
- D. Adaptations during stable and storage . . . 8
  - Stable adaptations . . . 8
  - Covering manure storage facilities . . . 10
  - Biofiltration or bioscrubbing . . . 10

IV. APPLICATION OF MANURE . . . 11
- A. Introduction . . . 11
- B. The algorithm . . . 12
- C. The costs of low nitrogen application . . . 14

V. COSTS OF COMBINATIONS . . . 15

VI. INDUSTRIAL PROCESS EMISSIONS . . . 15

VII. RESULTS . . . 15
- A. Future emissions without abatement . . . 15
- B. Average costs per animal and per ton ammonia abated . . . 16
- C. Cost functions . . . 17

REFERENCES . . . 19

APPENDIX I. COSTS OF LOW N-FEED 41
A. DAIRY COWS 41
B. PIGS 41
C. LAYING HENS 41
D. BROILERS 42

APPENDIX II. COSTS OF STABLE ADAPTATIONS 42
A. DAIRY COWS 42
B. PIGS 42
C. LAYING HENS 43
D. BROILERS 44

APPENDIX III. COVERING MANURE STORAGE 45
A. DAIRY COWS AND OTHER CATTLE 45

APPENDIX IV. BIOFILTRATION AND BIOSCRUBBING 46
A. PIGS 46
B. LAYING HENS AND BROILERS 48

APPENDIX V. LOW MANURE APPLICATION 48

APPENDIX VI. ADDING ACID TO MANURE 49

APPENDIX VII. COMBINATIONS OF TECHNIQUES 50

COST FUNCTIONS FOR CONTROLLING AMMONIA EMISSIONS IN EUROPE[1]

I. INTRODUCTION

Acidification of the environment caused by atmospheric pollution is one the major environmental problems in Europe. Not only sulphur compounds but also nitrogen compounds contribute to acidification in the form of nitrogen oxides (NO_x) and ammonia (NH_3).

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. 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. Since the RAINS model is designed as a tool for the assessment of the efficiency of different pollution control strategies, the analysis of removal potential and the associated control costs forms an essential part of the model. At present cost functions for controlling SO_2 emissions (Amann and Kornai, 1987) as well as for NO_x emissions are incorporated in the model (Amann, 1989). Potential and costs of control of NH_3 emissions, however, have not yet been incorporated.

The aim of this paper is to describe the design for the costs of control model for NH_3 emissions and the algorithm. Major sources of ammonia emissions in Europe (Buijsman et al. 1987; Asman, 1990; Klaassen, 1990) are:

- livestock farming (animal manure).
- fertilizer use in agriculture,
- industrial sectors, in especially fertilizer and ammonia production plants,

All these sources are included in the NH_3 emissions module of RAINS (Klaassen, 1990). This paper is restricted to the control of ammonia emissions from livestock farming, since this is by far the most important source (some 85%) and the abatement of industrial ammonia emissions. Moreover, options to control ammonia release from fertilizer use, other than a decrease in the use of fertilizer, do not exist. In contrast to the cost estimates available for controlling sulphur and nitrogen emissions, the cost estimates for the abatement of ammonia emissions are more uncertain, at least for specific control options such as stable adaptations, due to a lack of practical experience.

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[1] Mr. G. Klaassen is from the International Institute for Applied Systems Analysis, Laxenburg, Austria.

The remainder of this paper is as follows. Section II describes the options that are available to control ammonia emissions. Section III describes the costs of controlling ammonia emissions from livestock farming using low nitrogen feed or adaptations during stable and storage, such as manure flushing systems, bio scrubbers and covering manure storage. These techniques are described in one section since the algorithm is the same. Section IV presents the costs of manure application techniques (direct ploughing down, manure injection or trenching) that decrease ammonia emissions. Section V introduces the combinations of techniques available for livestock farming. Section VI presents the costs of controlling industrial ammonia emissions. Resulting cost estimates and cost functions are presented in section VII for Finland and the Netherlands. Tables and Figures are to be found after the main text. Details are provided in several Appendices.

II. OPTIONS TO CONTROL AMMONIA EMISSIONS

A. Introduction

Table 1 shows the emission coefficients for the different livestock categories and other emission sources that are used in this study for Finland and the Netherlands, countries which are used as an example in this paper. Emission coefficients for livestock population are based on recent research in the Netherlands (De Winkel, 1988; Van der Hoek, 1989) but modifications have been made to take into account country specific elements such as meadow period and nitrogen excretion (see Klaassen, 1990). Emission coefficients for nitrogen fertilizer were based on Buisman et al. (1987) and Asman (1990). Emission coefficients for industry, human population as well as emission of other anthropogenic sources are based on Klaassen (1990).

The requirement to assess the abatement costs for all 27 countries of Europe necessarily limits the level of detail which can be maintained. Although cost estimates are based on recent information, data and computational constraints require simplifications, which might appear to be too crude for studies focusing on one country. Therefore the results of the costs sub module should be seen as comparative rather than absolute cost estimates: the emphasis is put on international consistency and comparability.

B. Livestock farming

Ammonia from livestock farming is released during three basic processes (Figure 1):

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

For each of these processes options are available to control ammonia emissions. In addition, changes in the nitrogen content of the feed influences emissions of all three processes (see Figure 1).

The following options can be distinguished to control the ammonia emissions from livestock farming (see Baltussen et al. 1990a; Hannessen, 1990):

* changes in the nitrogen content of the fodder (such as multiple stage foddering)
* adaptations during stable and storage of manure:
  - stable adaptations (such as manure flushing)
  - closed storage
  - cleaning of stable air (biofiltration or scrubbing)
* low nitrogen application (e.g. direct ploughing down of manure on arable land, manure injection, sprinkling of manure).

Changing the nitrogen content of the fodder affects the ammonia emissions of all three processes: stable and storage, application and in the meadow (Figure 1). Adaptations of stable and storage affect both stable plus storage as well as emissions during application since the nitrogen content of the excretion after the stable emission may increase. Table 2 present the options distinguished in this study. Including the combinations of the various abatement techniques 41 or 54 different options are available. The combinations which are possible, as well as the reductions in emission coefficients of these techniques, are presented in Appendix VII. The combined impact of the techniques on emission reductions is calculated using nitrogen balances (see De Winkel, 1988).

Other options which are in principle conceivable, but excluded from the model, are: reducing livestock population (e.g. by decreasing meat consumption), reducing the meadow period for grazing cattle and processing of manure to control emission during application (Oudendag and Wijnands, 1989; Kuik, 1987). The impact of reducing the livestock population can be simulated by changing the (exogenous) forecasts of the livestock population in the model. Processing of manure was excluded since this option is generally more expensive than manure application (see Baltussen et al., 1990a), computational constraints require that the number of single abatement techniques per animal type is limited to four, and this option appears to be less likely in countries where manure surpluses are less excessive as in the Netherlands. Therefore only one of the options to control emissions during application is included in the model. Reducing the meadow period is not very effective since emissions during stable period may even increase more so that the sum of the emissions may even increase (Oudendag and Wijnands, 1989).

The algorithm uses technology and animal specific, as well as country specific, factors for comparing the costs of abating ammonia emissions per country (see Table 3).

C. Industrial emissions

In several branches of the chemical industry emission reductions of 95% can be achieved. This is possibly through the application of stripping and absorption techniques (Tangena, 1985; Technica, 1984). For the total chemical industry causing ammonia emissions in the Netherlands the average reduction that can be achieved is 50%.

III. LOW NITROGEN FEED AND ADAPTATIONS OF STABLE AND STORAGE

A. Introduction

Low nitrogen feed is a combination of various techniques to reduce emissions such as:

- reductions in the level of nitrogen application on grassland or the substitution of grass by silage for dairy cows (Baltussen, 1990b; Spiekers and Pfeffer, 1990),
- reductions in the nitrogen content of feed through an improved agreement between the amino acids in the diet and the amino acid requirements of animals (multi-phase feeding) or through changes in the composition of the raw materials and supplementing diets with synthetic amino acids for pigs and poultry (Baltussen, 1990a; Lenis, 1989: Spiekers and Pfeffer, 1990),

For various animal categories stable adaptations or low emission stable systems, are possible which prevent the escape of ammonia during the stable period (Baltussen, 1990a; Oosthoek et al. 1990a; Oosthoek et al., 1990b). NH_3 emissions from stalls can be reduced by limiting the time that manure remains in the stable (e.g. by using manure flushing systems) keeping floors as dry and free of manure as possible, drying manure quickly, minimization of the time during which ammonia is in contact with air or adding acid to manure.

Covering storage of manure is another way to prevent the escape of ammonia during the stable and storage period. A third option to control the emissions from the stable is the application of various techniques that clean the stable air: biofiltration, biological scrubbers or chemical scrubbers.

B. The algorithm

Investment costs

The following description uses the indices i, k, l to indicate the nature of the parameters:

i	the type of animal
k	the control technology
l	the country

The investment function describes the investment costs of the control technology as a function of the number of animals per stable:

$$I_{i,k,l} = ci^{f}_{i,k} + \frac{ci^{v}_{i,k}}{ss_{i,l}} \tag{1.1}$$

In which $ci^{f}_{i,k}$ and $ci^{v}_{i,k}$ are the coefficients of the investment function and $ss_{i,l}$ is the number of animal places per stable.

The investment costs are annualized over the lifetime lt of the installation using the interest rate q_l:

$$I^{an}_{i,k,l} = \frac{I_{i,k,l} \times ql^{lt} \times (ql-1)}{ql^{lt}-1} \tag{1.2}$$

Fixed operating costs

Fixed operating costs may comprise of maintenance, insurance and administrative overhead, in analogy to cost accounting for technical installations. They are presented as a fixed percentage $fk_{i,k}$ of the investments per animal place:

$$OM^{fix}_{i,k,l} = I_{i,k,l} \times fk_{i,k} \tag{1.3}$$

Variable operating costs

Variable operating costs may consist of the following elements:

- increase in feed costs per animal due to the higher prices of low nitrogen feed.
- costs of natural gas use,
- electricity use,
- water use,
- labor use,
- waste disposal costs.

These variable costs are presented as costs per delivered animal:

$$OM^{var}_{i,k,l} = Q^f_i \times c^f + Q^g_i \times c^g + Q^l_i \times c^l + Q^w_i \times c^w + Q^e_i \times c^e_l + Q^d_i \times c^d \qquad (1.4)$$

Q^f_i	the quantity of feed per animal
c^f	the price (increase) of feed
Q^g_i	the quantity of natural gas per animal
c^g	the price (increase) of natural gas
Q^l_i	the quantity of labor per animal
c^l	the price of labor
Q^w_i	the quantity of water per animal
c^w	the price of water
Q^e_i	the quantity of electricity per animal
c^e_l	the price of electricity
Q^d_i	the quantity of waste per animal
c^d	the price (increase) of waste disposal

Unit costs of NH_3 control

Based on the above mentioned items the unit costs for the control of NH_3 emissions can be calculated. Unit costs are expressed in costs per animal per year by taking into account the number of animal rounds per year ar_i and the utilization factor of the capacity sb_i:

$$ca_{i,k,l} = \frac{(I^{an}_{i,k,l} + OM^{fix}_{i,k,l})}{sb_i} + \frac{OM^{var}_{i,k,l} \times ar_i}{sb_i} \qquad (1.5)$$

The cost efficiency of the abatement option can only be evaluated if the annual costs are related to the amount of emissions reduced in order to obtain the cost per unit of NH_3 removed. In doing so it has to be taken into account that (combinations of) abatement options may simultaneously reduce emissions during stable and storage, application and in the meadow:

$$cn_{i,k,l} = \frac{ca_{i,k,l}}{nh3s_{i,l} \times xs_{i,k} + nh3a_{i,l} \times xa_{i,k} + nh3m_{i,l} \times xm_{i,k}} \qquad (1.6)$$

In which:

$nh3s_{i,l}$ emission coefficient of stable
$nh3a_{i,l}$ emission coefficient of application
$nh3m_{i,l}$ emission coefficient meadow
$xs_{i,k}$ efficiency of reduction stable
$xa_{i,k}$ efficiency of reduction application
$xm_{i,k}$ efficiency of reduction meadow

C. Low nitrogen feed

Low nitrogen feed is a combination of various techniques to reduce emissions:

- reductions in the level of nitrogen application on grassland in combination with an increase in silage for grazing cattle (dairy cows),
- reductions in the albumen content of feed through changes in the composition of the raw materials and supplementing synthetic amino acids or as a result of directing the feed composition to the specific demand for amino acids (multi-phase feeding) for pigs and poultry.

