Status Report

COSTS OF CONTROLLING AMMONIA EMISSIONS IN EUROPE

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Abstract

This paper presents the costs of controlling ammonia emissions in 27 countries in Europe. Abatement options are low nitrogen feed, stable adaptations, covering manure storage, cleaning stable air and low ammonia applications of manure. Cost estimates are based on country-, animal-, and technology-specific data such as stable size, fertilizer price, manure per hectare and the investments per animal place. The results suggest that a 30 per cent flat rate reduction would cost 5.5 billion Deutsche Marks/year, but would not be feasible everywhere in Europe. The maximum feasible reduction in total European emissions is 40 per cent. The associated costs are 67 billion Deutsche Marks/year.

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COSTS OF CONTROLLING AMMONIA EMISSIONS IN EUROPE

Ger Klaassen[1]

1 Introduction

Acidification of the environment caused by atmospheric pollution is one of 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 (see Figure 1), 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 (Alcamo et al., 1990). 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.

This paper describes the costs of control strategies for NH_3 emissions. It is an extension and update of previous work (Klaassen, 1990). In contrast to the cost estimates available for controlling sulphur and nitrogen oxides emissions, the cost estimates for ammonia emissions are more uncertain, at least for specific control options such as stable adaptations, due to a lack of practical experience. 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 should be seen as comparative rather than absolute cost estimates: the emphasis is put on international consistency and comparability.

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Major sources of ammonia emissions are: livestock farming, fertilizer use and industry (Klaassen, 1991). Options are available to control ammonia emissions from livestock farming and industry. Ammonia from livestock farming is released during three basic processes (Figure 2):

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

For each of these processes techniques are available to control ammonia emissions. In addition, changes in the nitrogen content of the feed influence emissions of all three processes. In brief, the following options can be distinguished to control the ammonia emissions from livestock farming (see Baltussen et al., 1990a; Hannessen, 1990; Kuik, 1987; Oudendag and Wijnands, 1989):

– 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),
    - covering manure storage,
    - cleaning of stable air (bio filtration or -scrubbing),
– low ammonia application (e.g. direct ploughing down 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 2). 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 1 presents the abatement options distinguished in RAINS. Including combinations of the various abatement techniques, 48 different options are available. The combinations which are possible, as well as the reductions in emissions of these techniques, are presented in Appendix VII.

In several branches of the chemical industry emission reductions of 95 per cent can be achieved. This is possible through the application of stripping and absorption techniques (Tangena, 1985; Technica, 1984).

The remainder of this paper is as follows. Section II describes the costs of controlling ammonia emissions from livestock farming of: low nitrogen feed, stable adaptations, covering manure storage and biological filters. These techniques are described in one section since the algorithm is the same. Section III presents the costs of manure application techniques that decrease ammonia emissions. Section IV introduces the combinations of techniques available for livestock farming. Section V presents the costs of controlling industrial ammonia emissions. Resulting cost coefficients, cost functions and costs of various control scenarios are presented in section VI.

2 Low Nitrogen Feed, Stable Adaptations, Covering Manure Storage and Cleaning Stable Air

2.1 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 maize for dairy cows (Baltussen, et at., 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 changes in the composition of the raw materials and supplementing diets with synthetic amino acids for pigs and poultry (Baltussen, et al., 1990a; Lenis, 1989: Spiekers and Pfeffer, 1990),

For various animal categories, low emission stable systems that prevent the escape of ammonia are possible. 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, minimizing the time during which ammonia is in contact with air, or adding acid to manure (Hannessen, 1990). The preliminary cost estimates used in this study are based on 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 : forced drying of littered, slatted floor.

For most of these systems, especially for pigs and dairy cows, cost estimates are uncertain since hardly any practical experience exists. [2]

Covering manure storage facilities 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. However, these techniques can only be applied in those cases where stables are equipped with mechanical ventilation. This is usually the case for poultry but not always for pigs (Asman, 1990). Techniques for mechanical ventilation are bio filtration, bio scrubbing and chemical scrubbers, however the application of bio filtration for poultry stables may be difficult due to dust problems.

[2] For dairy cows another alternative stall system involves the addition of nitric acid to the manure, which suppresses ammonia formation. Details are provided in Appendix VI. This alternative was not considered since only one stable system could be included for each animal type, and adding acid was believed to be a less likely alternative (Baltussen et al., 1990b).

2.2 The algorithm

The algorithm used in the cost calculation routine includes technology- and animal-specific, as well as country-specific, factors for comparing the costs of abating ammonia emissions per country (see Table 2).

2.2.1 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 stable size:

$$I_{i,k,l} = ci^{f}_{i,k} + \frac{ci^{v}_{i,k}}{ss_{i,l}} \qquad (2.1)$$

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:

$$I^{an}_{i,k,l} = \frac{I_{i,k,l} \times (1+q_l)^{lt} \times q_l}{(1+q_l)^{lt}-1} \qquad (2.2)$$

2.2.2 Fixed operating costs

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

$$OM^{fix}_{i,k,l} = I_{i,k,l} \times fk_{i,k} \qquad (2.3)$$

2.2.3 Variable operating costs

Variable operating costs may consist of the following elements:

- increase in feed costs per animal due to 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:

$$OM^{var}_{i,k,l} = Q^f_i \times c^f + Q^g_i \times c^g + Q^l_i \times c^l + Q^w_i \times c^w + Q^e_i \times c^e_l + Q^d_i \times c^d \qquad (2.4)$$

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

2.2.4 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:

$$ca_{i,k,l} = \frac{(I^{an}_{i,k,l} + OM^{fix}_{i,k,l})}{sb_i} + \frac{OM^{var}_{i,k,l} \times ar_i}{sb_i} \qquad (2.5)$$

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 abatement options may simultaneously reduce emissions during stable and storage, application and in the meadow:

$$cn_{i,k,l} = \frac{ca_{i,k,l}}{nh3s_{i,l} \times xs_{i,k} + nh3a_{i,l} \times xa_{i,k} + nh3m_{i,l} \times xm_{i,k}} \qquad (2.6)$$

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

2.3 Costs of low nitrogen feed

For dairy cows nitrogen excretion can be lowered if the level of nitrogen application on grassland is reduced from 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 calculations show that reductions in stall emissions by 10 to 30 per cent (on average 20 per cent) and in meadow emissions of around 25 per cent for dairy cows are possible. Spiekers and Pfeffer (1990) indicate that a reduction of 10 to 15 per cent in nitrogen excretion would be possible. Whether this alternative is possible in other European countries, with the exception of Denmark and the Federal Republic of Germany, is uncertain since levels of nitrogen application of grassland in other European countries are generally far below the level in the Netherlands. Consequently, the user of RAINS is allowed to limit the potential applicability of this alternative.

For pigs, multi-phase feeding, in combination with nitrogen poor feed or synthetic amino acids, reduces nitrogen in the excretion by 5 per cent for fattening pigs and 20 per cent for sows

(Baltussen et al., 1990c). Spiekers and Pfeffer (1990) even suggest that reductions up to 35 per cent are possible for fattening pigs and 15 per cent for sows. Lenis (1989) is of the opinion that synthetic amino acids my achieve reductions of 25 per cent for both pigs and sows in the long term.

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 in the case of pigs is the introduction of low nitrogen feed 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 3. Appendix I provides details. Data are based on Baltussen et al. (1990a, 1990b, 1990c) and Van Horne (1990). The investment costs are annualized over the lifetime lt of the installation using the interest rate q_l. There are no fixed operating costs. Variable operating costs consist of the increase in feed costs per animal due to the higher prices of low nitrogen feed. These costs are based on changes in the composition of raw materials for feed production for the situation in the Netherlands. Results for the Federal Republic of Germany (Spiekers and Pfeffer, 1990) however, show that the cost increases for pigs in the Netherlands and the Federal Republic of Germany are comparable.

2.4 Costs of stable adaptations

Washing the stable floor of dairy cow stables and frequently removing the manure to a closed storage system, can reduce ammonia emissions by 50 to 70 per cent (Oosthoek et al., 1990a). Costs consist of the washing system in combination with manure storage capacity (Baltussen, 1990b). For pig stables, Oosthoek et al. (1990a, 1990b) conclude that the reduction in ammonia emissions that can be achieved is 60 to 70 per cent. This is based on 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 and Paques (1984). The application of a manure belt with forced drying of manure reduced emissions from laying hens stables by some 60 per cent (Van Horne, 1990; Kroodsma et al, 1990). Forced drying of slatted, littered floors or trampoline systems are expected to reduce ammonia emissions from broiler housing systems by 90 per cent (Boonen, 1990; Brunnekreef, 1991). Costs mainly consist of additional investments, costs of recirculating air, energy and litter use.

The investment function for stable adaptations is the same as for low nitrogen feed. The technology- and animal-specific data are presented in Table 4. For cow sheds and pig sties the investments depend on the stable size. These relationships should be regarded as tentative, in view of the lack of experience. Country-specific data on the number of animals per stable (see Table 9) are based on national and international statistics. For Eastern Europe these data are generally absent. 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 both types of farms. Appendix II supplies details. The 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 investment per animal place. Due to a lack of experience with these techniques generally no specification of the variable operating costs for pigs and dairy cows was possible yet. 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 laying hens.

2.5 Costs of covering manure storage

Covering the storage of manure prevents 90 per cent of the ammonia emissions (Baltussen et al. 1990b). Since only part (some 10 per cent) of the total ammonia released during stable and storage actually escapes from the storage, the overall removal efficiency is only 10 per cent. Costs consist of investments only (Baltussen et al., 1990b)(see Table 5). 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. The investments depend on the size of the silo and thus indirectly on the number of animals per stable (Table 9). Appendix III provides details. Covering of storage is only feasible if storage facilities already exist or are expected as a result of national legislation.

2.6 Costs of cleaning stable air (bio filtration or scrubbing)

Another possibility to control the emissions from the stable is the application of various techniques that clean the stable air. Techniques are bio filtration, bio scrubbing and chemical scrubbers. The removal efficiency is generally very high: 80 to 90 per cent of the stable emissions are removed. Cost estimates show wide ranges (Zeisig and Wolferstetter, 1990; Eggels and Scholtens, 1989; Demmers, 1989; Jol, 1990; van Horne, 1990; Baltussen et al., 1990b). The investment depends on the size of the installation (Scholtens, 1990; Jol, 1990). The data are included in Table 6 (also compare Appendix IV).

Again investment costs are annualized over the lifetime of the installation using the interest rate. Fixed operating costs are presented as a fixed percentage of the investments per animal place. No country specific prices are incorporated for labor, water and waste disposal 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 than capital costs and electricity prices (Table 9).

3 Low Ammonia Application of Manure

3.1 Introduction

To prevent the escape of ammonia during application of manure on arable land or grassland a wide variety of techniques exists (Huijsmans, 1990; Krebbers, 1990; Havinga, 1991):

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

Furthermore, the processing of manure to control manure surpluses, as a side effect, reduces ammonia emissions during application. This option, however, is less likely in countries where the manure surplus is less of a problem than in the Netherlands. In addition, the costs of manure processing are too high to justify its application for controlling ammonia emissions only.

The applicability of these techniques (apart from manure processing) depends, amongst other things, on soil type, water availability (sprinkling), and the slope of the soil. Sod manuring can be applied on soils with low carrying capacity (heavy clay soils or peat soils) where manure injection may not be feasible. Dilution of manure is partly practiced in Alpine countries and may be more appropriate for soils in steeply sloped areas.

Costs are expressed per m^3 manure applied since these techniques are usually carried out by contractors whose services can be rented by the individual farmer. In addition, this avoids unnecessary complications in the cost calculation routine. Costs per m^3 manure depend on, among other things, the technique, the volume of manure applied (m^3 per hectare)(Huijsmans, 1991) and the distances between land and storage (Krebbers, 1990; Havinga, 1991). 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 ammonia 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, sod manuring, sprinkling or manure processing) minus the cost savings.

3.2 The algorithm

The costs of direct application or ploughing down per m^3 manure are:

$$c^{ma}_l = c^{fma} + c^{vma} \times Q^{mh}_l \qquad (3.1)$$

With:

c^{fma} the fixed costs of direct application per m^3 manure

c^{vma} the variable costs of direct application

Q^{mh}_l the amount of manure applied per hectare

The cost of manure injection per m^3 manure are:

$$c^{mi}_l = c^{fmi} + c^{vmi} \times Q^{mh}_l \qquad (3.2)$$

c^{fmi} the fixed costs of injection per m^3 manure

c^{vmi} the variable cost of injection per m^3 manure

Q^{mh}_l the amount of manure applied per hectare

The cost of sod manuring, or shallow injection, per m^3 manure are:

$$c^{ms}_l = c^{fms} + c^{vms} \times Q^{mh}_l \qquad (3.3)$$

c^{fms} the fixed costs of sod manuring per m^3 manure

c^{vms} the variable cost of sod manuring per m^3 manure

Q^{mh}_l the amount of manure applied per hectare

The costs of sprinkling, c^{mr}, per m^3 manure consist of fixed and variable elements. The fixed costs consist of the investment in the installation. The costs per m^3 manure then depend on the manure production per farm, a function of the number of animals:

$$c^{mr}_{l} = c^{fmr} + \frac{c^{vmr}}{ss_{dl}} \qquad (3.4)$$

c^{fmr} the fixed costs of sprinkling per m^3 manure

c^{vmr} the variable cost of sprinkling

ss_{dl} the stable size for dairy cows

The costs of manure processing, c^{mp}, cannot be fully attributed to ammonia emission control since the technique is primarily directed at controlling nitrate and phosphate surpluses. Therefore only a fraction of the costs (fcn3) is attributed to ammonia:

$$c^{mp}_{l} = fcn3 \times c^{fmp} \qquad (3.5)$$

c^{fmp} the costs of processing per m^3 manure

fcn3 fraction of costs attributed to ammonia

In addition to the costs of low ammonia application of manure there are also costs savings due the reduction in fertilizer use. Per animal these costs savings are:

$$OM^{nf}_{i,k,l} = nh3a_{i,l} \times xa_{i,k} \times (1-S^{mp}{}_l) \times 0.5 \times \frac{14}{17} \times c^{k}_{l} \times \frac{sb_i}{ar_i} \qquad (3.6)$$

With:

$nh3a_{i,l}$ the emission coefficient for application

$xa_{i,k}$ the removal efficiency of application

c^{k}_{l} the fertilizer price

S^{mp}_{l} the share of manure processed

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 by a factor of two. Therefore only half of the ammonia is assumed to lead to savings in fertilizer use. For that part of the manure that is processed (S^{mp}_l) there are no savings in fertilizer use.

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

$$OM^{var}_{i,k,l} = (c^{ma} \times S^{ma}_l + c^{mi} \times S^{mi}_l + c^{ms} \times S^{ms}_l + c^{mr} \times S^{mr}_l + c^{mp} \times S^{mp}_l) \times M_{i,l} - OM^{nf}_{i,k,l} \tag{3.7}$$

In which:

S^{ma}_l	the share of manure directly applied
S^{mi}_l	the share of manure injected
S^{ms}_l	the share of manure sod manured
S^{mr}_l	the share of manure sprinkled
S^{mp}_l	the share of manure processed
$M_{i,l}$	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. 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:

$$ca_{i,k,l} = \frac{OM^{var}_{i,k,l} \times ar_i}{sb_i} \tag{3.8}$$

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:

$$cn_{i,k,l} = \frac{ca_{i,k,l}}{nh3s_{i,l} \times xs_{i,k} + nh3a_{i,l} \times xa_{i,k} + nh3m_{i,l} \times xm_{i,k}} \tag{3.9}$$

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

3.3 The costs of low ammonia application

Direct application of manure, or ploughing down, can reduce ammonia emission by 80 to 90 per cent in comparison to superficial application. The removal efficiency of manure injection is 90 to 99 per cent. The reduction to be achieved by sod manuring, or shallow injection, varies between 75 and 99 per cent. Sprinkling, trenching or the dilution of manure has a removal efficiency of 75 to 90 per cent (Havinga, 1991; Huijsmans, 1990; Huijsmans and Bruins, 1990; Krebbers, 1989, 1990). When manure is processed the reduction would be 100 per cent.

The net costs for direct application are 0 to 7 DM/m^3 and for manure injection 0 to 5 DM/m^3. Sod manuring costs vary between 3 and 7 DM/m^3. Sprinkling is more expensive: costs are 6 to 18 DM/m^3. The data are based on Baltussen et al. (1990b), Krebbers (1990), Huijsmans (1990), Havinga (1991). Manure processing costs around 25 to 35 DM/m^3 (Stoop, 1989: Reichow and Yawari, 1990; Vroege, 1990).

The costs are, amongst other things, dependent on the amount of manure applied (Huijsmans, 1991; Baltussen et al., 1990b). Table 7 gives the cost data used in this study. Country specific elements are: the shares of the different low ammonia application techniques (Table 10), the volume of manure per hectare and the fertilizer price (Table 11) and the manure production per animal (Table 12). As default values 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 to the share of grassland in each country (FAO, 1989b). For the time being the default value for the shares of sod manuring and sprinkling are set zero due to a lack of data. The user of RAINS is allowed to change these values. Only in the Netherlands is manure processing assumed to take place (8 per cent of the manure; Vroege, 1990). Since the costs of manure processing are much higher than the other techniques it is not applied for ammonia control but geared towards controlling manure (mineral) surpluses. Therefore, the fraction of the costs of manure processing attributed to ammonia control is zero in this specific example. Appendix V supplies more details on the calculation of the parameters.