For dairy cows nitrogen excretion can be lowered if the level of nitrogen application on grassland is reduced 400 or even 500 kg nitrogen per ha to 200 kg nitrogen per ha and grass silage is partly substituted by silage maize, according to Baltussen et al. (1990b) for the Netherlands. Their results show that reductions in stall emissions by 10 to 30 % and in meadow emissions of around 25 % are possible (see Appendix I). Spiekers and Pfeffer (1990) indicate that a reduction in the nitrogen excretion would be possible of 10 to 15 %. Whether this is an alternative that is possible in most

European countries is uncertain. Data of the European Commission (CEC, 1989) and own calculations using international statistics on fertilizer use and areas of permanent pasture (Klaassen, 1990) show that levels of nitrogen application of grassland in other European countries are generally far below the level in the Netherlands. It therefore is not sure that this alternative, perhaps with the exception of a few countries such as Denmark and the Federal Republic of Germany, is feasible for other countries. Consequently this alternative was only included in the model for the Netherlands, Denmark and the FRG.

For pigs multi-phase feeding, in combination with nitrogen poor feed or synthetic amino acids, reduces the nitrogen in the excretion by 5 % for fattening pigs and 20 % for sows (Baltussen et al., 1990c; see Appendix I). Spiekers et al (1990) even suggests that reductions up to 35 % are possible for fattening pigs and 15% for sows. Lenis (1989) is of the opinion that synthetic amino acids my achieve reductions of 25 % for both pigs and sows on the long run.

For laying hens a reduction in the albumen content may reduce the nitrogen excretion by some 10 per cent. Multi-phase feeding and synthetic amino acid are expected to reduce the nitrogen excretion for broilers by 20 per cent (Van Horne, 1990).

Only for pigs the introduction of low nitrogen feed is associated with investment costs. For all other animals costs only consist of higher feed prices. The technology and animal specific data are presented in Table 4. Data are based on Baltussen et al. (1990a, 1990b, 1990c) and Van Horne (1990). Details on the calculation are given in Appendix I. The investment costs are annualized over the lifetime lt of the installation using the interest rate q_l. There are no fixed operating cost. Variable operating costs consist of the increase in feed costs per animal due to the higher prices of low nitrogen feed. Note that the costs are based on changes in the composition of raw materials for feed production for the situation in the Netherlands (see also Blom et al., 1990). Results for the Federal Republic of Germany (Spiekers et al, 1990) however, show that the cost increases for pigs in the Netherlands and the Federal Republic of Germany are approximately as high.

D. Adaptations during stable and storage

Stable adaptations

For various animal categories stable adaptations or low emission stable systems, are possible which prevent the escape of ammonia during the stable period. It is believed that NH_3 emissions from stalls can be reduced by limiting the time that manure remains in the stable, keeping floors as dry and free of manure as possible, drying manure quickly, minimization of the time during which ammonia is in contact with air or adding acid to manure (Hannessen, 1990). The preliminary costs estimates used in this study are based in the following systems:

- dairy cows : stable washing and scraping systems, removing manure regularly to a (closed) storage basin,
- pigs : manure flushing and scraping systems
- laying hens : manure belt with forced drying of manure
- broilers : floor heating and insulation,

For most of these systems, especially for pigs and cattle, cost estimates are uncertain since hardly practical experience exist. [2] Therefore the estimates are preliminary. Details are provided in Appendix II.

Washing the stable floor of dairy cow stables and frequently remove the manure to a closed storage system, can reduce ammonia emissions by 50 to 70% (Oosthoek et al., 1990a). Costs consist of the washing system in combination with manure storage capacity (Baltussen, 1990b). Annual costs are still uncertain and therefore accounted for as fixed percentage of the investment. For pig stables, Oosthoek et al. (1990a, 1990b) conclude that the reduction in ammonia emissions that can be achieved is 60 to 70%. using a manure flushing system in combination with a replacement pump or drainage system in the stable. Provisional cost estimates were made by Baltussen et al. (1990c) and Hakvoort et al. (1990). The application of a manure belt with forced drying of manure reduced emissions from laying hens stables by some 60% (Van Horne, 1990). Floor heating and insulation reduce ammonia emissions from broiler housing systems with only 10 % (Kroodsma et al., 1990). Costs mainly consist of additional investments (Van Horne, 1990; Evers, 1988).

The investment function for stable adaptations is the same as for low nitrogen feed. $ci^{f}_{i,k}$ and $ci^{v}_{i,k}$ are the coefficients of the investment function and $ss_{i,l}$ is the number of animal places per stable. The technology and animal specific data are presented in Table 5. Only for dairy cows and pigs a relation between the size of the stable and the investment per animal place is constructed. This relationship should be seen as tentative, in view of the lack of experience. Country specific data on

[2] For dairy cows another alternative is the addition of sulfuric acid which suppresses the formation of NH3 in the manure. Details are provided in appendix VI. Since only one stable adaptation system can be included in the model for each animal type, due to computational constraints, the addition of sulfuric acid was left out of the analysis as a less likely alternative (Baltussen, 1990b).

the number of animals per stable (see Table 10) are based on international and national livestock statistics.

The investment costs are annualized over the lifetime lt of the installation using the interest rate q_l. Fixed operating costs may consist of maintenance, insurance and administrative overhead. They are presented as a fixed percentage of the investment per animal place. Due to a lack of experience with these techniques generally no specification of the variable operating costs was possible yet for pigs and dairy cows. Therefore annual operating costs are assumed to be a fixed percentage of the investment. Variable operating costs consist only of the additional costs of natural gas use for broilers and laying hens. Table 5 shows the cost parameters.

Covering manure storage facilities

Covering storage of manure is one way to prevent the escape of ammonia during the stable and storage period. Covering the storage prevents 90% of the ammonia emissions (Baltussen et al. 1990b). However, since only part (some 10%) of the total ammonia released during stable and storage actually escapes from the storage the overall removal efficiency is only 10%. Costs only consist of investments (Table 6). The additional investments consist of the costs of the roof or the cover minus the smaller investments in the silo. The silo can be smaller since no rain enters the silo. Appendix III provides details on the cost calculation. The investments depends on the size of the silo and thus indirectly on the number of animals per stable. Covering of storage is only feasible if storage facilities already exist or are expected as a result of national legislation.

Biofiltration or bioscrubbing

Another possibility to control the emissions from the stable is the application of various techniques that clean the stable air. These techniques can only be applied in case stables are equipped with mechanical ventilation. This is usually the case for poultry but not always for pig stables (Asman, 1990). Techniques are biofiltration, bioscrubbing and chemical scrubbers. Application of biofiltration for poultry stables may be difficult due to dust problems.

Cost estimates show wide ranges (Zeisig, 1990; Eggels and Scholtens, 1989; Demmers, 1989; Jol, 1990; van Horne, 1990; Baltussen et al., 1990b) and mostly pertain to fattening pigs. Although insufficient experience exist it is likely that the amount of investment depends on the size of the installation. This relation between the size and the investment as given for pigs should be seen as indicative only. The technology and animal specific data are presented in Table 7. Country specific data are included in Table 10. Electricity prices are based on IIASA data base (Amann, 1989). Data for stable sizes are based on national and international statistics. For Eastern-European countries these data are generally lacking. Instead data were used on the distribution of the number of animals over state or collective farms and individual farmers in combination with assumptions on the average size of collective and individual farms. Details on the cost calculation are presented in Appendix IV.

Again investment costs are annualized over the lifetime lt of the installation using the interest rate q_l. Fixed operating costs are presented as a fixed percentage of the investments per animal place. The cost parameters are shown in Table 6. Table 10 presents the country specific elements. No country specific prices are incorporated for labor, water and waste disposal prices due to a lack of data on the one hand and the fact that these cost items are relatively less relevant for the total annual costs.

IV. APPLICATION OF MANURE

A. Introduction

To prevent the escape of ammonia during application of manure on arable land or grassland the following techniques exist (Huismans, 1990; Krebbers, 1990):

- direct application (ploughing down) of manure on arable land,
- manure injection, sod injection or sod manuring for manure on grassland,
- sprinkling or drenching of manure on grassland.

The applicability of these techniques depends, amongst other things, on soil type, water availability (sprinkling), and the slope of the soil. Costs are expressed per m3 manure applied since these techniques are usually carried out by specialized firms whose services can be rented by the individual farmer. In addition, this avoids unnecessary complications in the cost calculation routine. Costs per m3 manure depend on, among other things, the technique, the volume of manure applied (m3 per hectare) and the distances between land and storage (Krebbers, 1990). The most important country specific element is probably the mixture of techniques. Not only are there additional cost but there are also cost savings since less artificial fertilizer has to be applied. It is also possible that, because of the poor uptake of phosphate from injected manure, an additional amount of phosphate fertilizer will have to be applied at the start of the growing season.

Since we assume that these low nitrogen application techniques are carried out by specialized firms there are no investments, annualized investments costs or fixed operating costs. The cost only consist of the variable costs of the mixture of techniques (ploughing down, manure injection, or sprinkling) minus the cost savings.

B. The algorithm

The costs of direct application or ploughing down per m3 manure are:

$$c^{ma}{}_{l} = c^{fma} + \frac{c^{vma}}{Q^{mh}{}_{l}} \tag{2.1}$$

With:

c^{fma} the fixed costs of direct application per m3 manure

c^{vma} the variable costs of direct application

$Q^{mh}{}_{l}$ the amount of manure applied per hectare

The cost of manure injection on grassland per m3 manure are:

$$c^{mi}{}_{l} = c^{fmi} + c^{vmi} \times Q^{mh}{}_{l} \tag{2.2}$$

c^{fmi} the fixed costs of injection per m3 manure

c^{vmi} the variable cost of injection per m3 manure

$Q^{mh}{}_{l}$ the amount of manure applied per hectare

The costs of sprinkling, c^{mr}, per m3 manure consist of fixed and variable elements. The fixed costs consist of the investment in the installation. The costs per m3 manure than depend on the manure production per farm, a function of the number of animals:

$$c^{mr}{}_{l} = c^{fmr} + \frac{c^{vmr}}{ss_{dl}} \tag{2.3}$$

c^{fmr} the fixed costs of sprinkling per m3 manure

c^{vmr} the variable cost of sprinkling

ss_{dl} the stable size for dairy cows

In addition to the costs of low nitrogen application of manure there are also costs savings due the reduction in fertilizer use per animal:

$$OM^{nf}_{i,k,l} = nh3a_{i,l} \times xa_{i,k} \times 0.5 \times \frac{14}{17} \times c^{k}_{l} \times \frac{sb_i}{ar_i} \tag{2.4}$$

With:

- $nh3a_{i,l}$ the emission coefficient for application
- $xa_{i,k}$ the removal efficiency of application
- c^k_l the fertilizer price
- sb_i the rate of utilization
- ar_i the number of animal rounds per year

The factor 14/17 is used to recalculate the emission reduction expressed in kg NH_3 into kg nitrogen. It is expected that the ammonia that is not emitted does not fully lead to equal savings in fertilizer. Krebbers (1990) is of the opinion that the effectiveness of the nitrogen uptake by grassland increases with a factor 2. Therefore only half of the ammonia is assumed to lead to savings in fertilizer use.

The total annual costs of the low nitrogen application techniques are:

$$OM^{var}_{i,k,l} = (c^{ma} \times S^{ma}_{l} + c^{mi} \times S^{mi}_{l} + c^{mr} \times S^{mr}_{l}) \times M_i - OM^{nf}_{i,k,l} \tag{2.5}$$

In which:

- S^{ma}_l the share of manure directly applied
- S^{mi}_l the share of manure injected
- S^{mr}_l the share of manure sprinkled
- M_i the production of manure per animal

Based on the above mentioned items the unit costs for the control of NH_3 emissions can be calculated. The equations are the same as for low nitrogen feed and adaptations during stable and storage. Unit costs are expressed in costs per average present animal by taking into account the number of animal rounds per year ar_i and the capacity utilization factor sb_i:

$$ca_{i,k,l} = \frac{(I^{an}{}_{i,k,l} + OM^{fix}{}_{i,k,l})}{sb_i} + \frac{OM^{var}{}_{i,k,l} \times ar_i}{sb_i} \tag{2.6}$$

The cost efficiency of the abatement option can only be evaluated if the annual costs are related to the amount of emissions reduced in order to obtain the cost per unit of NH_3 removed. In doing so it has to be taken into account that (combinations of) abatement options may simultaneously reduce emissions during stable and storage, application and in the meadow:

$$cn_{i,k,l} = \frac{ca_{i,k,l}}{nh3s_{i,l} \times xs_{i,k} + nh3a_{i,l} \times xa_{i,k} + nh3m_{i,l} \times xm_{i,k}} \tag{2.7}$$

In which:

- $nh3s_{i,l}$ emission coefficient of stable
- $nh3a_{i,l}$ emission coefficient of application
- $nh3m_{i,l}$ emission coefficient meadow
- $xs_{i,k}$ efficiency of reduction stable
- $xa_{i,k}$ efficiency of reduction application
- $xm_{i,k}$ efficiency of reduction meadow

C. The costs of low nitrogen application

Table 8 shows the technology specific parameters for low N-application. Direct application of manure or manure injection is generally believed to reduce ammonia emission by 90% in comparison to superficial application. The reduction to be achieved by sod manuring and sprinkling or drenching is somewhat less: 70 to 85%. Costs are based on data provided by Baltussen et al. (1990b), Krebbers (1990) and Huijsmans (1990). The country specific elements are incorporated in Table 11. Fertilizer prices are based on FAO data (1989a). The amount of manure applied is based on international statistics on animal population and land use (1989b) in combination with data on the manure production per animal (Table 9). The share of manure ploughed down is assumed to be equal to the share of arable land and the share of manure injected is equal the share of grassland in each country (FAO, 1989b). For the time being the default value for the share of manure sprinkled is assumed to be zero due to a lack of data. This assumption can easily be changed in case new data become available. Table 9 provides some animal specific elements. Appendix V supplies more details on the calculation of the parameters.

V. COSTS OF COMBINATIONS

The options which are available per animal category (see Table 1) can also be applied in combination. In that case the costs are simply the sum of the costs of the separate options. More details on the options which are allowed for and the associated removal efficiencies are given in appendix VII. For example, the costs of closed storage and low n-application for dairy cows is the sum of the costs of closed storage plus low n-application. The efficiency of control however is not equal to the sum of the efficiency of the separate abatement techniques. The efficiency of the combination is calculated using nitrogen balances based on De Winkel (1988).

VI. INDUSTRIAL PROCESS EMISSIONS

The total annual costs of controlling ammonia emissions from industrial processes are estimated at DM 1250 per ton NH_3 removed. The removal efficiency is 50% (Tangena, 1985; Technica, 1984).

VII. RESULTS

A. Future emissions without abatement

The development of the NH_3 emissions without control is shown for two example countries, Finland and the Netherlands, in Tables 12 and 13. Finland is selected because it is presently collecting data on the costs of controlling ammonia. The Netherlands was chosen since most of the data is based on Dutch experience. The projections are based on: national forecasts for livestock population and fertilizer use in Finland (Kettunen, 1990), national forecasts for livestock population (Oudendag et al., 1989), the assumption that fertilizer use will stabilize in the Netherlands, stable levels of industrial emissions and human population forecasts according to the UN medium scenario (United Nations, 1989).

Finnish NH_3 emissions will be 46 kilotons in 2000 if no control would take place (Table 12). That is 25% lower than the 1980 level of 62 kilotons (Klaassen, 1990). This mainly results from the considerable reduction in the livestock population. Note, however, that this assumes that emission coefficients are constant over time. Ammonia emissions in the Netherlands (Table 13) slightly decrease compared to the 1980 level of 230 kilotons (Klaassen, 1990). Most important sources of ammonia are dairy cows, other cattle and fertilizer. In the Netherlands emissions from pigs are also relevant. Application of manure is the most important source of livestock ammonia in both countries. Other sources consist of human respiration and other, anthropogenic emissions like cats and dogs and fur animals.

B. Average costs per animal and per ton ammonia abated

The average costs per animal per year and the costs per ton ammonia controlled by the different ammonia control options are presented in Table 14 (Finland) and Table 15 (The Netherlands). A comparison of both Tables shows that the cost of low nitrogen application are only partly different in both countries. Although in Finland, cost savings on fertilizer use are somewhat higher since the fertilizer price and the emission coefficient for application for some animal categories (dairy cows e.g) is higher, in the Netherlands the amount of manure applied per hectare is higher which in turn reduces the costs. Costs of stable adaptations (dairy cows and pigs), covering manure storage (dairy cows, other cattle) and biofiltration (pigs) are lower in the Netherlands mainly because the size of the stables is larger. A major difference is that in the Netherlands, low nitrogen feed for dairy cows is assumed to be possible whereas in Finland it is not. Costs of low nitrogen feed and stable adaptations for poultry (hens and broilers) are the same in both countries. Costs of biofiltration of bio-scrubbing for poultry are somewhat smaller in Finland because the electricity price is lower. Average costs per ton NH_3 abated range from 12 DM/ton NH_3 (low nitrogen application broilers) to more than 137000 DM/ton NH_3 (dairy cows covered storage) in Finland. In the Netherlands average costs per ton NH_3 vary between 453 DM/ton NH_3 (low nitrogen application broilers) and 56500 DM/ton NH_3 (pigs biofiltration). One should note that the cost of some combinations per ton ammonia abated are sometimes lower for a combination of options than for a single option. This is due to the fact that the abatement efficiency of the combination might be more than the sum of the abatement efficiencies of the separate options. Although stable adaptation would reduce ammonia emissions escaping from the stall it would also increase the nitrogen content of the manure and consequently might increase ammonia emissions during application. In combination with application, however, both stable and application are removed very effectively.

C. Cost functions

Table 16 and 17 presents the optimal, least cost combination of abatement options for Finland and the Netherlands (The cost functions). Both the marginal and the total costs function for Finland are presented in Figure 2. Figure 3 contains the cost functions for the Netherlands.

Table 16 shows that the marginal costs in Finland range from 12 DM/ton NH_3 abated to around 165000 DM/ton NH_3 removed. Relatively cheap options are low N-application, stripping/absorption of industrial process emissions and stable adaptations for laying hens and broilers. More expensive are options which include biofiltration for pigs or covering manure storage for cattle. With best available technologies, 17.6 kilotons of NH_3 could be removed in the year 2000; 28 kilotons would be left. This would imply a reduction of 40% over the uncontrolled emissions in 2000 and a reduction of 55% over the 1980 emissions. The associated marginal costs would be 165000 DM/ton NH_3 and the total annual costs would be 269 million DM. A 30 % reduction of the emissions over the 1980 level would imply an emission ceiling of 43 kilotons in 2000. This result can be achieved with only a few control measures since unabated emissions are already expected to drop to 46 kilotons in 2000. Low nitrogen application of the manure of laying hens, broilers and part of the pig manure, in combination with a reduction in industrial emissions, will suffice to reach a 30% reduction. The associated marginal costs are 2334 DM/ton NH_3. Total annual costs are 3 million DM. Figure 2 shows that a reduction of the emissions from 46 to 32 kilotons is relatively cheap. After that point marginal as well as total costs will increase sharply. This being so because more expensive techniques like stable adaptations and biofiltration will have to be applied.

Marginal costs for the Netherlands are shown in Table 16. They range between 354 DM/ton NH_3 abated and 165000 DM/ton NH_3 removed. Relatively cheap options are low N-application, stripping/absorption of industrial process emissions and stable adaptations for laying hens and low nitrogen feed for broilers. More expensive are options which include biofiltration for pigs. With best available technologies, 140 kilotons of NH_3 could be removed in the year 2000; 80 kilotons would be left. This would imply a reduction of 65% over the uncontrolled emissions in 2000. The reduction over the 1980 level would also be 65%. This implies that the official goal of the Netherlands policy, a reduction of the ammonia emissions by 70% in the year 2000 (ceiling of 70 kilotons) would not be feasible with the control options incorporated into the model. However, one has to take into account that the overall application of direct ploughing down of manure and manure injection will reduce artificial fertilizer use. Consequently NH_3 emissions from fertilizer use will also decline. If fertilizer use would be halved, 17 kilotons of ammonia would be avoided and a reduction of nearly 70% could be attained. However, the associated marginal costs would be 165000 DM/ton NH_3 and the total annual costs would be 2299 million DM. A 30 % reduction of the emissions over the 1980 level would imply an emission ceiling of 161 kilotons in 2000. Marginal costs would be 4400 DM/ton NH_3 abated and the total costs would be 130 million DM. Figure 3 shows that a reduction from 220 to 100 kilotons ammonia would be relatively cheap. After that point marginal as well as total costs tend to increase drastically since relatively expensive techniques will have to be introduced.

A number of factors influence the results of the analysis. First of all, forecasts on livestock population and fertilizer use and the emission coefficients, that are assumed to be constant over time, determine the level of unabated emissions in 2000. Emission coefficients might increase in the future as a result of increase in yield per animal (e.g. milk yield per cow). Forecasts on livestock population might differ as a result of changes in population growth, income per capita, export performance, agricultural policy and consumer preferences. Secondly, cost estimates of stable adaptations for pigs and dairy cows are uncertain due to the lack of practical experience. The efficiency of reduction that might be achieved might be higher or lower. This could especially be true for low nitrogen feed. By contrast cost estimates for low nitrogen application seem more firm although it is not quite sure to which extent techniques as manure injection and direct ploughing down can be applied in all countries in Europe. Finally, several options such as manure processing, biofiltration for fattening calves and low nitrogen feed for dairy cows in several countries, are not included because of computational and data constraints. For several other options it is assumed that they would be applicable in all countries. This might lead to a slight underestimation or overestimation of the abatement potential. Given the fact that our calculations for unabated emissions in the past for both countries correspond very well to national estimates (Klaassen, 1990), bearing in mind the aforementioned uncertainties, the cost functions for Finland and the Netherlands give a reasonable picture of the potential and costs of reducing ammonia emissions.