4 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 per animal per year are simply the sum of the costs of the separate options, but the removal efficiencies of the combinations are less or equal than the sum of the removal efficiencies of the separate options. For example, low nitrogen feed for dairy cows may reduce ammonia emissions during application with 20 per cent. Manure injection may reduce application emissions with 90 per cent. In combination, however, the reduction is only 92 per cent. Details on the combinations that are allowed for, and the associated removal efficiencies, are given in Appendix VII. The removal efficiencies of these combinations are calculated using nitrogen balances for each animal type.

5 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 per cent (Tangena, 1985; Technica, 1984).

6 Results and Discussion

6.1 Average costs per ton emission abated

RAINS (Figure 1) offers the user two possibilities to reduce the emissions:

- scenario analysis: calculating the costs and emissions of a variety of combinations of control options, on any part of the emissions,
- optimization: i.e. reaching emission or deposition targets at minimal costs.

For the scenario analysis, the user is free to specify which number of animals have to apply specific control options. This allows the user for example, to calculate, what the impact would be of low ammonia application for all animals on sandy soils only. For this type of analysis the costs per animal per year and per ton ammonia abated for all control options are used. These can be calculated using the algorithms and parameters of the previous sections. Due to limited space, this paper will give some examples only. A complete listing can be obtained by model runs.

Table 13 shows the average costs per animal per year and the costs per ton ammonia of low ammonia application for pigs, and stable adaptations for dairy cow sheds. The costs per pig per year of low ammonia application roughly differ by a factor of two. The differences are explained by:

- the relative shares of the different low ammonia application techniques (in this example: direct ploughing down, manure injection and manure processing),
- the volume of manure per hectare,
- the emission coefficient for application of pig manure,
- the fertilizer price.

The first two elements determine the costs per m^3 manure, whereas the latter two influence the savings in the costs of fertilizer use. The costs per ton ammonia are not only affected by the costs per animal per year but also by the emission coefficient for application. At present, these differences are only of minor importance for pigs. They are more relevant for other animals, especially dairy cows.

The costs of stable adaptations for dairy cows per animal per year differ roughly by a factor of two and a half. These cost differences are caused by "economies of scale" expressed in the size of the stable (dairy cows per shed). The costs per ton ammonia abated show a wider range since the emission coefficients for application show a wide range (Klaassen, 1991). Due to the limited accuracy of the underlying statistics, especially for Eastern Europe, and the limited availability of cost data for some of the control options (e.g. stable adaptations) the magnitude of the observed variations might be questioned. Still, it seems better to introduce such differences rather than to ignore them.

6.2 Cost functions and cost minimization

For the optimization mode in RAINS it is necessary to create "national cost functions" for controlling ammonia. According to economic theory, cost functions are derived from the production possibilities, or production function, for a company, or the aggregate level of more companies. The cost function represents the offers, expressed in monetary units, that have to be made to attain a certain level of production or, in this case, a certain amount of emission control. The costs depend on the quantities of the production factors necessary to reach a certain emission level, multiplied by their prices. As shown in the previous section, national circumstances result in variations in the costs for applying the same technology in different countries in Europe. Another source of difference is to be found in the structural differences between the agricultural systems, especially in the structure of the livestock population and the intensity and type of fertilizer use, which determines the potential for application of individual control options.

One way to combine these factors is to compile national cost functions. These functions display the lowest costs for achieving various emission levels by applying the cost optimal combination of abatement options. This is done by ranking the options according to their marginal costs and their individual potential for removal and can be performed within each animal category. First, the option with the lowest (average) costs is selected. Options which have higher cost and less removal potential are considered inefficient and are removed. For the remaining options, the marginal costs are calculated compared to the first alternative, and the option with the lowest marginal costs is then considered the second best alternative. Its removal potential is subsequently compared to the remaining efficient options. Options with less removal potential are considered inefficient and removed. If further alternatives remain, their marginal costs are again computed but now in comparison to the second best alternative. The procedure is repeated until the last best alternative with the highest removal potential is selected. This procedure is repeated for each animal category, as well as for industrial emission control, and finally all the options that proved efficient are ranked according to (increasing) marginal costs. This is expressed in the national cost function.

For the purpose of this study it was not always certain to what extent the options included in the model could be (fully) applied in each country. For example, low ammonia application might not be applicable everywhere, in spite of the wide offer of techniques, due to the type or slope of the soil. Therefore, the alternative was created to restrict the potential application of options where necessary to less than 100 per cent. In this example, the following assumptions (see Appendix VIII) were made on the potential application of the techniques. Low nitrogen feed for dairy cows is fully possible in countries were the N_fertilizer level plus the N_content of animal manure exceed 200 kg N/ha, and partly possible in all other countries. Stable adaptations (dairy cows, pigs and poultry) and low nitrogen feed (pigs, poultry) are possible everywhere. The potential of (further) covering manure storage is limited if it had already been applied (Asman, 1990). If no data were available it is assumed to be partly possible. Cleaning stable air is only possible in those cases where mechanical ventilation is applied. Low ammonia application is assumed applicable on 50 per cent of the grassland only, except for the Netherlands were 100 per cent is assumed. To a certain extent the limitation of this potential seems arbitrary. Still it appears better to include the possibility to reduce the potential application, rather than to assume 100 per cent application.

The resulting national cost functions for controlling ammonia emissions, given the limited potential application, are given in Appendix IX. They are based on national agricultural pathways for the year 2000 (Klaassen, 1991). The two curves per country describe the marginal, as well as the total costs, as a function of the remaining ammonia emissions in the year 2000. In general, relatively cheap options are low ammonia application, control of industrial process emissions and stable adaptations for laying hens and broilers. More expensive are options which include bio filtration for pigs and laying hens or, depending on the stable size, covering manure storage for cattle.

6.3 Costs of several scenarios and maximum feasible reductions

The national cost functions can be used to evaluate the costs of several scenarios to control ammonia emissions in Europe. In contrast to sulphur and nitrogen oxides emissions, there are presently no overviews of national plans, nor do international agreements exist to reduce ammonia emissions. Some countries however, have already accepted legislation to control ammonia emissions (Netherlands) or are interested in doing so (Finland).

For this analysis the following scenarios were selected:

- no control (unabated emissions) in the year 2000,
- standstill (no increase over 1980 emissions), a scenario comparable to that agreed upon for NO_x (the Sofia protocol),
- a 30 per cent reduction over 1980, a scenario comparable to existing international agreements for SO_2 emissions,
- maximum feasible reductions, given the assumed limited potential applicability of some options,
- maximum feasible reduction without limits on the applicability.

Table 14 shows the ammonia emissions in the year 2000 under the various scenarios. As can be seen, unabated emissions in the year 2000 in Europe would increase by 8 per cent over 1980. In some countries, however, emissions would decrease (even by 30 per cent), in others they would increase considerably. The limited potential applicability scenario shows that the maximum feasible overall reduction in Europe would be 31 per cent. In some countries, however, this 30 per cent, or even a standstill would not be feasible, whereas other countries could reduce their emissions by 75 per cent. This occurs because in some countries (e.g., Greece) unabated emissions rise sharply from 1980 to 2000, and because the dominating sources are those (sheep, fertilizer, other cattle) for which no abatement options are available, or they are options with limited removal efficiency. If all abatement options could be applied in any situation (full potential) Europe-wide, a 40 per cent reduction in ammonia emissions is the maximum achievable. Even then, for some countries (Albania, Greece, Ireland, Spain, UK, USSR) a 30 per cent reduction would not be possible, although a standstill could be attained in every country except Greece.

The costs of the scenarios are presented in Table 15. The table shows that the total European costs of a standstill, or a 30 per cent flat rate reduction, would be nearly the same, but can not be achieved everywhere. That is, if we assume the limited potential application of various techniques, most countries can reach a 30 per cent reduction without significant costs. The maximum reduction with limited potential would cost 58 billion DM per year. If the potential were not restricted, overall NH_3 emissions in Europe could be reduced by 40 per cent at a cost of 67 billion DM per year.

6.4 Discussion

A number of factors influence the results of the analysis. First of all, forecasts on livestock population, fertilizer use and the emission coefficients determine the level of unabated emissions in 2000. Emission coefficients for ammonia require more fundamental research at the national level to produce significantly better data than now exists. Forecasts on livestock population might differ as a result of changes in population growth, income per capita, export performance, agricultural policy and consumer preferences. It seems advisable to improve the existing scenario (national agricultural pathway) where necessary and to create alternative scenarios. Secondly, cost estimates of stable adaptations for pigs, dairy cows and broilers are uncertain due to the lack of practical experience. In contrast, cost estimates for low ammonia application and cleaning stable air are firmer. Thirdly, the emission reduction that can be achieved might be underestimated for the following reasons.

- For some animal types within the category of other cattle, techniques are possible with higher removal efficiencies (e.g., bio filtration for fattening calves or stable adaptations for young cattle); generally, neither national nor international statistics supply data on the number of these type of animals.
- As a secondary effect, emissions from fertilizer use will decline if low ammonia application techniques are applied.

On the other hand, emission reductions might be overestimated, since it is not quite sure to what extent such techniques as manure injection and direct ploughing down can be applied in all countries in Europe. Since low manure application techniques are generally the cheapest, the underpinning of their potential application in Europe (e.g., using soil maps) might require some further research.

In view of the above uncertainties, the RAINS model offers the user the possibility to modify the most relevant assumptions to test the firmness of the results. In spite of the uncertainties, the results do suggest that the maximum feasible overall reduction in ammonia emissions that can be achieved in Europe is 30 to 40 per cent over the 1980 level, although this 30 per cent reduction, or even a standstill, will not be achievable everywhere.

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Figures

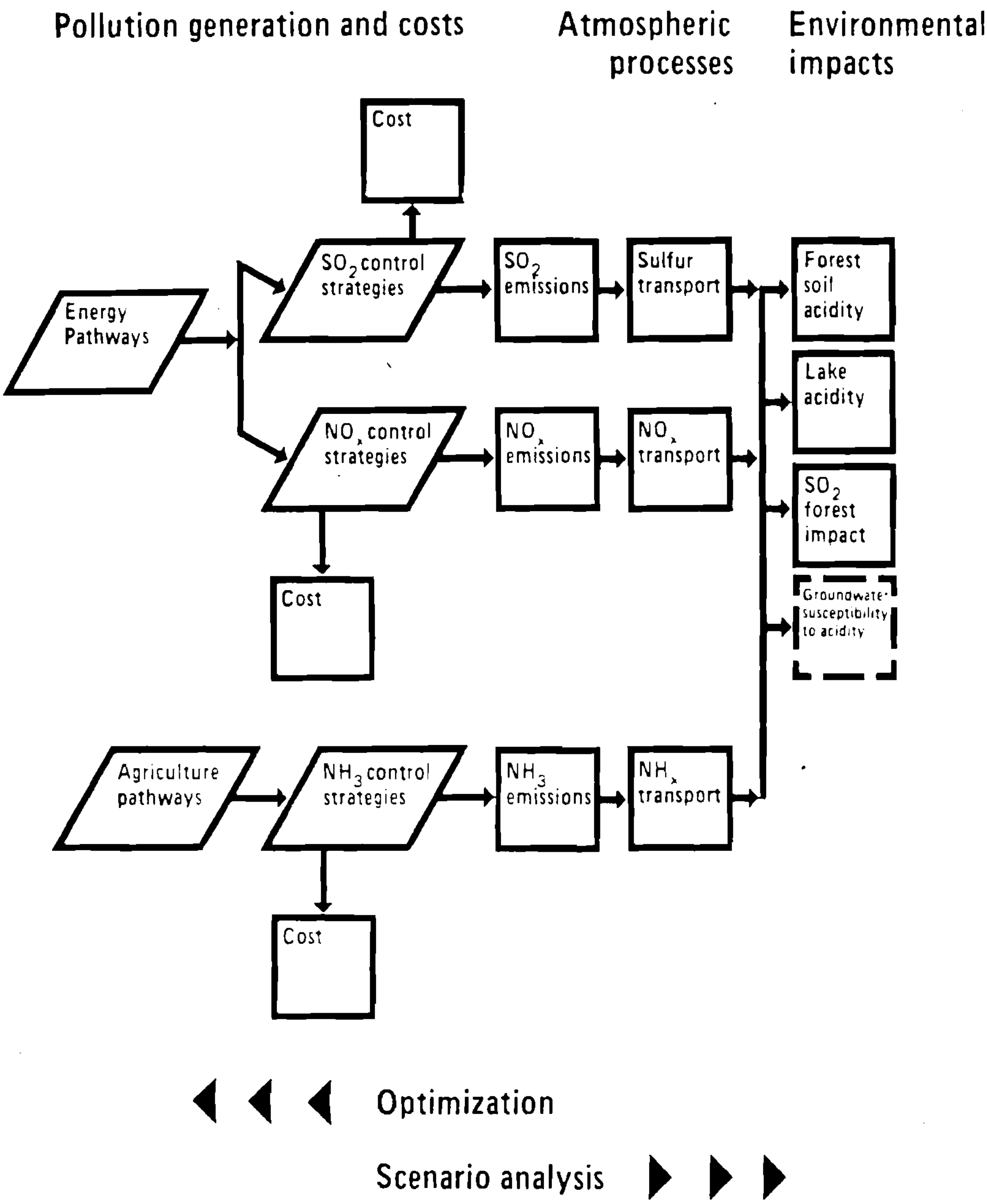

Figure 1 Flowchart of the RAINS model.

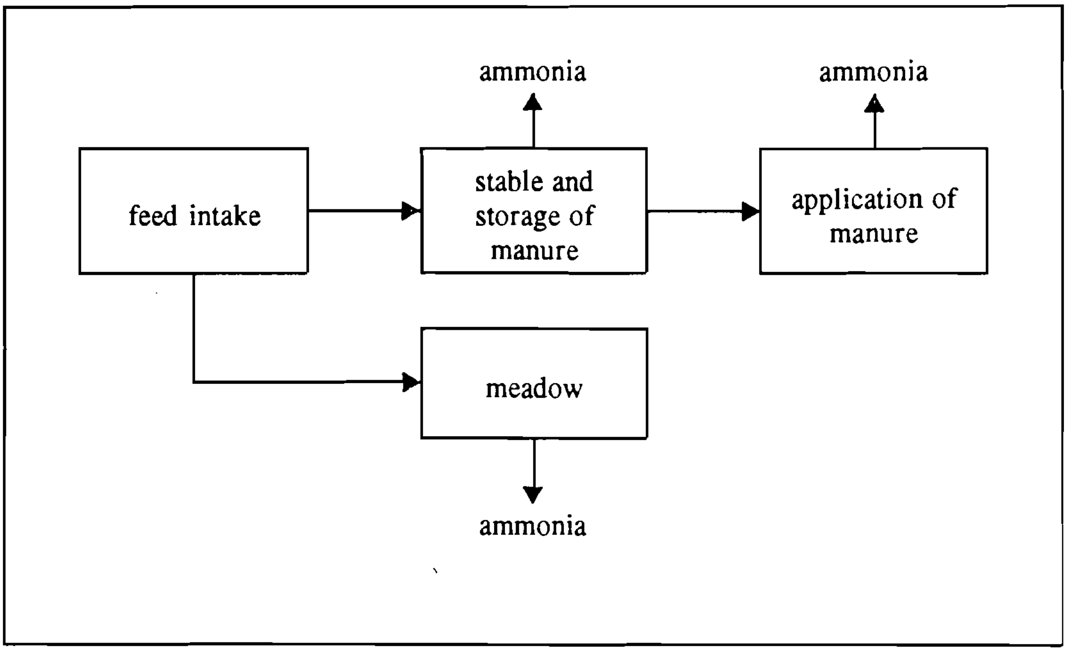

Figure 2 Ammonia losses from livestock farming.