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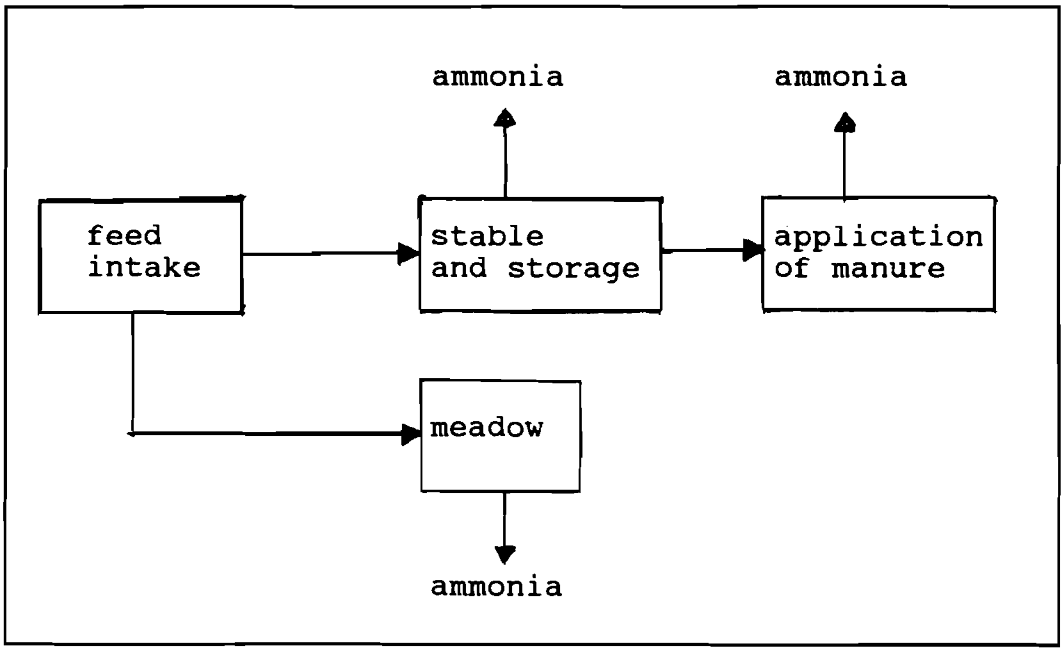

Figure 1 Ammonia losses from livestock farming.

FIG 2 COST FUNCTION FINLAND

YEAR 2000

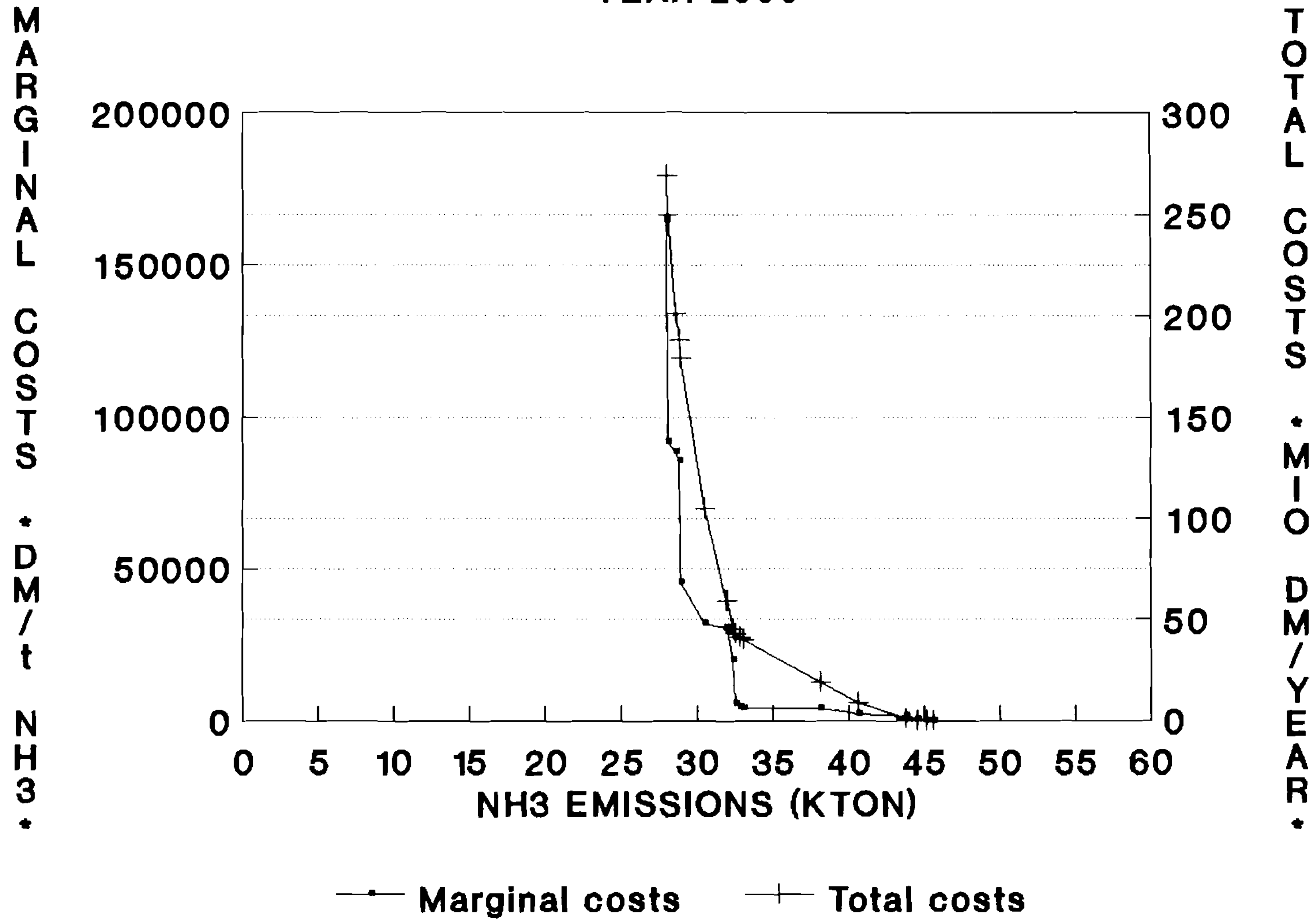

FIG 3 COST FUNCTION NETHERLANDS

YEAR 2000

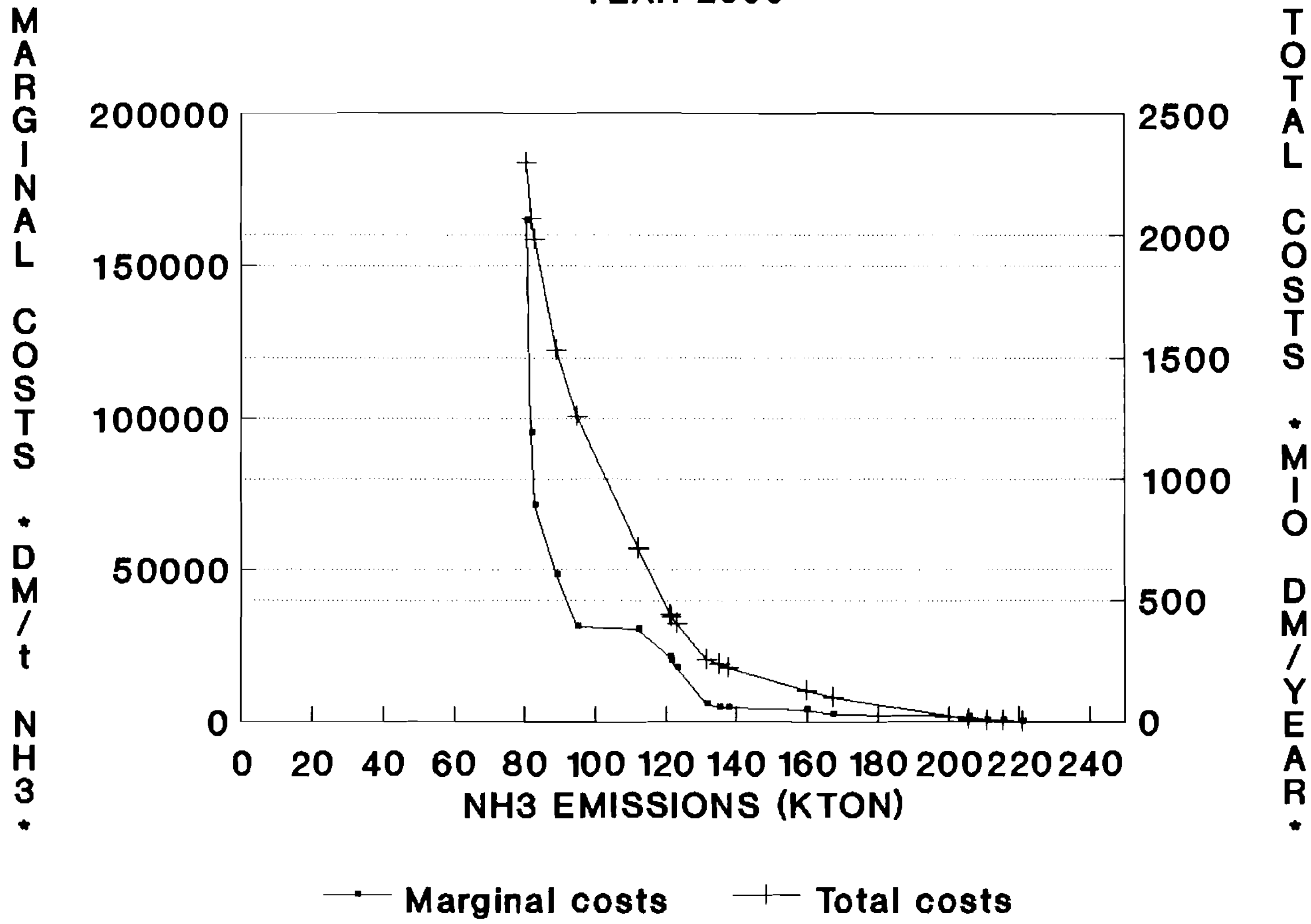

TABLE 1. EMISSION COEFFICIENTS FOR AMMONIA

COUNTRY: FINLAND

LIVESTOCK FARMING	Kg NH3/animal per year			
	Stable/ Storage	Application	Grazing period	TOTAL
DAIRY COWS	9.30	15.20	7.30	31.80
OTHER CATTLE	2.10	3.90	3.80	9.80
PIGS	1.87	2.96	0.00	4.82
LAYING HENS	0.15	0.17	0.00	0.33
BROILERS	0.21	0.08	0.00	0.28
SHEEP	0.90	1.60	0.40	2.90
HORSES	5.00	4.00	3.50	12.50
FERTILIZER CONSUMPTION		(Ktons NH3/kton)		0.0583
INDUSTRY - FERTILIZER PROD.		(Ktons NH3/kton)		0.0058
HUMAN POPULATION		(Tons NH3/1000 heads)		0.30
OTHER SOURCES		(Kton NH3/year)		4.00

COUNTRY: NETHERLANDS

LIVESTOCK FARMING	Kg NH3/animal per year			
	Stable/ Storage	Application	Grazing period	TOTAL
DAIRY COWS	8.79	14.40	12.34	35.53
OTHER CATTLE	3.61	6.14	2.74	12.49
PIGS	1.87	2.96	0.00	4.82
LAYING HENS	0.15	0.17	0.00	0.33
BROILERS	0.21	0.08	0.00	0.28
SHEEP	0.39	0.71	0.96	2.06
HORSES	5.00	4.00	3.50	12.50
FERTILIZER CONSUMPTION		(Ktons NH3/kton)		0.0328
INDUSTRY - FERTILIZER PROD.		(Ktons NH3/kton)		0.0058
HUMAN POPULATION		(Tons NH3/1000 heads)		0.30
OTHER SOURCES		(Kton NH3/year)		7.00

Source: Klaassen (1990).

TABLE 2. ABATEMENT OPTIONS						
OPTIONS PER PROCESS	FODDER	STABLE AND STORAGE			APPLICATION	TOTAL NUMBER OF OPTIONS
	low n-fodder	stable adaptation	closed storage	biofil-tration	low N-application	
	(LNF)	(SA)	(CS)	(BF)	(LNA)	(number)
ANIMAL TYPE						
dairy cows	(x)	x	x		x	5/11
other cattle			x		x	3
pigs	x	x		x	x	11
laying hens	x	x		x	x	11
broilers	x	x		x	x	11
sheep						
horses						
(x) implies only possible for some countries.						41/54

TABLE 3. Parameters used in the cost calculation routine	
Technology (and animal) specific parameters	
cif, civ	parameters of the investment functions
fk	annual fixed (maintenance) costs
lt	lifetime of the installation
Qf	fodder use per animal
Qg	heating fuel use
Ql	labor use
Qw	water use
Qe	electricity use
Qd	disposal of waste
Mi	manure production per animal
ar	number of animal rounds per year
sb	capacity utilization factor
cf	fodder price (increase)
cg	heating fuel price
cl	labor price
cw	water price
cd	disposal price
cfma	fixed costs manure application
cvma	variable costs manure application
cfmi	fixed cost manure injection
cvmi	variable costs manure injection
cfms	fixed costs manure sprinkling
cvms	variable costs manure sprinkling
xs	removal efficiency stable
xa	removal efficiency application
xm	removal efficiency meadow
Country specific parameters	
ce	electricity price
ck	fertilizer price
Qma	share manure ploughed down
Qmi	share manure injected
Qms	share manure sprinkled
Qmh	volume of manure per hectare
ssd	stable size dairy cows
sso	stable size other cattle
ssp	stable size pigs
ql	interest rate

TABLE 4. Cost parameters Low N-feed						
Animal type		**Units**	**Dairy cows**	**Pigs**	**Laying hens**	**Broilers**
Parameter						
Coefficients for the	cif	DM/animal-	0	5.33	0	0
investment function.	civ	place	0	0	0	0
Lifetime.	lt	years	10	10	10	10
Fixed operating costs.	fk	%	0	0	0	0
fodder use	Qfi	100 kg/animal	101	10.84	0.462	0.0332
fodder price	cf	DM/100 kg	0.89	0.68	0.49	0.91
removal efficiency						
stable	xs	%	20	15	10	20
application	xa	%	20	15	10	20
meadow	xm	%	25	0	0	0

TABLE 5. Cost parameters Stable adaptations

Animal type		Units	Dairy cows	Pigs	Laying hens	Broilers
Parameter						
Coefficients for the	cif	DM/	698	177	1.64	2.28
investment function	civ	animal-place	3997	176	0	0
Lifetime	lt	years	10	10	10	10
Fixed operating costs	fk	%	8	8	0	1
gas use	Qg	m3/animal	0	0	0.25	-0.0097
gas price	cg	DM/m3	0.44	0.44	0.44	0.44
electricity use	Qe	Kwh/animal	0	0	1	0
electricity price	ce	DM/Kwh	country specific (Table 10)			
removal efficiency stable	xs	%	50	65	60	10

Notes:
Pigs represents the weighted average of fattening pigs and sows.

TABLE 6. Cost parameters covering manure storage

Animal type		Units	Dairy cows	Other Cattle
Parameter				
Coefficients for the	cif	DM/	39	14
investment function	civ	animal-place	10766	3342
Lifetime	lt	years	10	10
Fixed operating costs	fk	%	0	0
removal efficiency stable	xs	%	10	10

TABLE 7. Cost parameters Biofiltration and bioscrubbers

Animal type		Units	Pigs	Laying hens	Broilers
Parameter					
Coefficients for the investment function	cif	DM/ animal-place	312.5	9.4	9.4
	civ		5030	0	0
Lifetime	lt	years	10	10	10
fixed operating costs	fk	%	2	4	4
labour use	Ql	h/animal	0.089	0	0
water use	Qw	m3/animal	0.57	0.0915	0.0121
electricity use	Qe	kwh/animal	16	10.2	1.34
disposal waste	Qd	i.e.	0.107	0.0055	0.00072
labour price	cl	DM/hour	22	22	22
water price	cw	DM/m3	0.89	0.89	0.89
electricity price	ce	DM/kwh	country specific		
disposal price	cd	DM/i.e.	46	46	46
removal efficiency stable	xs	%	90	80	80

TABLE 8. Cost parameters Low N- application

Parameter		Units	
fixed costs application	cfma	DM/m3 manure	2.89
variable costs application	cvma	DM/m3 manure	0.00
fixed costs injection	cfmi	DM/m3 manure	4.39
variable costs injection	cvmi	DM/m3 manure	-0.028
fixed costs sprinkling	cfms	DM/m3 manure	1.33
variable costs sprinkling	cvms	DM/m3 manure	242
manure/ha	Qmh	m3/ha	country specific
share direct application	Sma	%	country specific
share manure injection	Smi	%	country specific
share manure sprinkled	Sms	%	country specific
manure/animal	Mi	m3/animal	see Table 9
emission coefficient	NH3ai	kg NH3/animal	see Table 1
price fertilizer	ck	DM/kg	country specific
removal efficiency application	xa	%	90

TABLE 9. ANIMAL SPECIFIC PARAMETERS

Animal type		Units	Dairy cows	Other cattle	Pigs	Laying hens	Broilers
Parameter							
manure production	Mi	m3/animal	22.000	8.384	1.245	0.061	0.0025
animal rounds	ar	rounds/year	1.00	0.90	2.00	0.80	6.08
utilization rate	sb	share	1.00	0.98	0.97	0.97	0.77

TABLE 10. Country specific parameters

	Electricity price	Stable size			Interest rate
		dairy cows	other cattle	pigs	
	ce	ss	ss	ss	ql
Country	(DM/kwh)	(number/stable)			(%/100)
Albania	0.088	43	43	214	0.04
Austria	0.211	17	17	25	0.04
Belgium	0.225	22	50	264	0.04
Bulgaria	0.088	31	31	154	0.04
CSSR	0.088	48	48	238	0.04
Denmark	0.116	23	58	269	0.04
Finland	0.126	13	25	60	0.04
France	0.181	19	19	45	0.04
FRG	0.211	15	31	58	0.04
GDR	0.211	49	49	228	0.04
Greece	0.146	3	4	10	0.04
Hungary	0.088	41	41	202	0.04
Ireland	0.217	21	33	199	0.04
Italy	0.151	9	20	21	0.04
Luxembourg	0.192	30	30	64	0.04
Netherlands	0.159	39	70	426	0.04
Norway	0.080	11	24	68	0.04
Poland	0.088	11	11	53	0.04
Portugal	0.183	3	3	7	0.04
Romania	0.088	34	34	154	0.04
Spain	0.216	5	5	20	0.04
Sweden	0.090	17	30	122	0.04
Switzerland	0.179	27	27	67	0.04
Turkey	0.050	3	4	10	0.04
UK	0.170	58	58	336	0.04
USSR	0.088	39	39	178	0.04
Yugoslavia	0.088	11	11	51	0.04

Sources: Statistisches Bundesamt Wiesbaden (1988), Various national Statistics. Electricity prices based on prices for households excluding taxes (IEA, 1989). Electricity prices for CMEA-countries reflect the export price due to lack of data (Amann, 1989).

Table 11. Country specific parameters application

	Share manure			Volume manure	Fertilizer price
	applied directly	injected	sprinkled	per ha	
Country	Sma	Smi	Sms	Qmh (m3/ha)	ck (DM/kg)
Albania	0.64	0.36	0.00	30	0.58
Austria	0.43	0.57	0.00	13	2.04
Belgium	0.54	0.46	0.00	36	1.05
Bulgaria	0.67	0.33	0.00	19	0.58
CSSR	0.76	0.24	0.00	14	0.87
Denmark	0.93	0.07	0.00	19	1.08
Finland	0.95	0.05	0.00	9	1.25
France	0.62	0.38	0.00	14	1.10
FRG	0.63	0.37	0.00	22	1.41
GDR	0.80	0.20	0.00	21	1.41
Greece	0.43	0.57	0.00	15	0.59
Hungary	0.81	0.19	0.00	10	0.36
Ireland	0.17	0.83	0.00	17	0.80
Italy	0.71	0.29	0.00	14	1.07
Luxembourg	0.54	0.46	0.00	36	1.05
Netherlands	0.46	0.54	0.00	57	1.13
Norway	0.90	0.10	0.00	35	2.00
Poland	0.78	0.22	0.00	13	0.50
Portugal	0.84	0.16	0.00	23	1.19
Romania	0.71	0.29	0.00	19	0.58
Spain	0.66	0.34	0.00	9	1.33
Sweden	0.84	0.16	0.00	9	1.83
Switzerland	0.20	0.80	0.00	17	1.43
Turkey	0.73	0.27	0.00	19	0.51
UK	0.38	0.62	0.00	21	1.11
USSR	0.38	0.62	0.00	5	0.58
Yugoslavia	0.55	0.45	0.00	12	0.73

References:Fertilizer prices based on FAO (1989). Share of manure directly applied and share manure injected based on shares of arable land and permanent pasture from FAO (1989) in land use. Manure per ha calculated from FAO livestock and land use data and the manure production per animal based on Kuik (1988).