Tables

Table 1. RAINS Abatement options for ammonia emissions						
LIVESTOCK FARMING:						
OPTIONS PER PROCESS	FODDER	STABLE AND STORAGE			APPLICATION	TOTAL NUMBER OF OPTIONS
	low N_fodder	stable adaptation	closed storage	biofil-tration	low NH_3 application	
	(LNF)	(SA)	(CS)	(BF)	(LNA)	(number)
ANIMAL TYPE						
dairy cows	x	x	x		x	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						
						47
INDUSTRY:						
Stripping/absorption						1

Table 2. 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
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 sod manuring
cvms	variable costs sod manuring
cfmr	fixed costs manure sprinkling
cvmr	variable costs manure sprinkling
cfmp	cost of manure processing
fcn3	fraction of costs attributed to ammonia
xs	removal efficiency stable
xa	removal efficiency application
xm	removal efficiency meadow
Country specific parameters	
ce	electricity price
ck	fertilizer price
Mi	manure production per animal
Sma	share manure ploughed down
Smi	share manure injected
Smr	share manure sprinkled
Sms	share sod manuring
Qmp	share manure processing
Qmh	volume of manure per hectare
ssd	stable size dairy cows
sso	stable size other cattle
ssp	stable size pigs
ql	interest rate

Table 3. Cost parameters low N_feed

Animal type		Units	Dairy cows	Pigs	Laying hens	Broilers
Parameter						
Coefficients for the investment function	ci^f	DM/animal-place	0	5.33	0	0
	ci^v		0	0	0	0
Lifetime	lt	years	10	10	10	10
Fixed operating costs	fk	%	0	0	0	0
fodder quantity	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
reduction efficiency						
stable	xs	%	20	15	10	20
application	xa	%	20	15	10	20
meadow	xm	%	25	0	0	0

Table 4. Cost parameters stable adaptations

Animal type		Units	Dairy cows	Pigs	Laying hens	Broilers
Parameter						
Coefficients for the	cif	DM/	698	177	1.64	3.55
investment function	civ	animal-place	3997	176	0	0
Lifetime	lt	years	10	10	10	10
Fixed operating costs	fk	%	8	8	0	0
gas use	Qg	m^3/animal	0	0	0.25	0
gas price	cg	DM/m^3	0.44	0.44	0.44	0.44
electricity use	Qe	Kwh/animal	0	0	1	0
electricity price	ce	DM/Kwh	country specific			
removal efficiency stable	xs	%	50	65	60	90

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

Table 5. 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 6. **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
labor use	Ql	h/animal	0.089	0	0
water use	Qw	m^3/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
labor price	cl	DM/hour	22	22	22
water price	cw	DM/m^3	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 7. Cost parameters low NH_3 application

Parameter		Units	
fixed costs application	cfma	DM/m³ manure	6.61
variable costs application	cvma	DM/m³ manure	-0.094
fixed costs injection	cfmi	DM/m³ manure	4.29
variable costs injection	cvmi	DM/m³ manure	-0.0395
fixed costs sod manuring	cfms	DM/m³ manure	6.29
variable costs sod manuring	cvms	DM/m³ manure	-0.0565
fixed costs sprinkling	cfmr	DM/m³ manure	1.33
variable costs sprinkling	cvmr	DM/m³ manure	242
fixed costs manure processing	cfmp	DM/m³ manure	30
fraction of costs attributed to NH_3	fcN3	fraction	0
manure/ha	Qmh	m³/ha	country specific
share direct application	Sma	%	country specific
share manure injection	Smi	%	country specific
share sod manuring	Sms	%	country specific
share manure sprinkled	Smr	%	country specific
share manure processed	Smp	%	country specific
manure/animal	Mi	m³/animal	country specific
emission coefficient	NH3ai	kg NH3/animal	country specific
price fertilizer	ck	DM/kg	country specific
removal efficiency application	xa	%	90

Table 8. Animal specific parameters

Animal type		Units	Dairy cows	Other cattle	Pigs	Laying hens	Broilers
Parameter							
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 9.	**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
CSFR	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	21	42	72	0.04
FRG	0.211	16	37	68	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	22	0.04
Luxembourg	0.12	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	4	4	7	0.04
Romania	0.088	34	34	154	0.04
Spain	0.216	5	5	20	0.04
Sweden	0.090	20	51	122	0.04
Switzerland	0.179	12	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 (1986a, 1986b, 1986c, 1987a, 1987b, 1988a, 1988b, 1989, 1990a, 1990b), Osterreichisches Statistisches Zentralamt (1989), Institute Economique Agricole (1989), Danmarks Statistik (1989), Central Statistical Office of Finland (1990), Service Central des Enquetes et Etudes Statitistiques (1990), Staatlichen Zentralverwaltung für Statistik (1989), National Statistical Service of Greece (1988), Stationary office (1989), Instituto Nazionale di Statistica (1990), Service Central de la Statistique et des Etudes Economiques (1990), Central Bureau of Statistics (1989), Statistisk Sentralbyra (1989), Instituto Nacional de Estatistica (1980), Statistiska Centralbyrän (1990), Prime Ministry State Institute of Statistics Turkey (1981) Central Statistical Office (1990). 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 10. Relative shares of low NH_3 application techniques

	Applied directly	Injected	Sod manuring	Sprinkled	Processed
Country	Sma	Smi	Sms	Smr	Smp
Albania	0.64	0.36	0.00	0.00	0
Austria	0.43	0.57	0.00	0.00	0
Belgium	0.54	0.46	0.00	0.00	0
Bulgaria	0.67	0.33	0.00	0.00	0
CSFR	0.76	0.24	0.00	0.00	0
Denmark	0.93	0.07	0.00	0.00	0
Finland	0.95	0.05	0.00	0.00	0
France	0.62	0.38	0.00	0.00	0
FRG	0.63	0.37	0.00	0.00	0
GDR	0.80	0.20	0.00	0.00	0
Greece	0.43	0.57	0.00	0.00	0
Hungary	0.81	0.19	0.00	0.00	0
Ireland	0.17	0.83	0.00	0.00	0
Italy	0.71	0.29	0.00	0.00	0
Luxembourg	0.54	0.46	0.00	0.00	0
Netherlands	0.42	0.50	0.00	0.00	0.08
Norway	0.90	0.10	0.00	0.00	0
Poland	0.78	0.22	0.00	0.00	0
Portugal	0.84	0.16	0.00	0.00	0
Romania	0.71	0.29	0.00	0.00	0
Spain	0.66	0.34	0.00	0.00	0
Sweden	0.84	0.16	0.00	0.00	0
Switzerland	0.20	0.80	0.00	0.00	0
Turkey	0.73	0.27	0.00	0.00	0
UK	0.38	0.62	0.00	0.00	0
USSR	0.38	0.62	0.00	0.00	0
Yugoslavia	0.55	0.45	0.00	0.00	0

Share of manure directly applied and share manure injected based on shares of arable land and permanent pasture from FAO (1989b) on land use. Manure processed based on Vroege (1990).

Table 11.	Manure per hectare and fertilizer price	
	Volume Manure per ha	Fertilizer Price
Country	Qmh (m^3/ha)	ck (DM/kg)
Albania	18	0.58
Austria	13	2.04
Belgium	39	1.05
Bulgaria	11	0.58
CSFR	13	0.87
Denmark	19	1.08
Finland	10	1.25
France	13	1.10
FRG	22	1.41
GDR	18	1.41
Greece	8	0.59
Hungary	8	0.36
Ireland	17	0.80
Italy	12	1.07
Luxembourg	39	1.05
Netherlands	40	1.13
Norway	24	2.00
Poland	12	0.50
Portugal	13	1.19
Romania	13	0.58
Spain	6	1.33
Sweden	8	1.83
Switzerland	17	1.43
Turkey	11	0.51
UK	15	1.11
USSR	16	0.58
Yugoslavia	9	0.73

Manure per hectare calculated from FAO data (1989b) on land use and livestock the manure production per animal in Table 12 (derived from Kuik, 1988) and national livestock statistics on the age and weight distribution of animals within one specific animal type. See Table 10 for the national references. Fertilizer prices based on FAO (1989a).

Table 12. Manure production per delivered animal (m^3/animal)

Country	Dairy cows	Other Cattle	Pigs	Laying hens	Broilers
Albania	22	8.34	0.97	0.061	0.0015
Austria	22	9.58	0.90	0.061	0.0015
Belgium	22	11.28	0.90	0.061	0.0015
Bulgaria	22	8.34	0.97	0.061	0.0015
CSFR	22	8.34	0.97	0.061	0.0015
Denmark	22	10.08	1.04	0.061	0.0015
Finland	22	9.59	0.95	0.061	0.0015
France	22	12.10	1.02	0.061	0.0015
FRG	22	9.32	1.00	0.061	0.0015
GDR	22	8.34	0.97	0.061	0.0015
Greece	22	11.97	1.09	0.061	0.0015
Hungary	22	8.34	0.97	0.061	0.0015
Ireland	22	14.22	1.01	0.061	0.0015
Italy	22	11.48	1.08	0.061	0.0015
Luxembourg	22	13.31	1.06	0.061	0.0015
Netherlands	22	8.34	0.97	0.061	0.0015
Norway	22	8.34	0.97	0.061	0.0015
Poland	22	8.34	0.97	0.061	0.0015
Portugal	22	8.34	0.97	0.061	0.0015
Romania	22	8.34	0.97	0.061	0.0015
Spain	22	12.62	1.02	0.061	0.0015
Sweden	22	8.34	0.97	0.061	0.0015
Switzerland	22	10.46	1.01	0.061	0.0015
Turkey	22	8.34	0.97	0.061	0.0015
UK	22	12.68	1.02	0.061	0.0015
USSR	22	8.34	0.97	0.061	0.0015
Yugoslavia	22	8.34	0.97	0.061	0.0015

Calculated from Kuik (1988) and detailed data on age and weight distribution in national statistics for cattle and pigs. (See Table 10 for listing of references.)

Table 13.	**Costs of low ammonia application for pigs and stable adaptation for dairy cows**			
	Low Ammonia Application Pigs		Stable Adaptation Dairy Cows	
Country	DM/animal per year	DM/t NH_3	DM/animal per year	DM/t NH_3
Albania	8.26	3220	160.8	49023
Austria	6.11	2349	189.7	44792
Belgium	4.13	1536	178.8	65386
Bulgaria	9.40	3666	168.1	51175
CSFR	9.08	3541	158.8	32713
Denmark	9.10	3860	177.2	38780
Finland	9.67	3951	204.4	29623
France	8.87	3422	180.6	61010
FRG	7.03	2761	192.7	35714
GDR	7.81	3045	158.6	43479
Greece	10.17	4265	412.8	134009
Hungary	10.62	4140	161.7	55382
Ireland	7.16	2715	180.6	60297
Italy	10.08	4227	232.2	74298
Luxèmbourg	5.09	1910	169.0	47467
Netherlands	4.01	1562	162.7	37111
Norway	6.39	2493	215.8	43326
Poland	9.70	3783	215.8	64503
Portugal	9.00	3510	345.0	109189
Romania	9.23	3598	165.8	50394
Spain	9.88	3839	304.4	99643
Sweden	9.18	3579	182.5	40925
Switzerland	6.85	3200	209.6	37034
Turkey	9.68	3776	412.8	165762
UK	7.43	2193	155.9	49494
USSR	7.80	3043	162.7	55635
Yugoslavia	9.11	3552	215.8	71093

Table 14. Ammonia emissions in 2000

	Base Year 1980	Unabated Emissions in 2000		30% Reduction of 1980	Maximum Reduction with Limited Potential		Maximum Reduction with Full Potential	
Country	(kton)	(kton)	(% 1980)	(kton)	(kton)	(% 1980)	(kton)	(% 1980)
Albania	25	33	-35	17	24	1	22	10
Austria	79	80	-1	55	39	51	28	65
Belgium	102	90	12	71	35	66	31	70
Bulgaria	122	141	-15	86	95	23	86	30
CSFR	200	191	4	140	101	49	93	53
Denmark	116	81	30	81	29	75	26	78
Finland	56	39	30	39	22	61	20	64
France	679	637	6	475	410	40	354	48
FRG	529	541	-2	370	232	56	231	56
GDR	228	176	23	159	88	61	74	67
Greece	88	125	-42	62	107	-21	102	-16
Hungary	156	161	-3	109	96	38	86	45
Ireland	128	156	-22	89	115	10	99	22
Italy	371	365	-3	252	240	33	214	40
Luxembourg	5	5	4	4	3	42	3	46
Netherlands	224	209	7	157	80	64	80	64
Norway	37	31	16	26	16	57	15	60
Poland	570	476	16	399	329	42	303	47
Portugal	66	62	6	46	41	39	38	42
Romania	297	422	-42	208	250	16	195	34
Spain	251	409	-63	175	266	-6	237	5
Sweden	66	59	10	46	25	62	22	67
Switzerland	64	52	19	45	31	52	22	66
Turkey	532	414	22	372	342	36	315	41
UK	482	509	-6	338	390	19	351	27
USSR	2288	2935	-28	1602	1980	13	1650	28
Yugoslavia	214	218	-2	150	128	40	107	50
Europe	7961	8620	-8	5573	5513	31	4804	40

% 1980 implies per cent reduction over the 1980 emission.
- means increase.

Table 15. Costs of various scenarios (million DM/year)				
Scenario Country	Standstill Over 1980	30 Per Cent Reduction of 1980	Maximum Reduction Limited Potential	Maximum Reduction 100% Potential
Albania	75	n.f.	137	161
Austria	0	123	995	1020
Belgium	0	22	683	924
Bulgaria	46	n.f.	650	867
CSFR	0	255	1371	1387
Denmark	0	0	990	1027
Finland	0	0	290	339
France	0	1214	3996	4947
FRG	13	689	5076	5121
GDR	0	42	1170	1639
Greece	n.f.	n.f.	367	525
Hungary	4	429	1017	1317
Ireland	258	n.f.	836	986
Italy	4	1230	2311	3147
Luxembourg	0	13	28	34
Netherlands	0	75	1774	1774
Norway	0	12	209	224
Poland	0	390	2749	3569
Portugal	0	96	419	675
Romania	733	n.f.	2579	3485
Spain	n.f.	n.f.	2899	4848
Sweden	0	43	630	641
Switzerland	0	26	432	498
Turkey	0	315	4986	3284
UK	36	n.f.	2153	2378
USSR	3670	n.f.	16975	20010
Yugoslavia	1	538	1813	2208
Europe	4838	5512	57535	67035

n.f.: not feasible

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 increased use of silage and 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 79.81 fl and 116.86 fl per animal. On average they are around 101 fl. 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 per cent). Costs consist of buying silage and fodder minus savings on fertilizer use and sewing costs. However, the report does not allow the inclusion of these elements separately due to a lack of data on quantities and prices. 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 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 per cent. Spiekers and Pfeffer (1990) conclude that reductions up to 35 per cent are possible for fattening pigs and Lenis (1989) believes that a reduction of some 25 per cent 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 per cent of N_excretion may result from low nitrogen fodder (Baltussen et al., 1990c). Spiekers and Pfeffer (1990) estimate reduction at 15 per cent and Lenis (1989) is of the opinion that synthetic amino acids my achieve reductions of 25 per cent in the long term. 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 per cent 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 and Pfeffer (1990).

C. Laying Hens

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

[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 by 11 per cent. There would be no additional costs for this option. In addition, adapted fodder can reduce N_content of the excretion by another 10 per cent. In combination a reduction of some 20 per cent 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 per cent 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 emissions from dairy cow 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 stables 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 per cent of the initial investments. The reduction in emissions is estimated at 50 per cent (Baltussen et al., 1990b, p 54.). Experiments reported by Oosthoek et al. (1990a, 1990b) confirm that a reduction of 50 per cent to 70 per cent 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 and Kornai, 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 per cent annualized capital costs are some 12 per cent of the investments. Remaining costs are assumed to be 8 per cent 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 per cent of the investments.

B. Pigs

Large adaptations in the stable may reduce emissions from the stable by 50 per cent (Baltussen et al., 1990c). Oosthoek et al. (1990a, 1990b) conclude that the reduction in ammonia emissions that can be achieved is 60 to 70 per cent. 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 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 and Paques (1989) estimate the reduction at 70 per cent for the Hepaq system. This is a system which frequently removes manure from the stable, the manure is split into 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 per cent 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 100 fl. 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 the 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, 1989; Amann and Kornai, 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 per cent of the investments. This is done because no data are 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 per cent of the investment. The reduction in stable emission is 65 per cent.

C. Laying Hens

The ammonia emissions of laying hen stables depend to a large extent on the type of stall system (Kroodsma et al, 1988, 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 straw-floor	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. Preferenice 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 per cent, depending on the reference situation (Kroodsma et al., 1988). We estimate the reduction at 60 per cent.

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, similar 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 countries other than the Netherlands, and the fact that subsidies and taxes are transfer payments which are to be discounted in cost-benefit types 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 5500 fl. Given a lifetime of 10 years, a real interest rate of 4 per cent, the investment is around 46000 fl. Electricity use is 20000 Kwh at 0.25 fl. This is 0.8 Kwh/animal place. This corresponds with 1 kwh per (delivered) animal [5]. Gas use is 5000 m^3 at 0.5 fl/m^3. That is, 0.2 m^3 per animal place, or 0.25 m^3 per delivered animal.

D. Broilers

New stable systems are currently applied on a practical scale. One of these systems consists of a trampoline that is placed above the existing stable floor. The manure is regularly removed using a scraper. In another system, heated air is continuously blown under a floating slatted and littered floor. Fans are used to dry the litter (Hendrix broiler stall). The removal efficiency of both systems is 90 per cent (Boonen, 1990).

Since there is only limited practical experience, cost estimates are preliminary and only a few details are available. Cost estimates are based on the heated air system since better data were available. According to Brunnekreef (1991) the additional investments per animal place are 4—4.5 fl. The (economic) lifetime is 10 years. The total annual costs are estimated at 0.15 fl per delivered animal. These costs consist of capital costs (annualized) and costs of recirculating air. Cost savings are expected on energy and litter use and (perhaps) loading. The order of magnitude of these savings

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[4] This also implies that the costs from a micro-economic perspective are somewhat different and that our cost calculations do 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

is 0.08 — 0.10 fl per delivered animal. Hence, net costs would amount to 0.05—0.07 fl per delivered animal. In view of the lack of data we will calculate with initial investments of 4 fl per animal place. Using a lifetime of 10 years, and a 4 per cent interest rate, this amounts to some 0.08 fl per delivered animal which appears to reflect the expected (net) costs reasonably well.