TABLE 12. NH_3 EMISSIONS IN FINLAND IN 2000 (IN KILOTONNES NH3)

PROCESS SECTOR	STABLE/ STORAGE	APPLICA-TION	MEADOW PERIOD	TOTAL
LIVESTOCK				
- dairy cows	3.4	5.5	2.7	11.6
- other cattle	1.5	2.8	2.7	7.0
- pigs	2.3	3.6	0.0	5.8
- laying hens	0.5	0.6	0.0	1.1
- broilers	1.3	0.5	0.0	1.8
- sheep	0.1	0.1	0.0	0.2
- horses	0.1	0.1	0.1	0.4
- Subtotal	9.2	13.2	5.5	27.9
FERTILIZER				10.5
INDUSTRY				1.7
OTHER SOURCES				5.5
TOTAL				45.6

TABLE 13. NH_3 EMISSIONS IN THE NETHERLANDS IN 2000 (IN KILOTONNES NH3)

PROCESS SECTOR	STABLE/ STORAGE	APPLICA-TION	MEADOW PERIOD	TOTAL
LIVESTOCK				
- dairy cows	15.7	25.6	12.5	53.8
- other cattle	4.5	8.4	8.2	21.1
- pigs	27.1	42.8	0.0	69.9
- laying hens	4.8	5.3	0.0	10.1
- broilers	16.5	6.0	0.0	22.5
- sheep	2.0	3.6	0.9	6.4
- horses	0.3	0.3	0.2	0.8
- Subtotal	70.9	92.0	21.8	184.6
FERTILIZER				14.6
INDUSTRY				10.1
OTHER SOURCES				11.6
TOTAL				220.9

TABLE 14. AVERAGE ABATEMENT COSTS FINLAND			
ABATEMENT MEASURE		COSTS (DM/animal per year)	COSTS DM/ton NH3 abated
DAIRY COWS			
2	Dairy Stable adaptation (SA)	204	62282
3	Dairy Covered storage (CS)	107	137429
4	Dairy Low N-application (LNA)	58	4629
8	Dairy SA+LNA	262	14431
9	Dairy CS+LNA	165	11282
OTHER CATTLE			
1	Cattle Covered storage	19	108658
2	Cattle Low N-application	21	3939
3	Cattle CS+LNA	39	10617
PIGS			
1	Pigs Low N-feed (LNF)	16	21940
2	Pigs Stable adaptation	38	39743
3	Pigs biofiltration (BF)	78	64450
4	Pigs Low N-application	6	2334
5	Pigs LNF+SA	54	34691
6	Pigs LNF+BF	94	50243
7	Pigs LNF+LNA	22	7437
8	Pigs SA+LNA	44	11423
9	Pigs BF+LNA	84	19649
10	Pigs LNF+SA+LNA	60	14959
11	Pigs LNF+BF+LNA	100	22841

Table 14. Continued on next page.

TABLE 14. AVERAGE ABATEMENT COSTS FINLAND			
ABATEMENT MEASURE		**COSTS (DM/animal per year)**	**COSTS DM/ton NH3 abated**
LAYING HENS			
1	Layhens Low N-feed	0.19	5727
2	Layhens Stable adaptation	0.40	6382
3	Layhens biofiltration	2.92	37185
4	Layhens Low N-application	0.07	439
5	Layhens LNF+SA	0.59	8725
6	Layhens LNF+BF	3.10	30381
7	Layhens LNF+LNA	0.25	1481
8	Layhens SA+LNA	0.47	1932
9	Layhens BF+LNA	2.99	10876
10	Layhens LNF+SA+LNA	0.66	2632
11	Layhens LNF+BF+LNA	3.17	11358
BROILERS			
1	Broiler Low N-feed	0.24	4185
2	Broiler Stable adaptation	0.36	23171
3	Broiler biofiltration	3.67	28599
4	Broiler Low N-application	0.00	12
5	Broiler LNF+SA	0.60	8415
6	Broiler LNF+BF	3.91	24510
7	Broiler LNF+LNA	0.24	2143
8	Broiler SA+LNA	0.36	4087
9	Broiler BF+LNA	3.67	15850
10	Broiler LNF+SA+LNA	0.60	4627
11	Broiler LNF+BF+LNA	3.91	16139
INDUSTRIAL EMISSIONS			
1	Stripping/absorption		1250

TABLE 15. AVERAGE ABATEMENT COSTS — NETHERLANDS			
ABATEMENT MEASURE		Costs DM/animal per year	Costs DM/ton NH_3 abated
DAIRY COWS			
1	Dairy Low N-feed	90	11639
2	Dairy Stable adaptation	163	52513
3	Dairy Covered storage	39	52851
4	Dairy Low N-application	57	4400
5	Dairy LNF+SA	253	24350
6	Dairy LNF+CS	129	15544
7	Dairy LNF+LNA	147	8121
8	Dairy SA+LNA	220	12559
9	Dairy CS+LNA	96	6928
10	Dairy LNF+SA+LNA	310	14427
11	Dairy LNF+CS+LNA	186	9884
OTHER CATTLE			
1	Cattle Covered storage	8	26016
2	Cattle Low N-application	19	3629
3	Cattle CS+LNA	27	4593
PIGS			
1	Pigs Low N-feed	16	21940
2	Pigs Stable adaptation	37	39186
3	Pigs biofiltration	68	56551
4	Pigs Low N-application	6	2273
5	Pigs LNF+SA	53	34349
6	Pigs LNF+BF	84	45127
7	Pigs LNF+LNA	22	7382
8	Pigs SA+LNA	43	11243
9	Pigs BF+LNA	74	17381
10	Pigs LNF+SA+LNA	59	14786
11	Pigs LNF+BF+LNA	90	20623

Table 15. Continued on next page.

TABLE 15. AVERAGE ABATEMENT COSTS — NETHERLANDS			
ABATEMENT MEASURE		Costs DM/animal per year	Costs DM/ton NH_3 abated
LAYING HENS			
1	Layhens Low N-feed	0.19	5727
2	Layhens Stable adaptation	0.40	6382
3	Layhens biofiltration	3.20	40722
4	Layhens Low N-application	0.07	451
5	Layhens LNF+SA	0.59	8725
6	Layhens LNF+BF	3.38	33098
7	Layhens LNF+LNA	0.26	1492
8	Layhens SA+LNA	0.47	1940
9	Layhens BF+LNA	3.27	11894
10	Layhens LNF+SA+LNA	0.66	2639
11	Layhens LNF+BF+LNA	3.45	12358
BROILERS			
1	Broiler Low N-feed	0.24	4185
2	Broiler Stable adaptation	0.36	23171
3	Broiler biofiltration	4.02	31318
4	Broiler Low N-application	0.02	354
5	Broiler LNF+SA	0.60	8415
6	Broiler LNF+BF	4.26	26698
7	Broiler LNF+LNA	0.26	2352
8	Broiler SA+LNA	0.39	4351
9	Broiler BF+LNA	4.05	17457
10	Broiler LNF+SA+LNA	0.62	4807
11	Broiler LNF+BF+LNA	4.29	17675
INDUSTRIAL EMISSIONS			
1	Stripping/absorption		1250

TABLE 16. COST FUNCTION FINLAND

ABATEMENT MEASURE	MARGINAL COSTS		AMMONIA EMISSIONS			ANNUAL COSTS	
	DM per animal per year	DM/ton NH3 abated	ABATED	TOTAL ABATED	REMAIN-ING	PER MEASURE	TOTAL CUMULA-TIVE
			kt NH3	kt NH3	kt NH3	mio DM	mio DM
				0	45.6	0	0
Broiler LNA	0.00	12	0.4	0.4	45.2	0	0
Layhens LNA	0.07	439	0.5	1.0	44.6	0	0
Industry		1250	0.9	1.8	43.8	1	1
Pigs LNA	6	2334	3.2	5.0	40.6	8	9
Cattle LNA	21	3939	2.5	7.5	38.1	10	19
Dairy LNA	58	4233	5.0	12.5	33.1	21	40
Layhens SA+LNA	0.40	4531	0.3	12.8	32.8	1	41
Broiler LNF+LNA	0.24	5507	0.3	13.1	32.5	2	43
Broiler LNF+SA+LNA	0.36	20000	0.1	13.2	32.4	2	45
Broiler LNF+BF+LNA	3.31	29398	0.5	13.6	32.0	14	59
Layhens LNF+SA+LNA	0.19	30309	0.0	13.7	31.9	1	59
Pigs SA+LNA	38	31816	1.4	15.1	30.5	46	105
Dairy SA+LNA	204	45445	1.6	16.7	28.9	74	179
Layhens LNF+BF+LNA	2.52	85434	0.1	16.8	28.8	8	188
Cattle CS+LNA	19	88479	0.1	17.0	28.6	13	201
Pigs BF+LNA	40	91907	0.5	17.5	28.1	49	250
Pigs LNF+BF+LNA	16	164551	0.1	17.6	28.0	19	269

LNF: Low nitrogen fodder
CS: covering storage
SA: stable adaptation
BF: biofiltration or scrubbing
LNA: Low nitrogen application

TABLE 17. COST FUNCTION NETHERLANDS							
ABATEMENT MEASURE	MARGINAL COSTS		AMMONIA EMISSIONS			ANNUAL COSTS	
	DM per animal per year	DM/ton NH3 abated	ABATED	TOTAL ABATED	REMAIN-ING	PER MEASURE	TOTAL CUMULA-TIVE
			kt NH3	kt NH3	kt NH3	mio DM	mio DM
				0	220.9	0	0
Broiler LNA	0.02	354	5.4	5.4	215.5	2	2
Layhens LNA	0.07	451	4.8	10.2	210.7	2	4
Industry		1250	5.1	15.2	205.7	6	10
Pigs LNA	6	2273	38.5	53.8	167.1	88	98
Cattle LNA	19	3629	7.6	61.3	159.6	27	125
Dairy LNA	57	4400	21.8	83.2	137.7	96	222
Layhens SA+LNA	0.40	4531	2.7	85.9	135.0	12	234
Broiler LNF+LNA	0.24	5507	3.4	89.4	131.5	19	253
Dairy LNF+LNA	90	17519	8.6	98.0	122.9	151	404
Broiler LNF+SA+LNA	0.36	20000	1.4	99.4	121.5	29	433
Cattle CS+LNA	8	21519	0.5	99.9	121.0	10	443
Broiler LNF+BF+LNA	3.40	30165	8.9	108.8	112.1	269	711
Layhens LNF+SA+LNA	0.19	30309	0.2	109.0	111.9	6	717
Pigs SA+LNA	37	31371	17.2	126.1	94.8	539	1256
Dairy LNF+SA+LNA	163	48262	5.7	131.8	89.1	274	1530
Pigs BF+LNA	31	71291	6.3	138.2	82.7	452	1982
Layhens LNF+BF+LNA	2.79	94863	0.9	139.1	81.8	86	2068
Pigs LNF+BF+LNA	16	164551	1.4	140.5	80.4	230	2299

LNF: Low nitrogen fodder
CS: covering storage
SA: stable adaptation
BF: biofiltration or scrubbing
LNA: Low nitrogen application

APPENDIX I. COSTS OF LOW N-FEED

A. DAIRY COWS

According to Baltussen et al. (1990b, p 66.) the nitrogen content of the fodder of dairy cows can be lowered through the increase of silage an a reduction in the level of fertilization of grassland. The costs per animal depend, among other things, on the stable type, the number of cows per hectare, and the soil type. The costs of reducing the level of fertilization from 400 to 200 kg nitrogen/ha vary between fl 79.81 and fl 116.86 per animal. On Average they are around fl 101. The efficiency of reducing the ammonia released in the stable varies between 10.4 and 31.5 per cent (average some 20 per cent). The reduction of the ammonia emission in the pasture varies between 22.4 and 25.5 per cent (average around 25%). Cost consist of buying silage and fodder minus savings on fertilizer use and sewing costs. However, the report does not allow the inclusion of these element separately due to a lack of data on quantities and prices published. We therefore assume that the aggregated price increase is 1 fl/ 100 kg fodder per animal and the quantity is 101 times 100 kg/animal.

B. PIGS

The reductions in nitrogen content and the associated costs are different for fattening pigs and sows (Baltussen et al. 1990c). For fattening pigs multi-phase feeding combined with nitrogen poor feed results in a reduction of the nitrogen excretion with 22%. Spiekers et al. (1990) concludes that reductions up to 35 % are possible for fattening pigs and Lenis (1989) believes that a reduction of some 25 % is possible. Additional investments are 5200 fl for a stable of 200 to 500 pigs (Baltussen et al., 1990c). With an average stable size of 450 pigs/stable this amounts to some 12 fl per pig place. [3] Lifetime is 10 years. Variable costs are the increase in the fodder price from 47.10 fl/kg to 47.39 fl/kg (0.29 fl/100 kg). The amount of fodder per pig is 235 kg.

For sows a reduction of 5% of N-excretion may result from low nitrogen fodder (Baltussen et al., 1990c). Spiekers et al. (1990) estimates reduction at 15% and Lenis (1989) is of the opinion that synthetic amino acids my achieve reductions of 25 % on the long run. There are no investments. Costs consist of variable costs only: the fodder price increases with 1.25 fl/100 kg. The amount of fodder per sow is 1986 kg.

The average investments, costs and emission reduction per pig are: 0.51 * fattening pigs + 0.49 * sows based on the composition of the animal stock in the Netherlands in 1988. The reduction in N-content of the excretion is estimated at 15% for the average pig. The investments are 6 fl/pig place. The price increase is 0.76 fl/100 kg and the fodder consumption per pig is 10.84 x 100 kg. That amounts to approximately fl.10 per delivered animal, a figure which corresponds with estimates by Spiekers et al. (1990).

C. LAYING HENS

Reduction of the albumen content of the fodder may reduce the nitrogen content of the excretion with 7.5%. (Van Horne, 1990, p27—29). This leads to a price increase of 1%. That is 0.55 fl/ 100 kg fodder. Fodder use per animal is 46.2 kg. There are no additional investments.

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[3] Conversion of figures in guilders (FL) to German Marks (DM) is based on the following exchange rate: 1 DM = 1.125 Fl.

D. BROILERS

Three phase feeding can reduce the nitrogen content of the excretion with 11%. There would be no additional costs for this option. In addition, adapted fodder can reduce N-content of the excretion with another 10%. In combination a reduction of some 20% is feasible (Van Horne, 1990, p25—26 and p46—47). The additional costs consist of a higher fodder price. The fodder price increase is 1.5 % of 68 fl/100 kg; that is 1.02 fl/100 kg fodder. The fodder use per animal is 3.315 kg/animal.

APPENDIX II. COSTS OF STABLE ADAPTATIONS

A. DAIRY COWS

One possibility to reduce stable emissions from dairy cows stables is the application of sluicing and scraping systems. Through washing or scraping the manure is frequently removed from the stable. Costs consist of the scraping or washing system in combination with manure storage capacity. The exact costs are not yet known. Investments are estimated at 500 to 1000 fl/animal place for stable with more than 40 cows (Baltussen et al., 1990b) and 1.5 times higher for smaller stables. Total annual costs are 100 to 200 fl/cow for large stables (> 40 cows) and 1.5 times as high for smaller stables. That is 20 % of the initial investments. The reduction in emissions is estimated at 50% (Baltussen et al., 1990b, p 54.). Experiments reported by Oosthoek et al. (1990a, 1990b) confirm that a reduction of 50% to 70% is feasible.

Assuming economies of scale in the investment costs, in correspondence with the relationships between size and investment for reducing sulphur and nitrogen oxides (Amann et al., 1987; Amann, 1989), the following relation between investments per cow and the stable size (expressed as the number of cows) was constructed:
Investment per cow (fl) = 785 + 4497 /stable size. With a lifetime of 10 years and a real interest rate of 4% annualized capital costs are some 12 % of the investments. Remaining costs are assumed to be 8 % of the initial investments due to a lack of data at present on the type of costs. Consequently, total annual costs per animal equal 20% of the investments.

B. PIGS

Large adaptations in the stable may reduce emissions from the stable with 50 % (Baltussen et al., 1990c). Oosthoek et al. (1990a, 1990b) conclude that the reduction in ammonia emissions that can be achieved is 60 to 70%. Their result is based on a pilot plant using a manure flushing system in combination with a replacement pump or drainage system in the stable. In this case the mixture of urine, faeces and flushing liquid is replaced at regular intervals. The mixture is separated into a liquid and solid fraction. The solids are disposed, the liquid is aerated to convert ammonia into nitrate (nitrification), followed by sedimentation. The flushing liquid is re-used. Since nitrate is converted into nitrogen (de-nitrification) the flushing liquid contains very low quantities of mineral nitrogen. Hakvoort et al. (1990) estimate the reduction at 70 % for the Hepaq system. This is as system which frequently removes manure from the stable, the manure is split into a solid and liquid fraction and finally the liquid fraction is treated and evaporated.

Cost estimates are preliminary due to a lack of experience. Baltussen et al. (1990c) estimate the investments at 75 — 150 fl/ pig place for fattening pigs. They are 1.5 times higher for stalls with less than 500 pigs (the average situation). For sows investments are 250 to 375 fl/animal place. Annual costs are roughly 20 % of the investments. Based on their present experience, Hakvoort et al. (1990) estimate the investments for a stall for fattening pigs with 80 pig places at 100 to 150 FL/pig place.

For pig stables smaller than 500 pigs we assume that investments for fattening pigs are 150 fl/ pig place. For larger stables investments are Fl 100. For sows investments are 280 fl/ pig place. Per average pig (0.51 fattening pig + 0.49 sow) the investment is 237 fl/ pig place for stables smaller than 500 pigs and 188 fl/pig place for larger stables. Given lack of observations on the economies of scale with respect to investment costs we simply assume the same function that proved correct for the reductions of sulphur and nitrogen oxides (Amann, 1990; Amann, 1987); that is investments are inversely correlated with the size of the installation. We derived the following function; investment per pig place (Fl): 199 + 198/stable size.

As with dairy cows we assume that fixed operating costs are 8% of the investments. This is done because no data were yet available on operating costs. The lifetime is 10 years. Given the standard net interest rate of 4 per cent total annual costs will be 20% of the investment. The reduction in stable emission is 65%.

C. LAYING HENS

The ammonia emissions of laying hen stables to a large extent depend on the type of stall system (Kroodsma et al, 1990, Van Horne, 1990) as table II.1 shows:

Table II.1. NH_3 emission and laying hen systems

Stable Type		NH_3 Emission Per Animal Place (gram NH_3)		Frequency in 1986 (%)
		Van der Hoek (1989)	De Winkel (1988)	
1.	Open storage below stall	83	308	25
2.	Removal belt and slurry storage	25	39	47
3.	Channel/highrise stall	386	386	10
4.	Removal belt with forced drying	35	30	6
5.	As 4 with open storage	85	60	9
6.	Ground- or strawfloor	178	178	3
Weighted average		91	146	

The application of a manure belt with forced drying of manure is clearly an option to reduce ammonia emissions. Other options are drying the manure in a tunnel. Preference for this option also exists because the manure is dryer and disposal and transportation costs are lower. Compared to the present situation, this would imply a reduction in ammonia emissions of 60 to 80%, depending on the reference situation (Kroodsma et al., 1990). We estimate the reduction at 60%.

The additional costs (Van Horne, 1990) are described in Table II.2.

Table II.2 Annual costs (25000 hens). In guilders.

		1986	Manure belt forced drying	Difference
		O	A	O—A
1.	Annualized investment costs	2100	12500	10400
2.	Manure surplus charge	5500	1875	-3625
3.	Storage costs	8800	3900	-4900
4.	Electricity	1060	6250	5190
5.	Heating	0	2500	2500
	Total	17460	27025	9565

The reference situation is the present situation, taking into account the frequency distribution of the stall types and their costs (Van Horne, 1990). The additional costs of other, comparable emission poor systems are more or less comparable (Total costs 20000 to 40000 fl). In view of the uncertainty involved in the cost estimates, the necessity to reduce the level of detail, the fact that surplus charges do not exist in other countries than the Netherlands,the fact that subsidies and taxes are transfer payments which are to be ignored in cost-benefit type of analysis (Hufschmidt et al., 1988), we ignore the surplus manure charge and extract the storage costs from the annualized additional investment costs [4]. The net annualized investments costs are therefore estimated at only of 5500 fl. Given a lifetime of 10 years, a real interest rate of 4%, the investment is around 46000 fl. Electricity use is 20000 Kwh a 0.25 fl. This is 0.8 Kwh/animal place. This corresponds with 1 kwh per (delivered) animal [5]. Gas use is 5000 m3 a 0.5 fl/m3. That is 0.2 m3 per animal place. That is 0.25 m3 per delivered animal.

D. BROILERS

Floor heating and insulation of broiler stables may reduce stable emissions with some 23 % (Van Horne, 1990). Recent measurements (Oosthoek et al., 1990, Kroodsma et al., 1990), however, indicate that the reduction is somewhat smaller: 11—13 %. Accordingly, the associated reduction in the stable and storage emission coefficient is assumed to be 10%.

Investments are 57600 fl for new stables and 83782 fl for existing stables for a stable of 23000 chickens (Van Horne, 1990; Evers, 1988). Lifetime of an existing stable is 10 years, of a new stable 15 years. Annualized investments costs are fl 10330 for existing stables and fl 4233 for new stables (interest rate 4%). That is fl 7280 on average. Assuming a standard (default) lifetime of ten years this corresponds with an investment of fl 59000. Per animal place this is fl 2.57.

Fixed costs are 1% of the investments. Variable costs consist of savings on natural gas use of 1350 m3 a fl 0.50 (Evers, 1988) for 23000 animal places: 0.0587 m3 per animal place. To obtain

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[4] This also implies that the costs from a micro-economic perspective are somewhat different and our costs calculation not necessarily reflect the cost the individual farmer has to make.

[5] Note that transformation from data per animal place or per delivered animal (x/animal) into data per animal per year is based on the following formulas:

x/animal place = x/animal * animal rounds per year

x/animal per year = x/animal place * 1/rate of occupation

x/animal per year = x/animal * animal rounds per year/rate of occupation the figure per animal we have to divide through the number of animal rounds per year (6.07). Energy savings per animal are thus 0.0097 m3/animal [6].

APPENDIX III. COVERING MANURE STORAGE

A. DAIRY COWS AND OTHER CATTLE

The additional investments for covering manure storage consist of the costs of the cover minus the smaller initial investment outlay for the silo itself, compared to open storage, since rain does not enter the silo. For a silo of 233 m3 manure the additional investments are fl 13610. Per m3 this is Fl 58,—. The storage capacity has to be sufficient for 2 months storage (Baltussen et al. 1990b p. 52).

The manure production per animal is 22 m3/dairy cow and 7.7 m3 for other cattle (based on Kuik (1987) and the 1989 distribution of cattle over the various animal types in the Netherlands). Consequently the storage capacity per dairy cow is 2/12 x 22 and for other cattle 2/12 x 7.7 m3. To calculate the investment per animal place we have to divide by the number of animal rounds per year. This leads to the following Table III.1. for a silo of 233 m3.

Table III.1. Costs of covering manure storage

		Dairy cows	Other Cattle
Investment	fl/m3	58	58
Manure production/animal	m3	22	7.7
Storage per animal	m3	3.67	1.28
Investment/animal	fl/animal	214	74.8
Animal rounds/year		1.00	0.9
Investment/animal place	fl/place	214	83

The investments depend on the size of the silo. Using the above figures for the storage capacity per animal and data on the investment as function of the silo size (see Baltussen, 1990b, p.53) we can determine the following function relations between stable size (number of animal places) and the investment:

Dairy cows: investment (Fl/animal) = 44.01 + 10765.78 / size

Other cattle: investment (FL/animal) = 15.34083 + 3759.42 / size.