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 m^3 manure the additional investments are 13610 fl. Per m^3 this is 58 fl,—. The storage capacity has to be sufficient for 2 months storage (Baltussen et al. 1990b p. 52).

The manure production per animal is 22 m^3/dairy cow and 7.7 m^3 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 m^3. 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 m^3.

Table III.1. Costs of covering manure storage

		Dairy cows	Other Cattle
Investment	fl/m^3	58.00	58.00
Manure production/animal	m^3	22.00	7.70
Storage per animal	m^3	3.67	1.28
Investment/animal	fl/animal	214.00	74.80
Animal rounds/year		1.00	0.90
Investment/animal place	fl/place	214.00	83.00

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

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 and Worferstetter, 1990; DHV, 1990; Jol, 1990; Eggels and Scholtens, 1990; Demmers, 1989). The total annual costs per pig place also show this range and vary between 23 fl to 95 fl 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 25 fl/hour 64 m³ at 1 fl/hour 1800 kwh at 0.25 fl/kwh 12 inhabitant equivalents at 25 fl/i.e.		250 64 450 624
Total annual costs	fl		3966

This corresponds to some 50 fl per pig place.

Economies of scale are likely although only rough estimates exist. Based on information from Scholtens (1990) and Eggels and Scholtens (1990) the following estimate of the relationship 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)	(m^2)	(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:

Investment/place = 183.0954 + 2947.096 /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	m^3	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 m^3 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 m^3 a fl 1/m^3 10000 kwh a fl 0.15/kwh 5.4 inhabitant equivalents fl 52/i.e.		90 1500 281
Total annual costs:			4019

Yearly variable costs per animal are calculated by dividing through the number of animal rounds per

laying hens:	0.8
broilers:	6.07

The removal efficiency is estimated at 80 per cent.

APPENDIX V. Low Ammonia Application

The following techniques to reduce ammonia emissions during the application of manure are available:

- direct application or ploughing down of manure,
- manure injection (deep injection or slurry injection),
- sod manuring or turf injection (shallow injection or turf impregnation),
- sprinkling or drenching of manure (irrigation or dilution of manure).

In addition, if part of the manure is processed in a factory, this will reduce ammonia emissions as well. Table V.I. gives an overview of the removal efficiencies and cost ranges as reported in the literature.

Table V.1. Costs of low ammonia application techniques

	Removal efficiency (%)	Cost range (Fl/m^3)
* direct application	80—90	0—7.5
* manure injection	90—99	0—5
* sod manuring	75—99	3—7
* sprinkling	55—90	6—18
* processing	100	25—35

The data in the Table are compiled from: Havinga (1991), Krebbers (1989, 1990), Huismans (1990), Huijsmans and Bruins (1990) Baltussen, et al. (1990b), Stoop (1989), Reichow and Yawari (1990).

The additional costs of direct ploughing down of slurry (direct application) on arable land are 3.25 fl per m^3 manure if 30 m^3 manure is applied per hectare. The rate is 97.50 fl/ha. If less manure per hectare is applied, the same rate per hectare can be used (Huijsmans, 1990). We, however, set an upper limit to the costs of 7.5 fl/m^3 in view of the ranges reported in the literature since the costs could also be zero if the farmer is able to apply the technique simultaneously with other activities such as ploughing.

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

Table V.2 Cost of manure injection.

M^3 Manure/ha	Costs (fl/m^3)
30	3.56
40	3.12

Manure injection on grassland is not applicable for every soil type, especially not for heavy clay soils or soils with a low carrying capacity. Sod manuring, however, is an alternative with approximately the same costs per m^3 as manure injection, although the removal efficiency is somewhat lower than with manure injection. For reasons of simplicity we calculate a 90 per cent efficiency.

For manure injection and sod manuring, Havinga (1991) provides cost estimates as a function of the distance between the plots and the manure applied per hectare. In combining Baltussen et al.

(1990b) data we constructed a relationship between the manure/hour and the manure per hectare. In this way we were able to relate the costs per m^3 manure and the volume of manure per hectare. The results are shown in Table V.3.

Table V.3. Costs of low NH_3 application

M^3 per hectare	M^3 manure per hour	Direct application	Manure injection	Sod manuring
(m^3/ha)	(m^3/hr)	(fl/m^3)	(fl/m^3)	(fl/m^3)
65.48	32.5	1.49	2.14	3.17
47.74	26.5	2.04	2.59	3.73
41.29	24.5	2.36	2.73	4.50
28.39	20.5	3.43	3.5	5.07
17.10	17	5.70	4.16	6.03
9.03	14.5	7.50	4.52	6.69

The information in Table V.3. has been used to estimate the relation between the volume of manure per hectare and the costs per m3, in order to obtain a more realistic picture of the costs for those countries where the intensity of livestock farming is lower than in the Netherlands. One should beware however, that the costs will differ from farmer to farmer owing to specific circumstances such as the distance to the plot, whether or not intermediate storage takes place, whether the work can be done by the individual farmer or by a contractor etc. The functional relationships take the following form:

Direct application:

Cost/m^3 manure (fl/m^3) = 7.44 — 0.1059 * m^3 per hectare

Manure injection:

Cost/m^3 manure (fl/m^3) = 4.822 — 0.04444 * m^3 per hectare

Sod manuring:

Cost/m^3 manure (fl/m^3) = 7.081 — 0.06362 * m^3 per hectare

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/m^3 manure and the fixed costs at 4410 — 7540 fl/year. The costs per m^3 manure then depend to a large extent on the manure production per year. Using the average stable size of dairy cow stables as an indicator, in combination with a manure production of 22 m^3/animal per year we assume the following relationship for manure sprinkling:

$$\text{Cost sprinkling fl/m}^3 = 1.5 + 6000/(ss_d * 22)$$

Where ss_d is the stable or herd size for dairy cows. Note that there are again savings on the costs of fertilizer use but 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, and soil type (underground and slope) do not permit manure injection.

The costs of manure processing vary between some 25 fl to 35 fl/m^3 manure. (Vroege, 1990; Stoop, 1990; Reichow and Yawari, 1990). The emission reduction is 100 per cent. In view of these costs, the technique is too expensive to be used as an option to control ammonia emissions only.

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. 1990b; Esteban Turzo et al., 1988). For dairy cows (cf. Baltussen et al. 1990b) stable emissions may be reduced by 50 per cent and emissions during application by 100 per cent. These results, however, are based on only one practical experiment. Further, the addition of acid may increase the nitrogen surplus on a farm level thereby limiting its applicability.

The associated costs can only be roughly 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 41000 fl). For larger stables two systems are necessary (investment 55000 fl). Assuming similar function shapes as usual the following relationship can be constructed: investment\animal place (fl) = 475 + 26490 / stable size.

Fixed costs are 2 per cent of the initial investments. Variable costs consist of the 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/ m^3 manure * 22 m^3/animal is 814 liter per animal. The savings in fertilizer use are 4.74 kg N per m^3 manure, and 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/liter	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 present the combinations of techniques that 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	0	0
3	Closed storage	(CS)	10	0	0
4	Low N_application	(LNA)	0	90	0
5	LNF + SA		60	20	25
6	LNF + CS		28	20	25
7	LNF + LNA		20	92	25
8	SA + LNA		50	90	0
9	CS + LNA		10	90	0
10	LNF + SA + LNA		60	92	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	0	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	0	0
3	Biofiltration	(BF)	90	0	0
4	Low N_application	(LNA)	0	90	0
5	LNF + SA		70	15	0
6	LNF + BF		92	15	0
7	LNF + LNA		15	91	0
8	SA + LNA		65	90	0
9	BF + LNA		90	90	0
10	LNA + SA + LNA		70	91	0
11	LNF + BF + LNA		92	91	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	0	0
3	Biofiltration	(BF)	80	0	0
4	Low N_application	(LNA)	0	90	0
5	LNF + SA		64	10	0
6	LNF + BF		82	10	0
7	LNF + LNA		10	91	0
8	SA + LNA		60	90	0
9	BF + LNA		80	90	0
10	LNF + SA + LNA		64	91	0
11	LNF + BF + LNA		82	91	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)	90	0	0
3	Biofiltration	(BF)	80	0	0
4	Low N_application	(LNA)	0	90	0
5	LNF + SA		92	20	0
6	LNF + BF		84	20	0
7	LNF + LNA		20	92	0
8	SA + LNA		90	90	0
9	BF + LNA		80	90	0
10	LNF + SA + LNA		92	92	0
11	LNF + BF + LNA		84	92	0

Combinations of 2 and 3 are excluded.

APPENDIX VIII. Potential Application of Techniques

The Tables below present the potential application of the techniques as they have been used in the example to create the cost functions.

Table VIII.1	Potential Application Abatement Options: Cows, Cattle and Pigs (%)						
	Animal Type						
	Dairy cows			Other Cattle	Pigs		
Country	LNF	SA	CS	CS	LNF	SA	BF
Albania	50	100	50	50	100	100	50
Austria	50	100	50	50	100	100	100
Belgium	100	100	50	50	100	100	40
Bulgaria	50	100	50	50	100	100	50
CSFR	50	100	100	100	100	100	100
Denmark	100	100	50	50	100	100	95
Finland	50	100	50	50	100	100	80
France	50	100	50	50	100	100	50
FRG	100	100	70	70	100	100	100
GDR	50	100	50	50	100	100	50
Greece	50	100	50	50	100	100	50
Hungary	50	100	100	100	100	100	50
Ireland	50	100	50	50	100	100	50
Italy	50	100	50	50	100	100	50
Luxembourg	100	100	50	50	100	100	50
Netherlands	100	100	100	100	100	100	100
Norway	50	100	50	50	100	100	100
Poland	50	100	50	50	100	100	50
Portugal	50	100	50	50	100	100	50
Romania	50	100	50	50	100	100	50
Spain	50	100	50	50	100	100	50
Sweden	50	100	50	50	100	100	100
Switzerland	50	100	50	50	100	100	50
Turkey	50	100	100	100	100	100	50
UK	50	100	80	80	100	100	60
USSR	50	100	50	50	100	100	50
Yugoslavia	50	100	50	50	100	100	50

DAIRY COWS:

LNF: if fertilizer level N plus N manure is higher than some 200 kg N/ha, then it is assumed to be fully applicable, otherwise only 50 per cent.

SA: Always possible.

CS: Based on Asman (1990). If no data then 50 per cent is assumed.

OTHER CATTLE:

CS: Asman (1990) else 50 per cent.

PIGS:

LNF: Always possible. Industrial farming mainly. Some limits for Hungary and Norway since pigs are partly outside.

SA: Always possible.

BF: Yes if by mechanical ventilation (Asman, 1990). Not feasible if by natural ventilation. If no data, then 50 per cent.

Table VIII.2 Potential Application Abatement Options: Poultry and LNA (%)							
	LAYING HENS			OTHER POULTRY			ALL ANIMALS
Country	LNF	SA	BF	LNF	SA	BF	LNA
Albania	100	100	50	100	100	50	80
Austria	100	100	50	100	100	50	70
Belgium	100	100	100	100	100	100	100
Bulgaria	100	100	50	100	100	50	85
CSFR	100	100	100	100	100	100	90
Denmark	100	100	100	100	100	100	95
Finland	100	100	90	100	100	90	95
France	100	100	50	100	100	50	80
FRG	100	100	100	100	100	100	100
GDR	100	100	50	100	100	50	90
Greece	100	100	50	100	100	50	70
Hungary	100	100	100	100	100	100	90
Ireland	100	100	50	100	100	50	70
Italy	100	100	50	100	100	50	85
Luxembourg	100	100	50	100	100	50	85
Netherlands	100	100	100	100	100	100	100
Norway	100	100	100	100	100	100	95
Poland	100	100	50	100	100	50	90
Portugal	100	100	50	100	100	50	90
Romania	100	100	50	100	100	50	70
Spain	100	100	50	100	100	50	85
Sweden	100	100	100	100	100	100	90
Switzerland	100	100	50	100	100	50	60
Turkey	100	100	50	100	100	50	70
UK	100	100	100	100	100	100	80
USSR	100	100	50	100	100	50	70
Yugoslavia	100	100	50	100	100	50	80

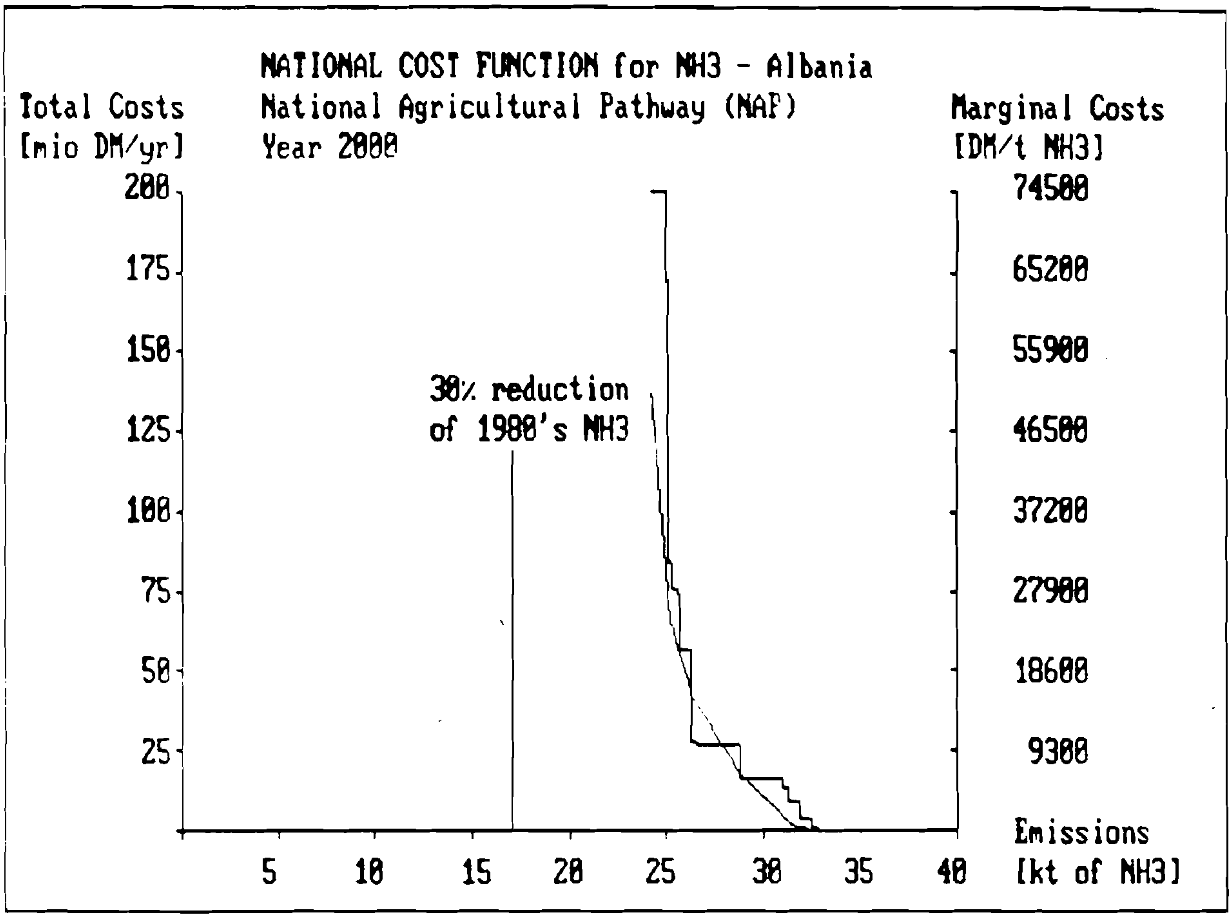
LAYING HENS + BROILERS:
LNF: Always possible. Mainly industrial farming.

SA: Always possible.
BF: Yes if mechanical ventilation, (Asman, 1990). Not feasible if by natural ventilation. If no data, then 50 per cent.

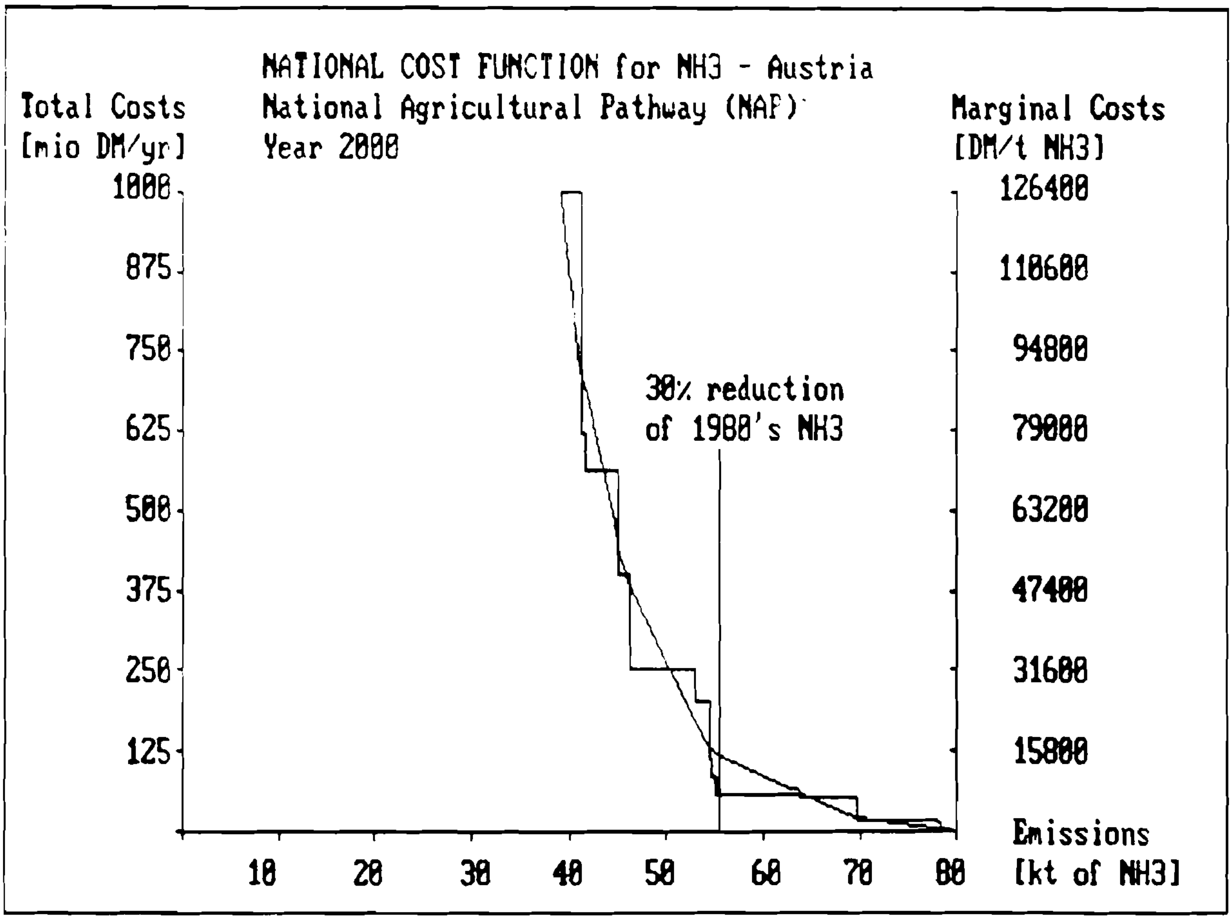
ALL ANIMALS:
LNA: Feasible on arable land and on 50 per cent of grassland. Except Netherlands always feasible.

APPENDIX IX. National Cost Functions for Ammonia

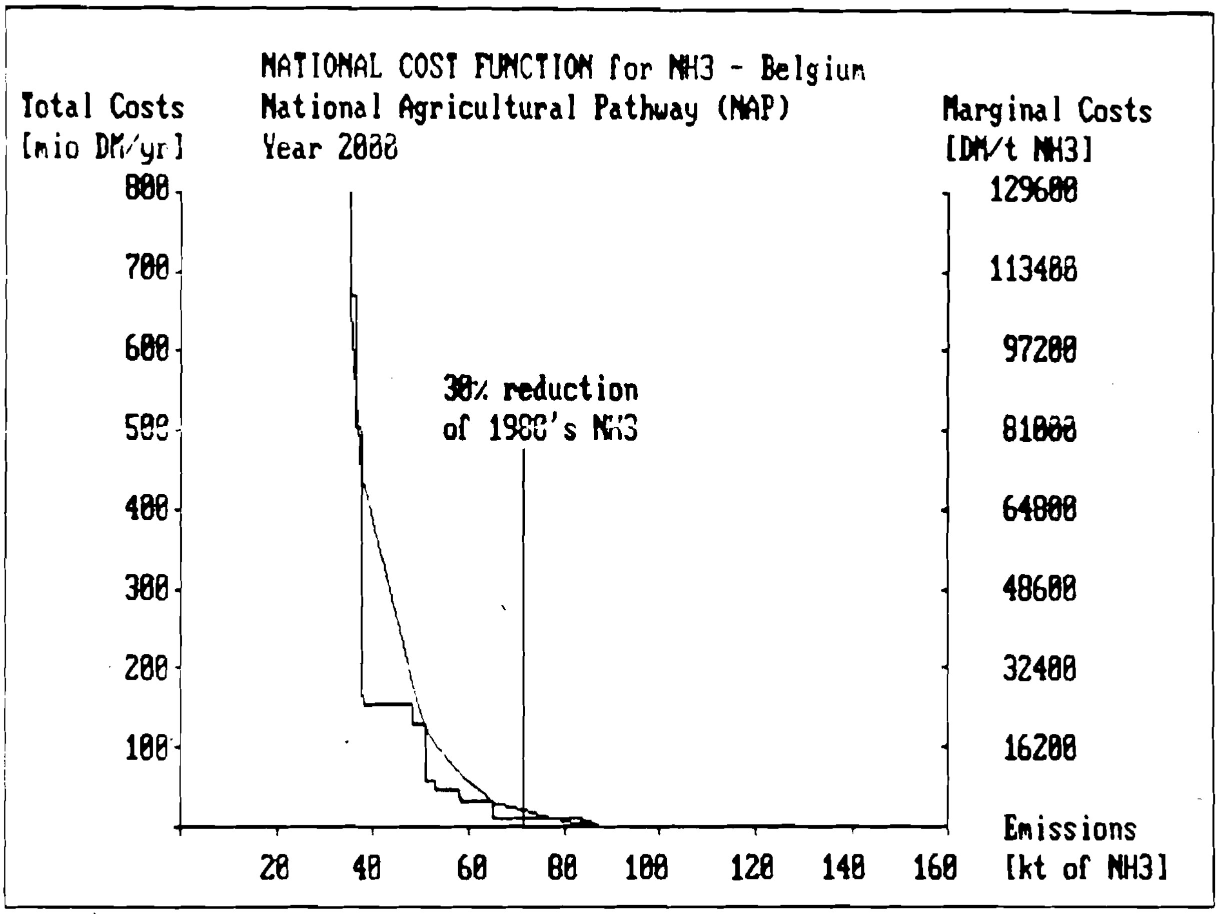
This appendix contains national cost curves for the abatement of NH_3 emissions in Europe. These calculations are based on the national agricultural pathways for the year 2000. In this example case the potential application of the abatement options was limited according to the data in Appendix VIII. The stepwise functions show the marginal cost functions, the curved lines show the total annual costs as functions of the remaining ammonia emissions in the year 2000.



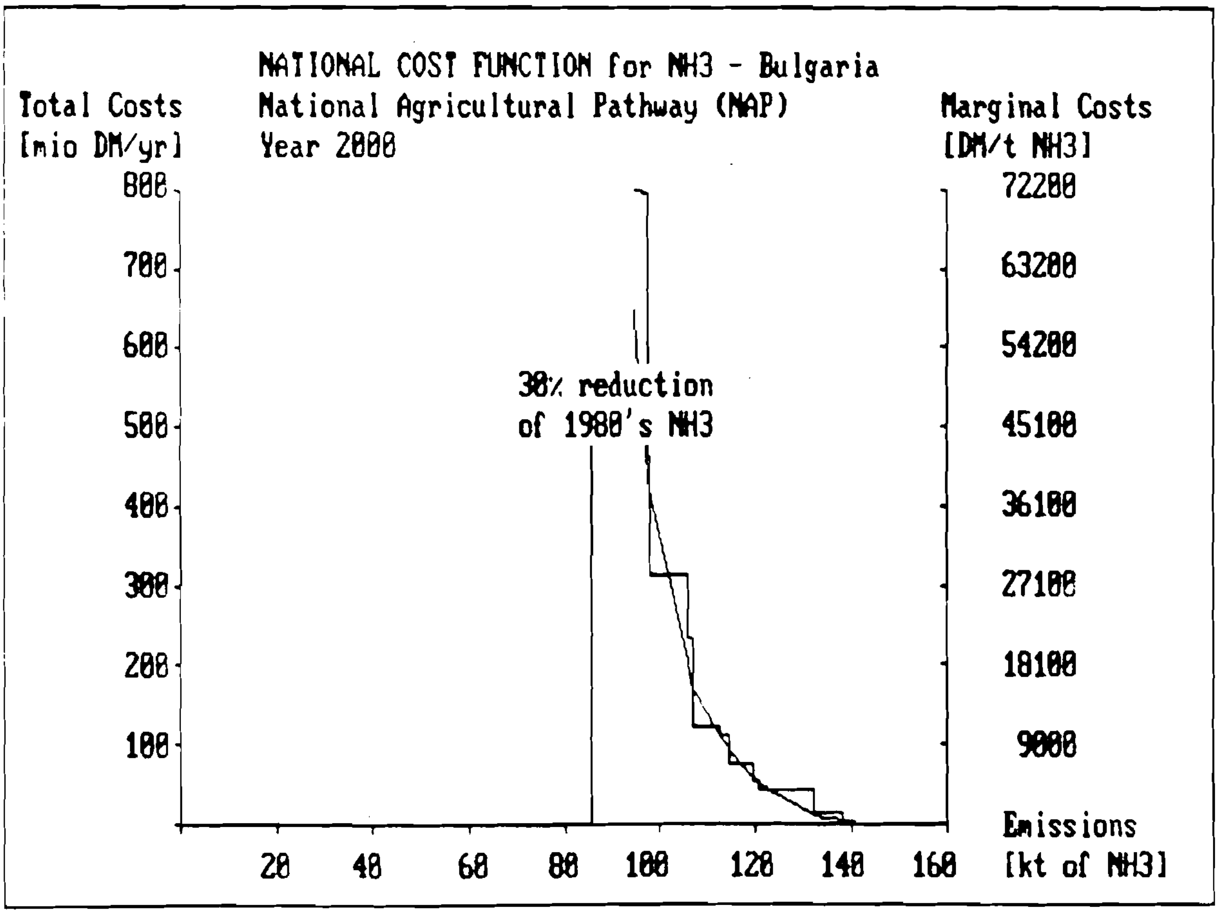
NATIONAL COST FUNCTION for NH3 - Albania
National Agricultural Pathway (NAP)
Year 2000
Total Costs
[mio DM/yr]
Marginal Costs
[DM/t NH3]
200
175
150
125
100
75
50
25
74500
65200
55900
46500
37200
27900
18600
9300
30% reduction
of 1980's NH3
5
10
15
20
25
30
35
40
Emissions
[kt of NH3]



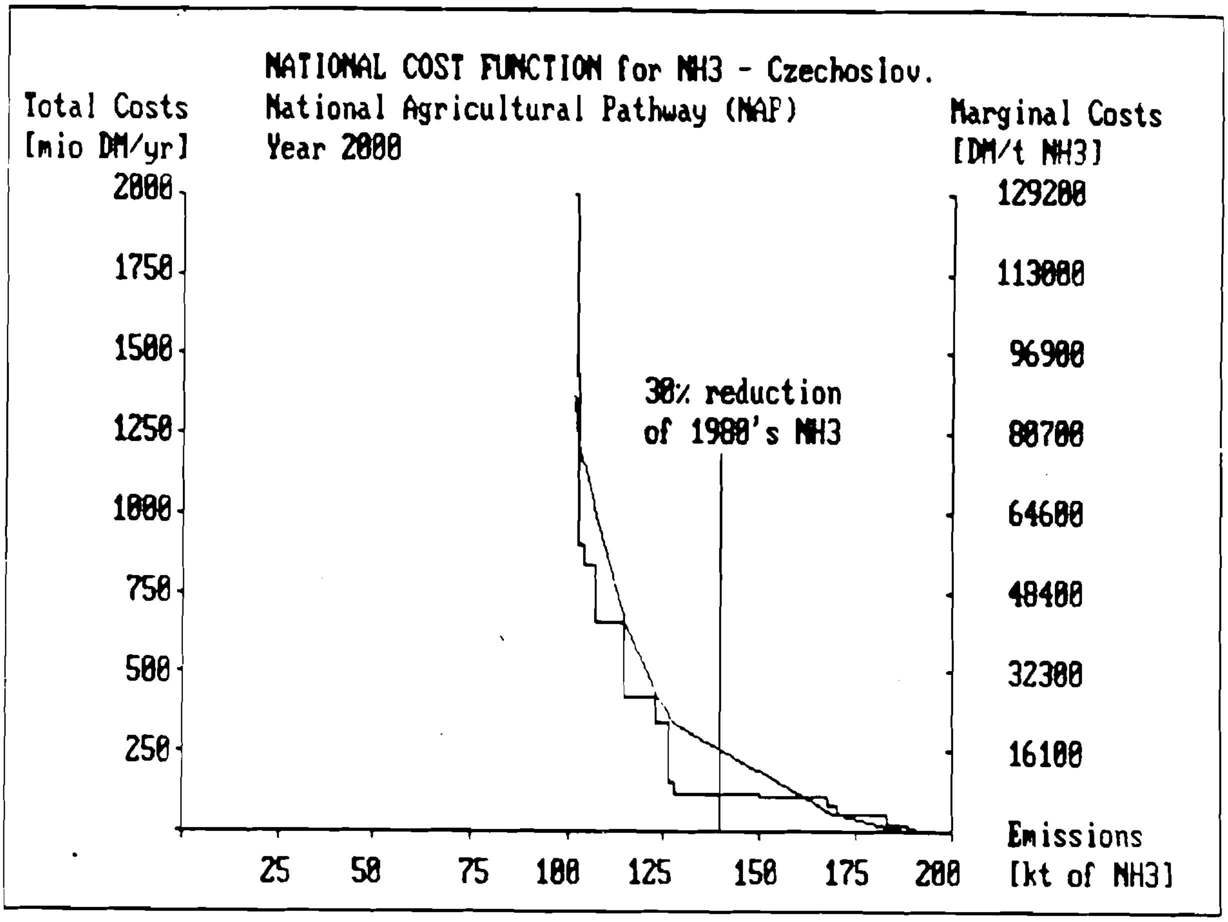
NATIONAL COST FUNCTION for NH3 - Austria
National Agricultural Pathway (NAP)
Year 2000
Total Costs
[mio DM/yr]
Marginal Costs
[DM/t NH3]
1000
875
750
625
500
375
250
125
126400
110600
94800
79000
63200
47400
31600
15800
30% reduction
of 1980's NH3
10
20
30
40
50
60
70
80
Emissions
[kt of NH3]