The lifetime of the installation is 10 years. Costs other than the annualized investment costs are negligible.

The emission reduction is 90 % compared to open storage. However, since only a small part (some 10 % , see Baltussen 1990b, p 52) of the emission during stable and storage is actually released during the storage the removal efficiency is only 10% times 90%. This is approximately 10% of the stable plus storage emission coefficient.

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[6] In order to account for differences in fuel prices the data might be converted into Kilojoule. 1 M3 natural gas corresponds with 35.2 MJ. Consequently the energy savings are 341 KJ per animal. The fuel price is 12.5 DM/KJ for the Netherlands. Country specific fuel prices might be found in Amann (1990). In view of the uncertainty in data and the necessity to restrict the number of variables, these fuel price differences are neglected.

APPENDIX IV. BIOFILTRATION AND BIOSCRUBBING

A. PIGS

Costs for biofiltration typically show a large spread. Investments for the total installation vary between 150 and 500 fl/animal place for fattening pigs (Zeisig, 1990; DHV, 1986; Jol, 1990; Eggels, 1989; Demmers, 1989). The total annual costs per pig place also show this range and vary between fl 23,— to fl 95 per pig place. Based on the literature we constructed Table IV.1 for a stable of 80 pigs:

Table IV.1. Costs of biofiltration

Investments Investment/pig place lifetime	fl fl/place year	18000 225 10	
Annualized capital costs (fl).			2217
Fixed costs	2% of Investment.		360
Variable costs: ●Labor ●Water ●Electricity ●Waste disposal	 10 hours at fl 25/hour 64 m3 at fl 1/hour 1800 kwh at fl 0.25/kwh 12 inhabitant equivalents at fl 25/i.e.		250 64 450 624
Total annual costs	fl		3966

This corresponds to some fl 50,- per pig place.

Economics of scale are likely although only rough estimates exist. Based on information of Scholtens (1990) and Eggels et al. (1990) the following estimate of the relation between investment and stable size was compiled for fattening pigs (see Table IV.2.):

Table IV.2. Investment in biofiltration and stable size.

Stall Size	Surface filter	Investments		Other	Total
		Filter and sluice	Filter Material		
(Pigs)	(m2)	(FL)	(FL)	(FL)	(FL)
20	4.5	5300	620	750	6670
40	9.0	7000	1240	1500	9740
60	13.5	10500	1859	2250	14609
80	18.0	12200	2479	3000	17679
100	22.5	14200	3099	3750	21049

This would imply the following relation between investment/pig place (in guilders) and stable size:

$$\text{Investment/place} = 183.0954 + 2947.096 \text{ /stable size.}$$

Variable costs per animal can be found by dividing the costs per animal place by the number of animal rounds per year (2.7 rounds per year).

For sows the investments and annual cost are 2.89 times the costs of fattening pigs (Baltussen et al. 1990c). For the average pig investments and costs are 0.51 x costs fattening pigs + 0.49 x costs sows (according to 1988 distribution of sows and fattening pigs in the Netherlands). Costs for pigs are thus 1.92 times the costs of fattening pigs. This implies the following Table IV.3.

Table IV.3. Costs for fattening pigs and pigs

Investment coefficients			**Fattening pigs**	**Pigs**
• fixed	cif	fl/animal place	183.1	351.6
• variable	civ	fl/animal place	2974	5658
Lifetime	lt	years	10	10
Fixed costs	fk	% of investment	2	2
Variable costs:				
• labor	Ql	hours	0.0463	0.089
• water	Qw	m3	0.296	0.57
• electricity	Qe	kwh	8.3	16.0
• waste	Qd	i.e	0.0556	0.107

Prices are as in the dutch examples unless country specific prices are used (e.g. electricity). The reduction in stable emission is 90%.

B. LAYING HENS AND BROILERS

Based on Van Horne (1990) the investments and costs of bioscrubbing for poultry (8000 m3 ventilation capacity which corresponds to 1230 animal places) are as follows (Table IV.4):

Table IV.4. Costs of biological scrubbers

Investments Investment/animal place Lifetime	fl fl/place year	13035 10.6 10	
Annualized capital costs (fl)			1627
Fixed costs	4% of Investment.		521
Variable costs:			
•water •electricity •waste disposal	90 m3 a fl 1/m3 10000 kwh a fl 0.15/kwh 5.4 inhabitant equivalents fl 52/i.e.		90 1500 281
Total annual costs:			4019

Variable costs per animal are calculated by dividing through the number of animal rounds per year:
laying hens: 0.8
broilers: 6.07
The removal efficiency is estimated at 80%.

APPENDIX V. LOW MANURE APPLICATION

The additional costs of direct ploughing down of manure (direct application) are fl 3.25 per m3 manure if 30 m3 manure is applied per hectare. (Baltussen, 1990b, p56; Huijsmans, 1990). The rate is fl 97.50 /ha. The removal efficiency is 90%.

The additional costs of manure injection, in comparison to superficial application, are (Baltussen, 1990b):

me Manure/ha	costs (fl/m3)
30	3.56
40	3.12

Cost estimates show a large spread (Huijsmans, 1990: Krebbers, 1990) and vary between fl 2.36 and fl 5.00 /m3. Assuming economics of scale and a linear function the following equation can be constructed:

Cost injection fl/m3 = 4.49 - 0.031 * m3 manure per hectare.

Manure injection on grassland is not applicable on every soil type. Sod injection, however, is an alternative with approximately the same costs per m3 as manure injection, although the removal efficiency is somewhat lower (80% reduction) than with manure injection (90%). For reasons of simplicity we calculate with a 90% efficiency.

The additional costs of manure sprinkling systems vary between 6 to 18 fl/manure (Huijsmans 1990). Baltussen et al (1990b) estimate the variable costs at 0 to 3.0 fl/m3 manure and the fixed costs at 4410 - 7540 Fl/year. The costs per m3 manure than depend to a large extent on the manure production per year. Using the average stable size of dairy cow stables as indicator, in combination with a manure production of 22 m3/ animal per year we assume the following relationship for manure sprinkling:

$$\text{Cost sprinkling fl/m3} = 1.5 + 6000/(ss_d * 22)$$

Where ss_d is the stable or herd size for dairy cows. Note that there are again savings on the costs of fertilizer use. Still sprinkling is generally speaking more expensive that manure injection. In addition, water availability may prohibit its use. It may however be an alternative for those cases where: a sprinkling installation is already available for other purposes, soil type (underground and slope) do not permit manure injection. The emission reduction is estimated at 70% compared to superficial application.

APPENDIX VI. ADDING ACID TO MANURE

Another alternative to reduce the emissions from the stable and during application is the addition of acid to the manure (Baltussen et al. 1990.b; Esteban Turzo et al, 1988). For dairy cows (cf. Baltussen et al. 1990b) stable emissions may be reduced with 50% and emissions during application with 100%. These results, however, are based on only one practical experiment. In addition the addition of acid may increase the nitrogen surplus on a farm level which limits its applicability.

The associated costs can only roughly be estimated. The investments depend on the size of the stable (Baltussen, 1990b). For stables with less than 40 cows one manure circulation system is sufficient (investment FL 41000). For larger stables two systems necessary (investment FL 55000). Assuming similar function shapes as usual the following relationship can be constructed: investment\animal place (FL) = 475 + 26490 / stable size.

Fixed costs are 2 % of the initial investments. variable costs consist of additional energy costs of mixing minus the costs savings on mixing (sum of both approximately zero) plus the costs of acid minus the savings on fertilizer use. The acid use is 37 liter/ m3 manure * 22 m3/animal is 814 liter per animal. The savings in fertilizer use are 4.74 kg N per m3 manure. This corresponds with 104 kg N per animal. This leads to the following Table VI.1:

Table VI.1 Cost of adding acid to the manure

Parameter		Units	
Coefficients for the investment	cif	Fl/animal	475
Function	civ		26490
Lifetime	lt	year	10
Fixed costs	fk	% investment	2
Variable costs			
Acid use	Qx	lit/animal	814
Fertilizer use	Qk	kg/animal	-104
Acid price	cx	fl/litre	0.27
Fertilizer price	ck	fl/kg	country specific
Removal efficiency			
Stable	xs	%	50
Application	xa	%	100

APPENDIX VII. COMBINATIONS OF TECHNIQUES

The following Tables A to E present the combinations of techniques which are allowed in the model and the associated removal efficiencies.

TABLE VII.1. COMBINATION OF OPTIONS DAIRY COWS

Option			Emission Reduction (%)		
			Stable	Application	Meadow
1	Low N-feed	(LNF)	20	20	25
2	Stable adaptation	(SA)	50	-9	0
3	Closed storage	(CS)	10	-1	0
4	Low N-application	(LNA)	0	90	0
5	LNF + SA		60	14	25
6	LNF + CS		28	19	25
7	LNF + LNA		20	92	25
8	SA + LNA		50	89	0
9	CS + LNA		10	90	0
10	LNF + SA + LNA		60	91	25
11	LNF + CS + LNA		28	92	25

Combinations of 2 and 3 are excluded.

TABLE VII.2. COMBINATION OF OPTIONS OTHER CATTLE				
Option		Emission Reduction (%)		
		Stable	Application	Meadow
1	Closed storage (CS)	10	-1	0
2	Low N-application (LNA)	0	90	0
3	CS + LNA	10	90	0

TABLE VII.3. COMBINATION OF OPTIONS PIGS					
Option			Emission Reduction (%)		
			Stable	Application	Meadow
1	Low N-feed	(LNF)	15	15	0
2	Stable adaptation	(SA)	65	-9	0
3	Biofiltration	(BF)	90	-16	0
4	Low N-application	(LNA)	0	90	0
5	LNF + SA		70	8	0
6	LNF + BF		92	5	0
7	LNF + LNA		15	91	0
8	SA + LNA		65	89	0
9	BF + LNA		90	88	0
10	LNA + SA + LNA		70	91	0
11	LNF + BF + LNA		92	90	0
Combinations of 2 and 3 are excluded.					

TABLE VII.4. COMBINATION OF OPTIONS LAYING HENS					
Option			emission reduction (%)		
			Stable	Application	Meadow
1	Low n-feed	(LNF)	10	10	0
2	Stable adaptation	(SA)	60	-17	0
3	Biofiltration	(BF)	80	-26	0
4	Low N-application	(LNA)	0	90	0
5	LNF + SA		64	-18	0
6	LNF + BF		82	-14	0
7	LNF + LNA		10	91	0
8	SA + LNA		60	88	0
9	BF + LNA		80	88	0
10	LNF + SA + LNA		64	88	0
11	LNF + BF + LNA		82	89	0
Combinations of 2 and 3 are excluded.					

TABLE VII.5. COMBINATION OF OPTIONS BROILERS					
Option			Emission Reduction (%)		
			Stable	Application	Meadow
1	Low n-feed	(LNF)	20	20	0
2	Stable adaptation	(SA)	10	-7	0
3	Biofiltration	(BF)	80	-51	0
4	Low N-application	(LNA)	0	90	0
5	LNF + SA		29	14	0
6	LNF + BF		84	-21	0
7	LNF + LNA		20	92	0
8	SA + LNA		10	89	0
9	BF + LNA		80	85	0
10	LNF + SA + LNA		29	91	0
11	LNF + BF + LNA		84	88	0
Combinations of 2 and 3 are excluded.					