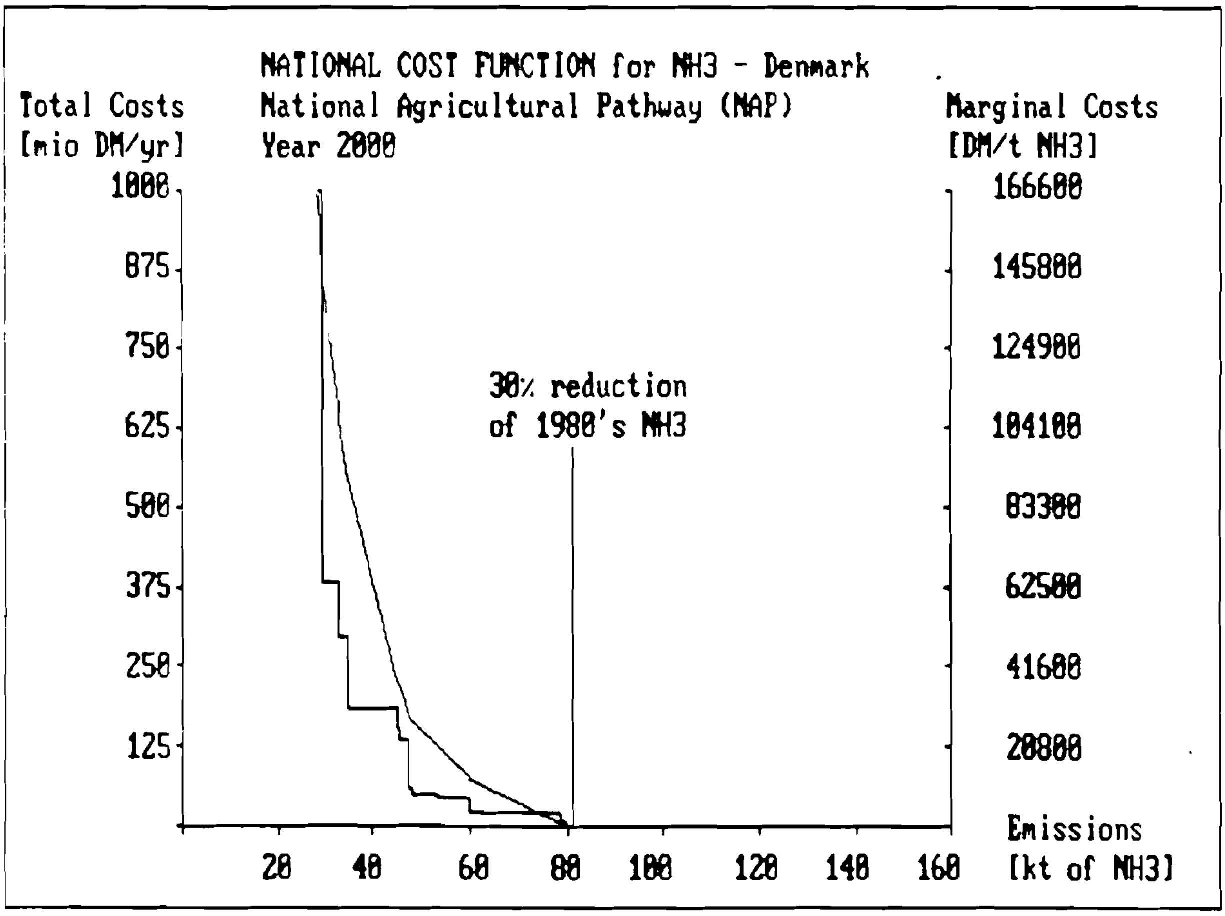


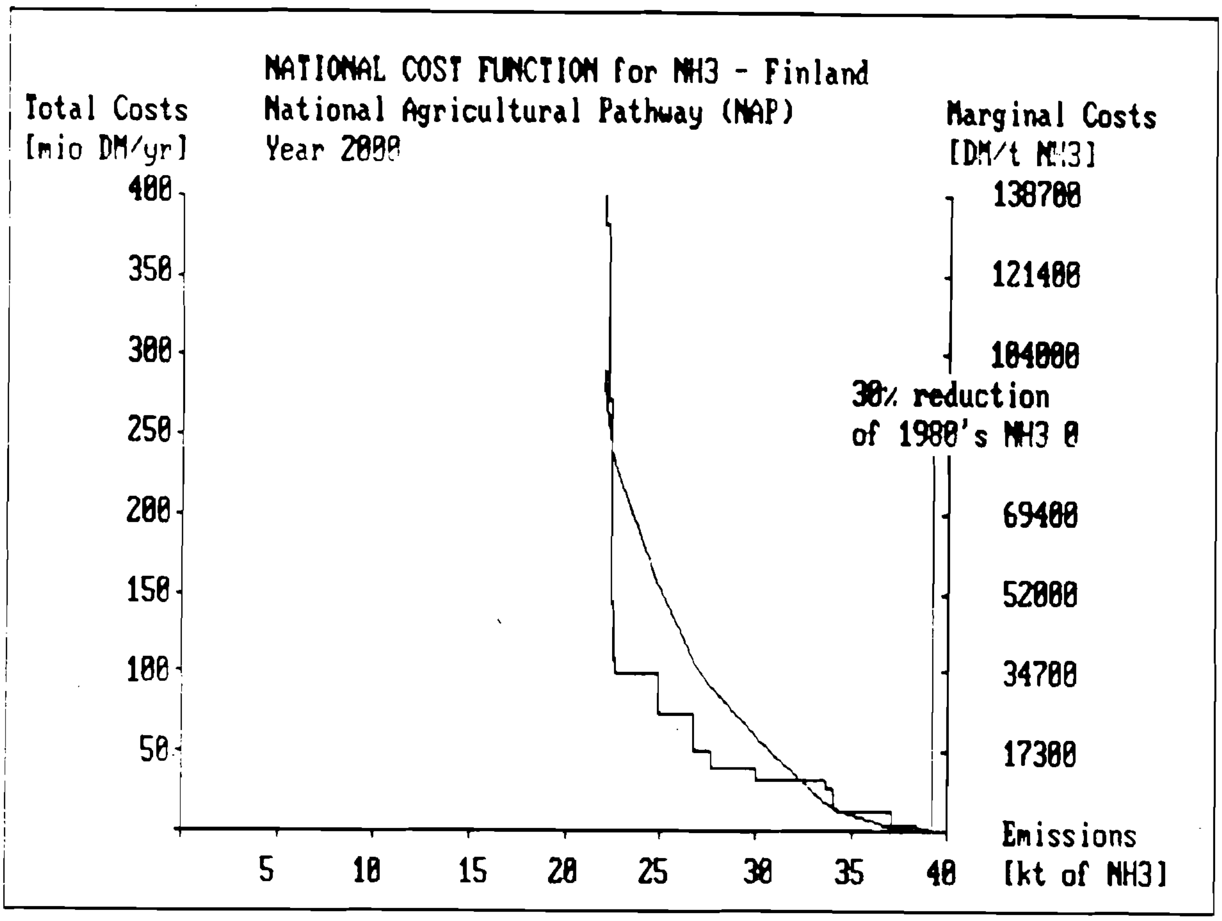
NATIONAL COST FUNCTION for NH3 - Belgium
National Agricultural Pathway (NAP)
Year 2000
Total Costs
[mio DM/yr]
Marginal Costs
[DM/t NH3]
800
700
600
500
400
300
200
100
129600
113400
97200
81000
64800
48600
32400
16200
30% reduction
of 1980's NH3
20
40
60
80
100
120
140
160
Emissions
[kt of NH3]

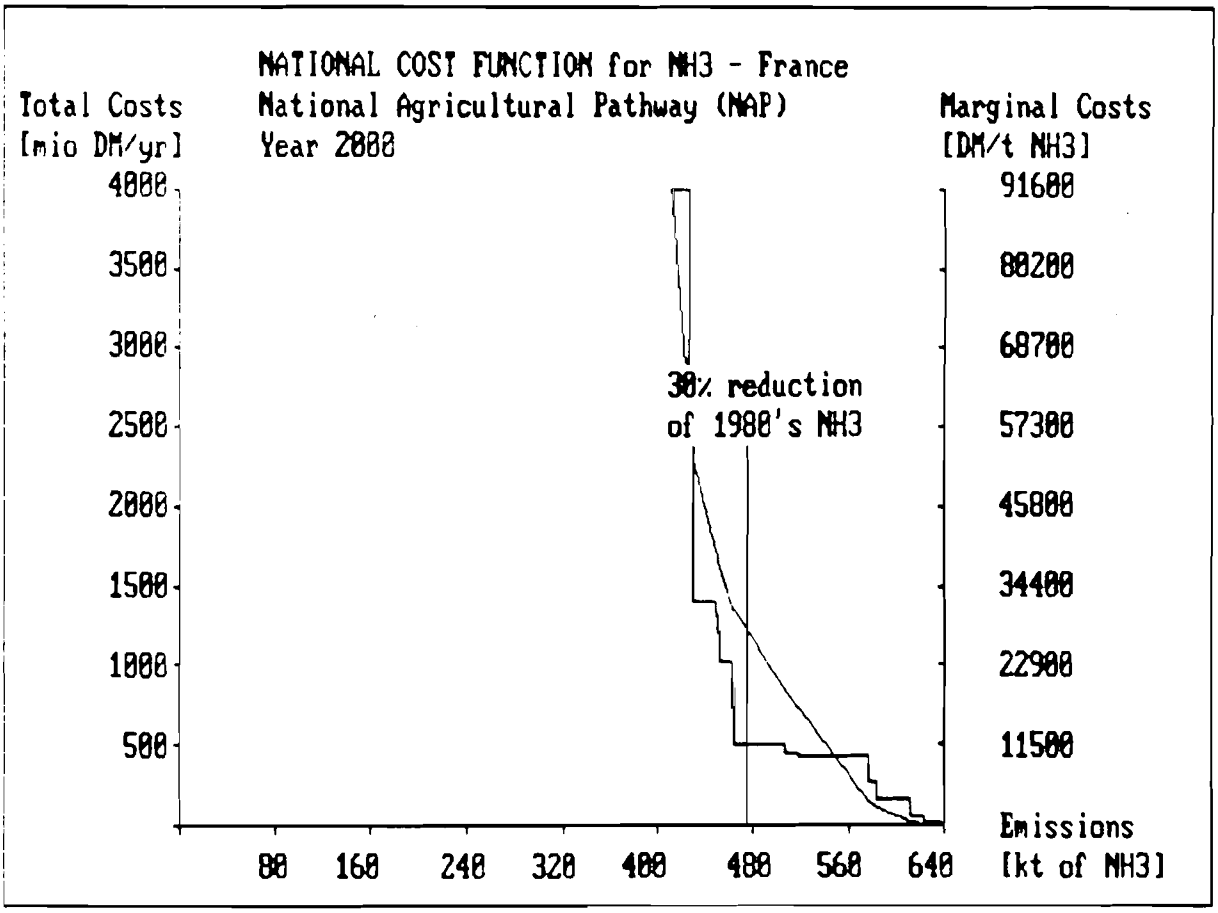


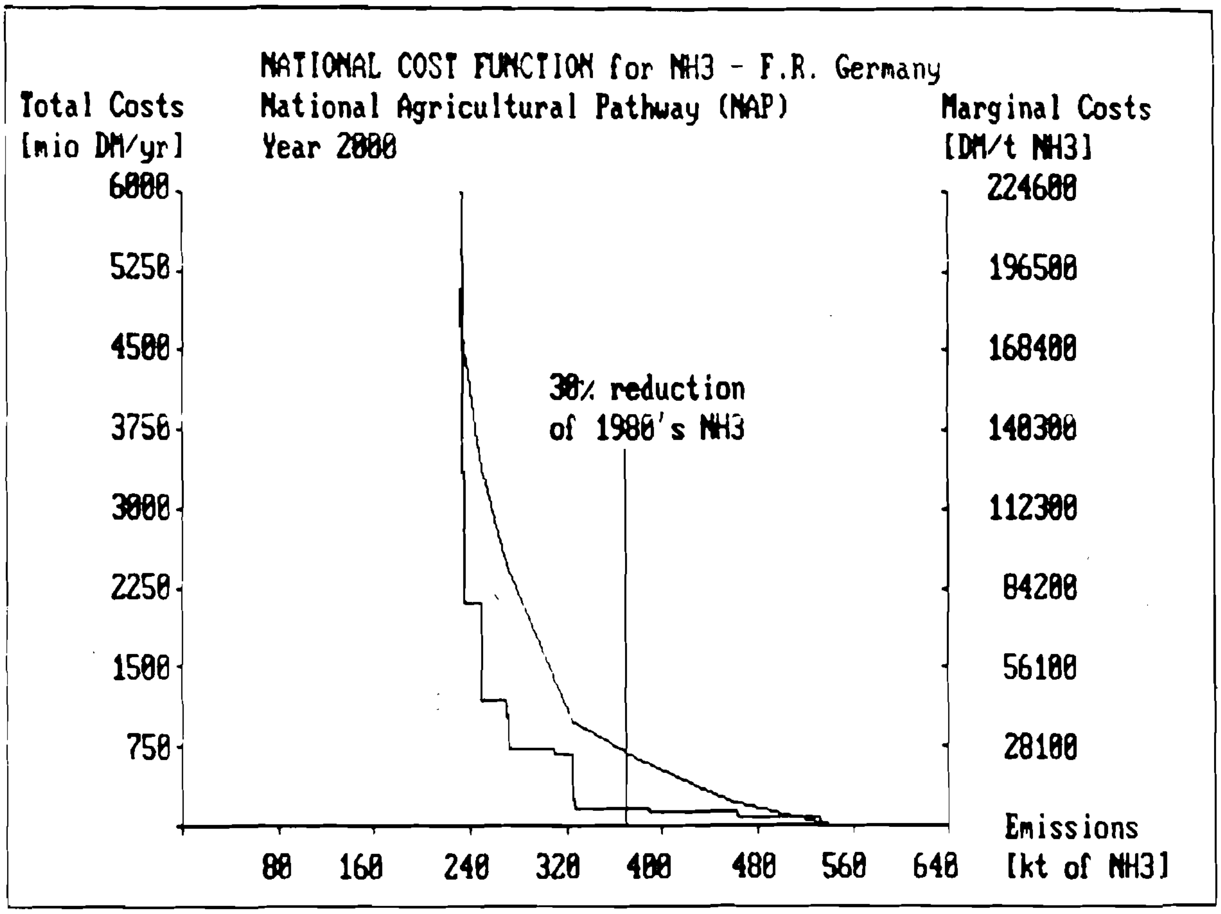
NATIONAL COST FUNCTION for NH3 - Bulgaria
National Agricultural Pathway (NAP)
Year 2000
Total Costs
[mio DM/yr]
Marginal Costs
[DM/t NH3]
800
700
600
500
400
300
200
100
72200
63200
54200
45100
36100
27100
18100
9000
30% reduction
of 1980's NH3
20
40
60
80
100
120
140
160
Emissions
[kt of NH3]


NATIONAL COST FUNCTION for NH3 - Czechoslov.
National Agricultural Pathway (NAP)
Year 2000
Total Costs
[mio DM/yr]
2000
1750
1500
1250
1000
750
500
250
Marginal Costs
[DM/t NH3]
129200
113000
96900
80700
64600
48400
32300
16100
30% reduction
of 1980's NH3
25
50
75
100
125
150
175
200
Emissions
[kt of NH3]

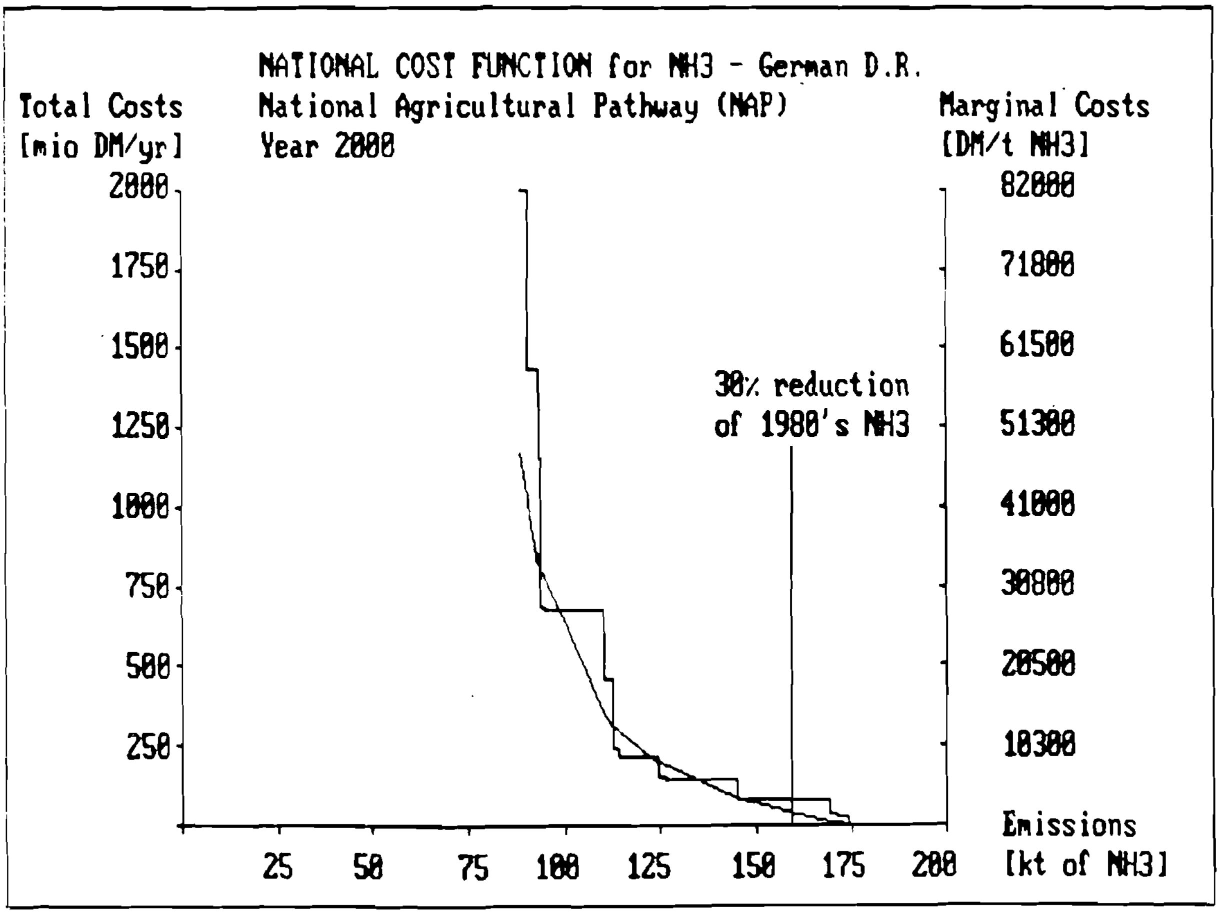

NATIONAL COST FUNCTION for NH3 - Denmark
National Agricultural Pathway (NAP)
Year 2000
Total Costs
[mio DM/yr]
1000
875
750
625
500
375
250
125
Marginal Costs
[DM/t NH3]
166600
145800
124900
104100
83300
62500
41600
20800
30% reduction
of 1980's NH3
20
40
60
80
100
120
140
160
Emissions
[kt of NH3]


NATIONAL COST FUNCTION for NH3 - Finland
National Agricultural Pathway (NAP)
Year 2000
Total Costs
[mio DM/yr]
400
350
300
250
200
150
100
50
Marginal Costs
[DM/t NH3]
138700
121400
104000
86700
69400
52000
34700
17300
30% reduction
of 1980's NH3 0
5
10
15
20
25
30
35
40
Emissions
[kt of NH3]

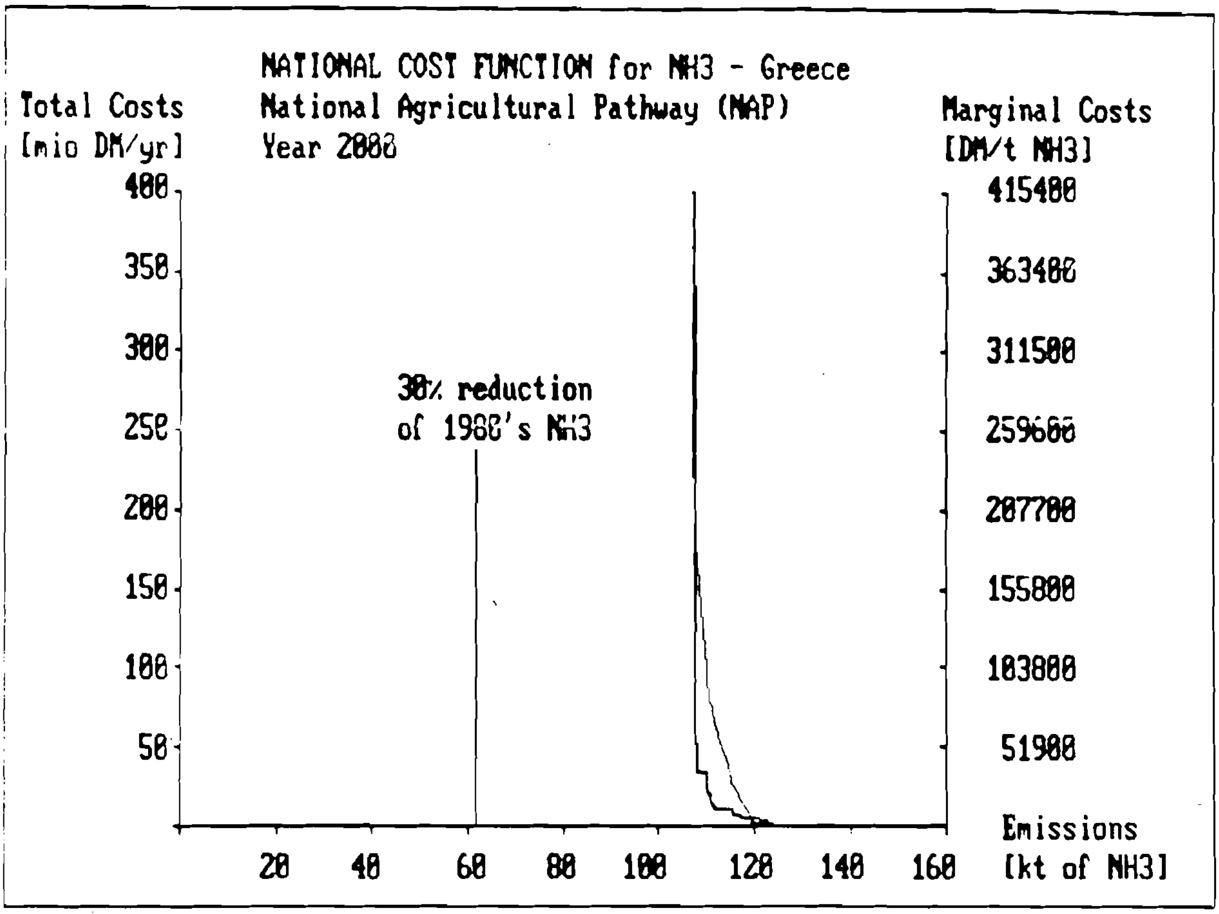

NATIONAL COST FUNCTION for NH3 - France
National Agricultural Pathway (NAP)
Year 2000
Total Costs
[mio DM/yr]
4000
3500
3000
2500
2000
1500
1000
500
Marginal Costs
[DM/t NH3]
91600
80200
68700
57300
45800
34400
22900
11500
30% reduction
of 1980's NH3
80
160
240
320
400
480
560
640
Emissions
[kt of NH3]

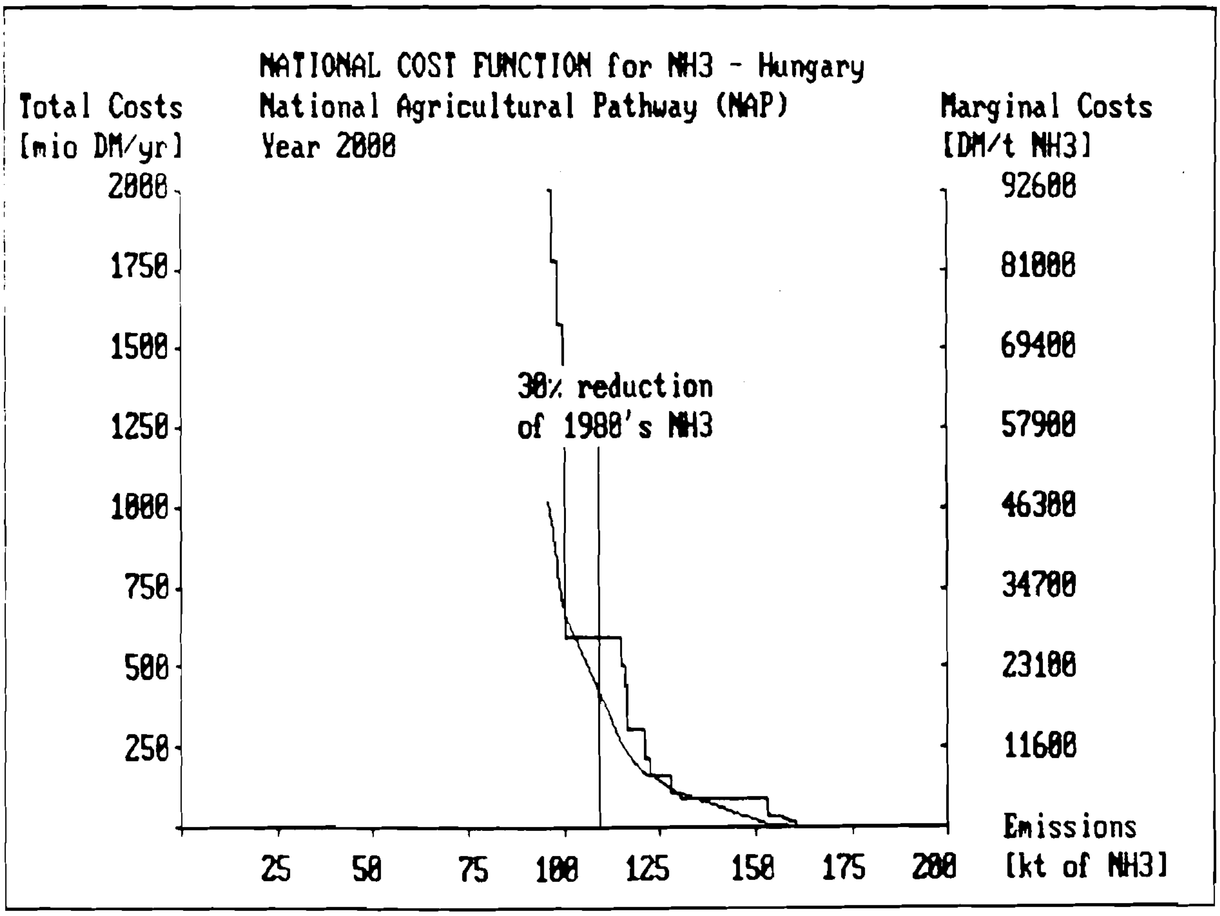


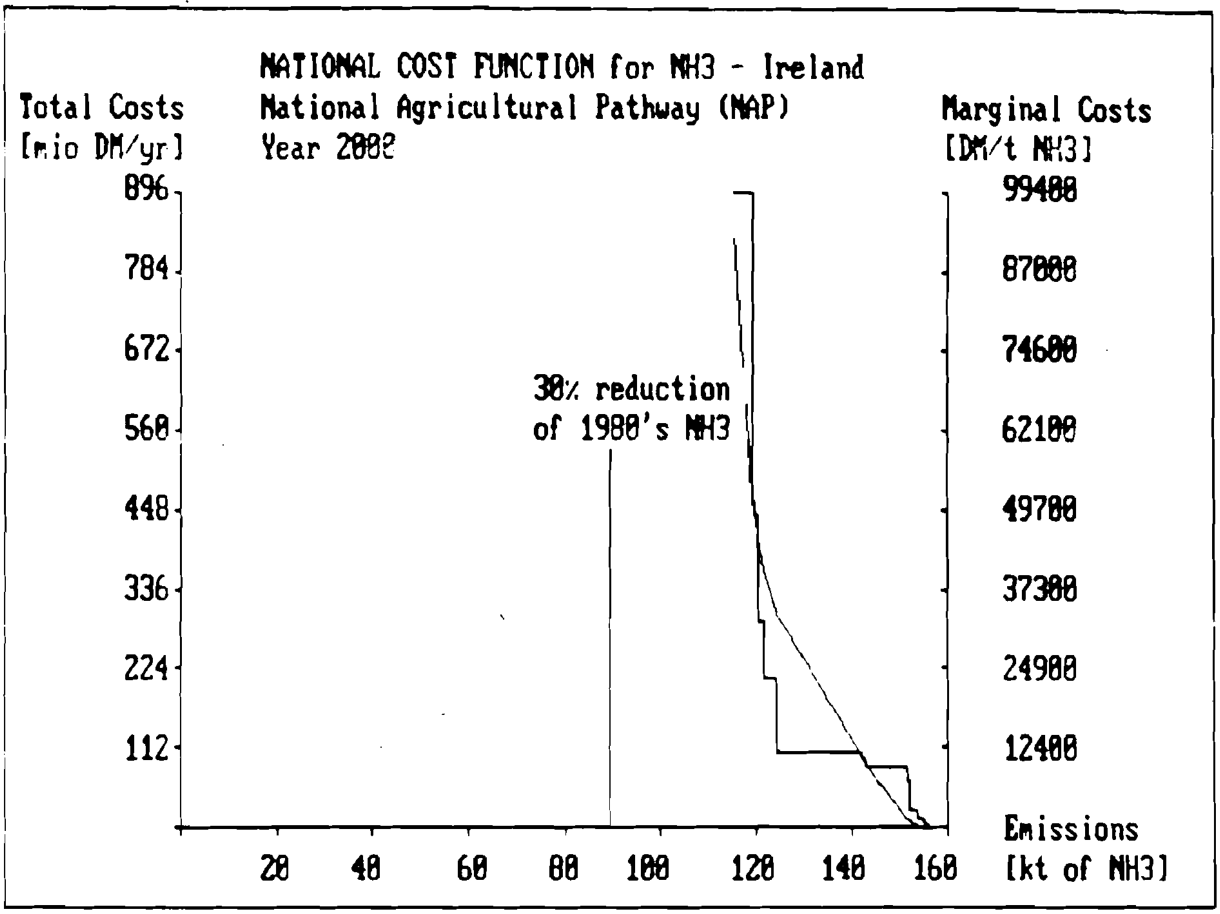
NATIONAL COST FUNCTION for NH3 - F.R. Germany
National Agricultural Pathway (NAP)
Year 2000
Total Costs [mio DM/yr]
Marginal Costs [DM/t NH3]
6000
5250
4500
3750
3000
2250
1500
750
224600
196500
168400
140300
112300
84200
56100
28100
30% reduction of 1980's NH3
80
160
240
320
400
480
560
640
Emissions [kt of NH3]

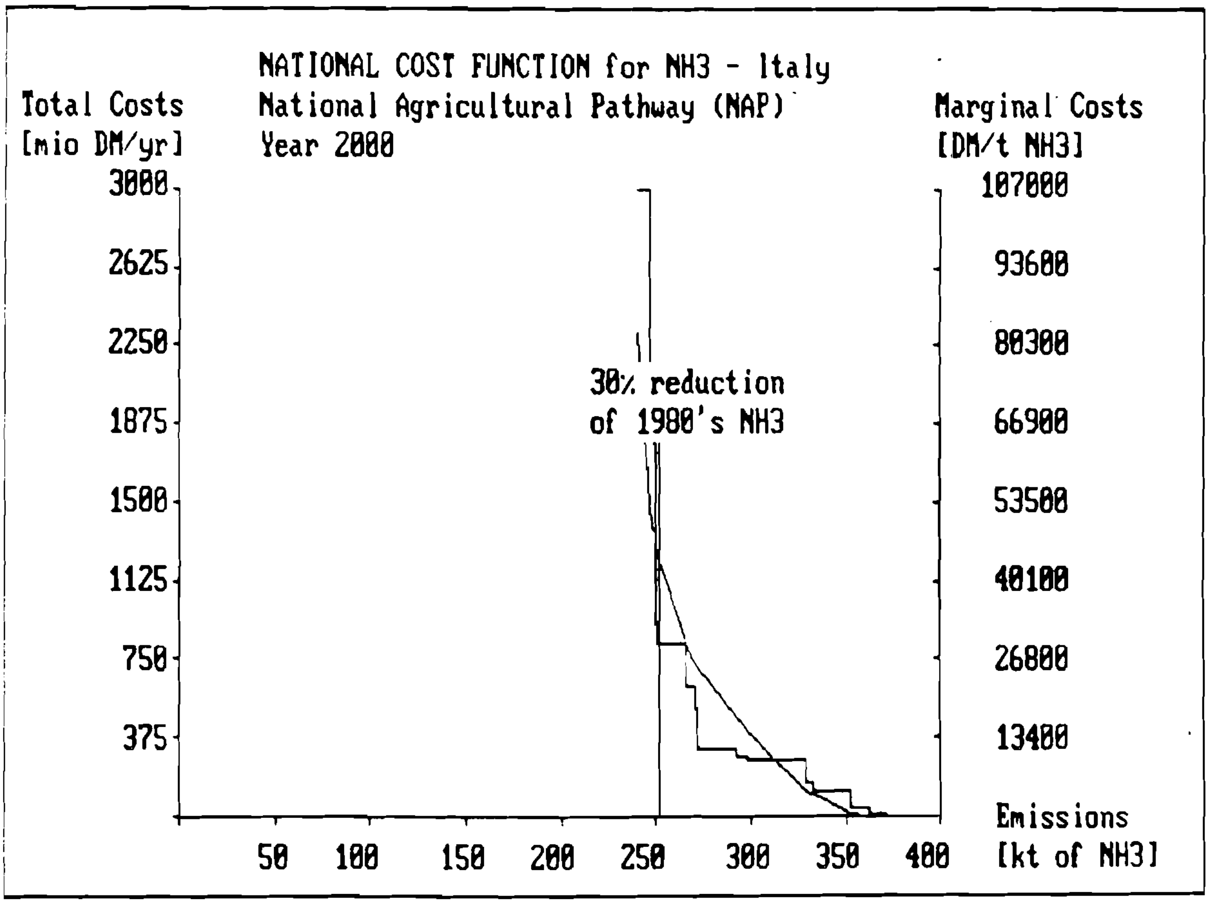


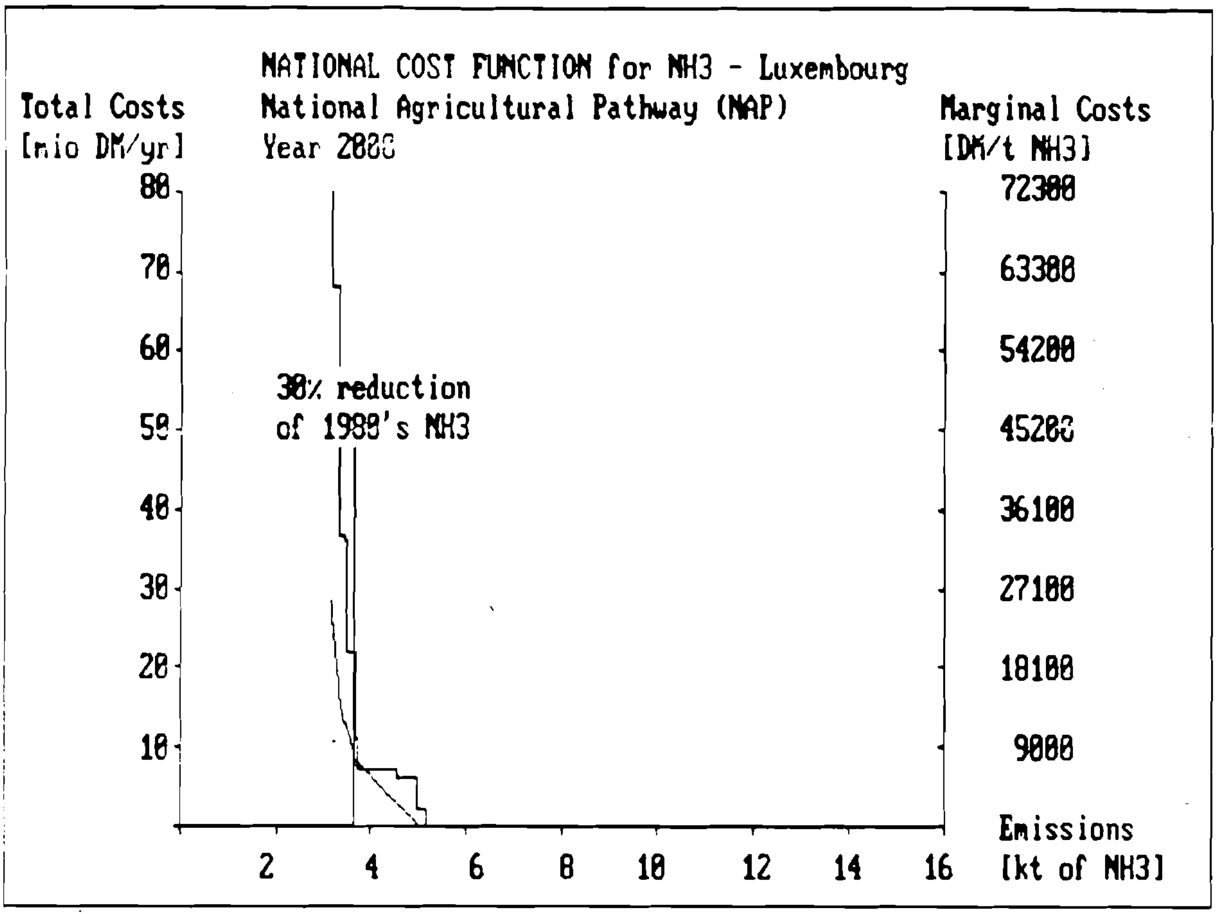
NATIONAL COST FUNCTION for NH3 - German D.R.
National Agricultural Pathway (NAP)
Year 2000
Total Costs [mio DM/yr]
Marginal Costs [DM/t NH3]
2000
1750
1500
1250
1000
750
500
250
82000
71800
61500
51300
41000
30800
20500
10300
30% reduction of 1980's NH3
25
50
75
100
125
150
175
200
Emissions [kt of NH3]

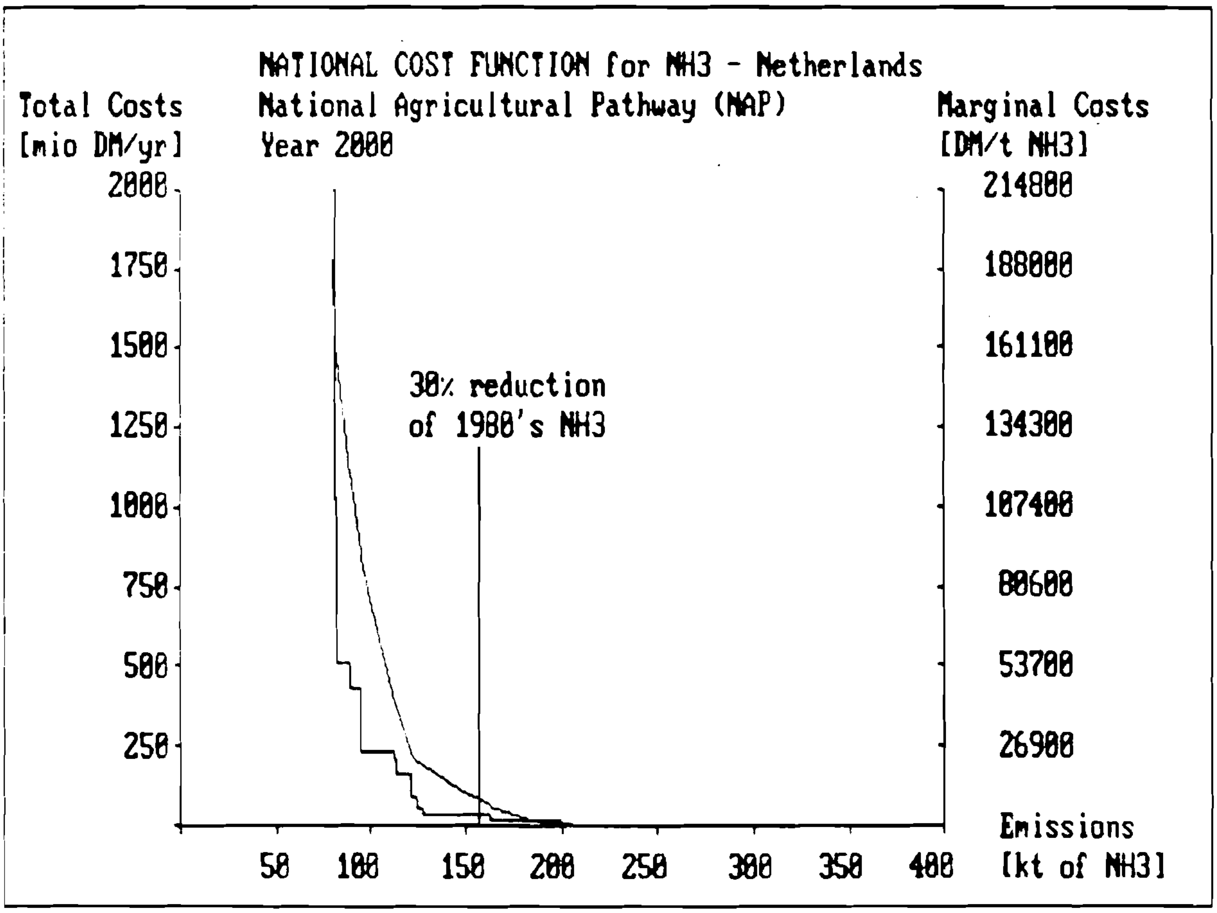

NATIONAL COST FUNCTION for NH3 - Greece
National Agricultural Pathway (NAP)
Year 2000
Total Costs [mio DM/yr]
Marginal Costs [DM/t NH3]
400
350
300
250
200
150
100
50
415400
363400
311500
259600
207700
155800
103800
51900
30% reduction of 1980's NH3
20
40
60
80
100
120
140
160
Emissions [kt of NH3]

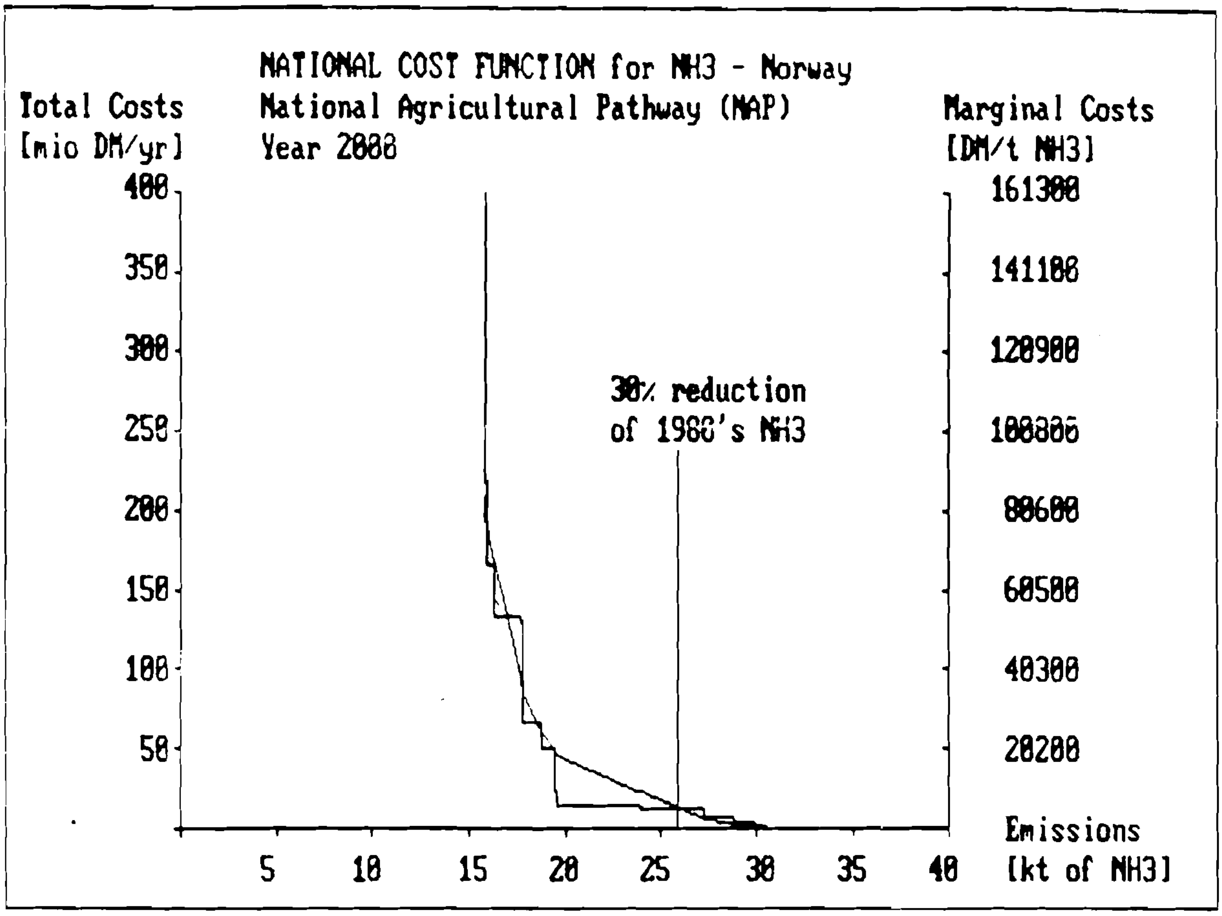

NATIONAL COST FUNCTION for NH3 - Hungary
National Agricultural Pathway (NAP)
Year 2000
Total Costs [mio DM/yr]
Marginal Costs [DM/t NH3]
2000
1750
1500
1250
1000
750
500
250
92600
81000
69400
57900
46300
34700
23100
11600
30% reduction of 1980's NH3
25
50
75
100
125
150
175
200
Emissions [kt of NH3]

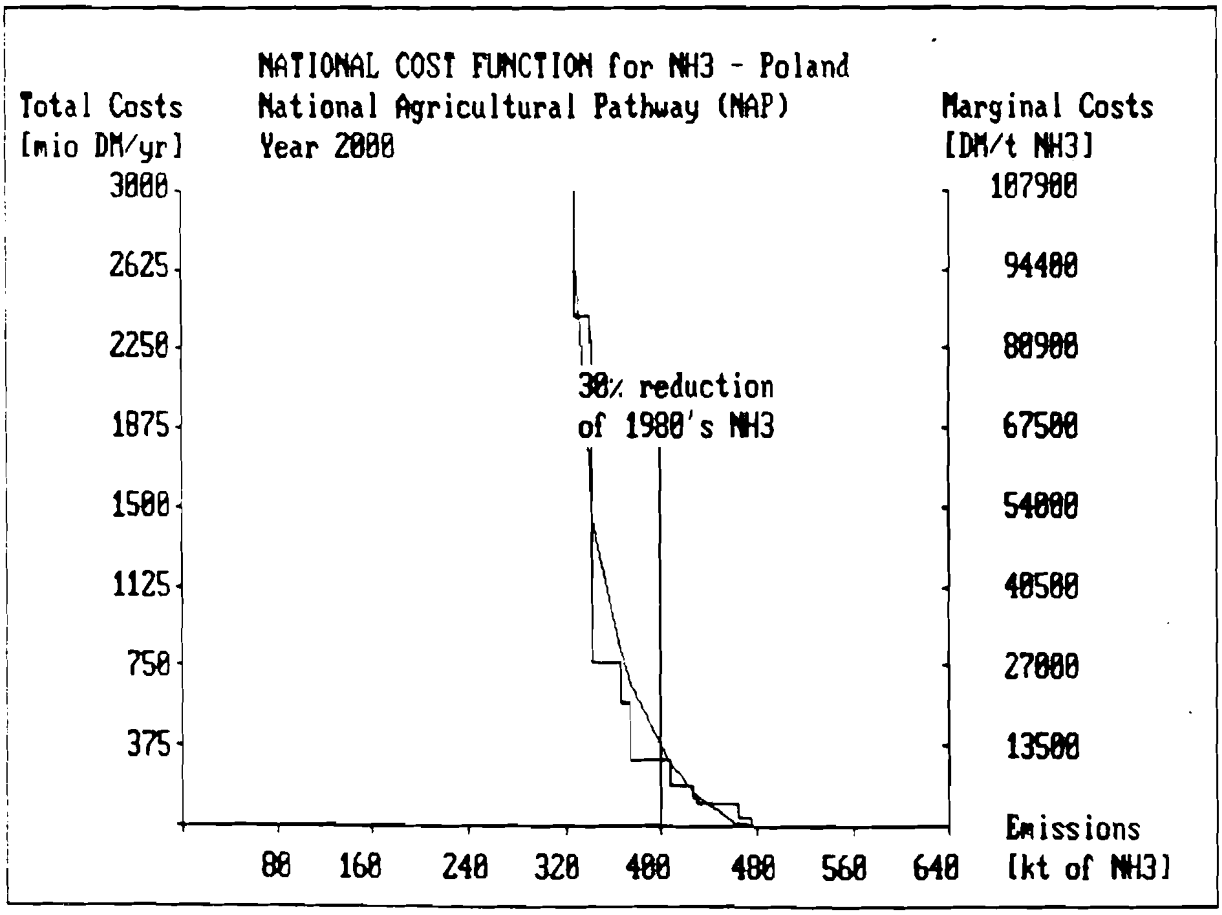

NATIONAL COST FUNCTION for NH3 - Ireland
National Agricultural Pathway (NAP)
Year 2000
Total Costs
[mio DM/yr]
Marginal Costs
[DM/t NH3]
896
784
672
560
448
336
224
112
99400
87000
74600
62100
49700
37300
24900
12400
30% reduction
of 1980's NH3
20
40
60
80
100
120
140
160
Emissions
[kt of NH3]

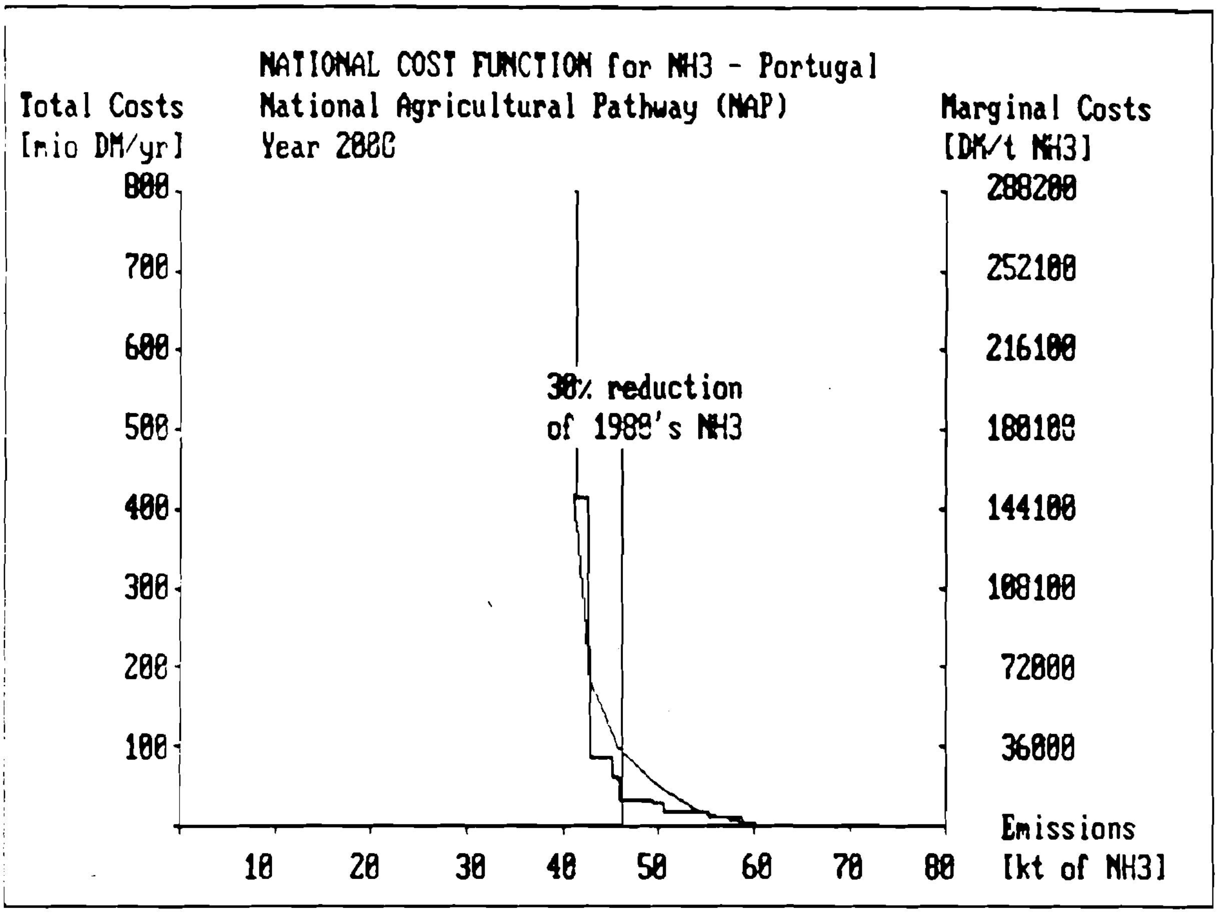

NATIONAL COST FUNCTION for NH3 - Italy
National Agricultural Pathway (NAP)
Year 2000
Total Costs
[mio DM/yr]
Marginal Costs
[DM/t NH3]
3000
2625
2250
1875
1500
1125
750
375
107000
93600
80300
66900
53500
40100
26800
13400
30% reduction
of 1980's NH3
50
100
150
200
250
300
350
400
Emissions
[kt of NH3]

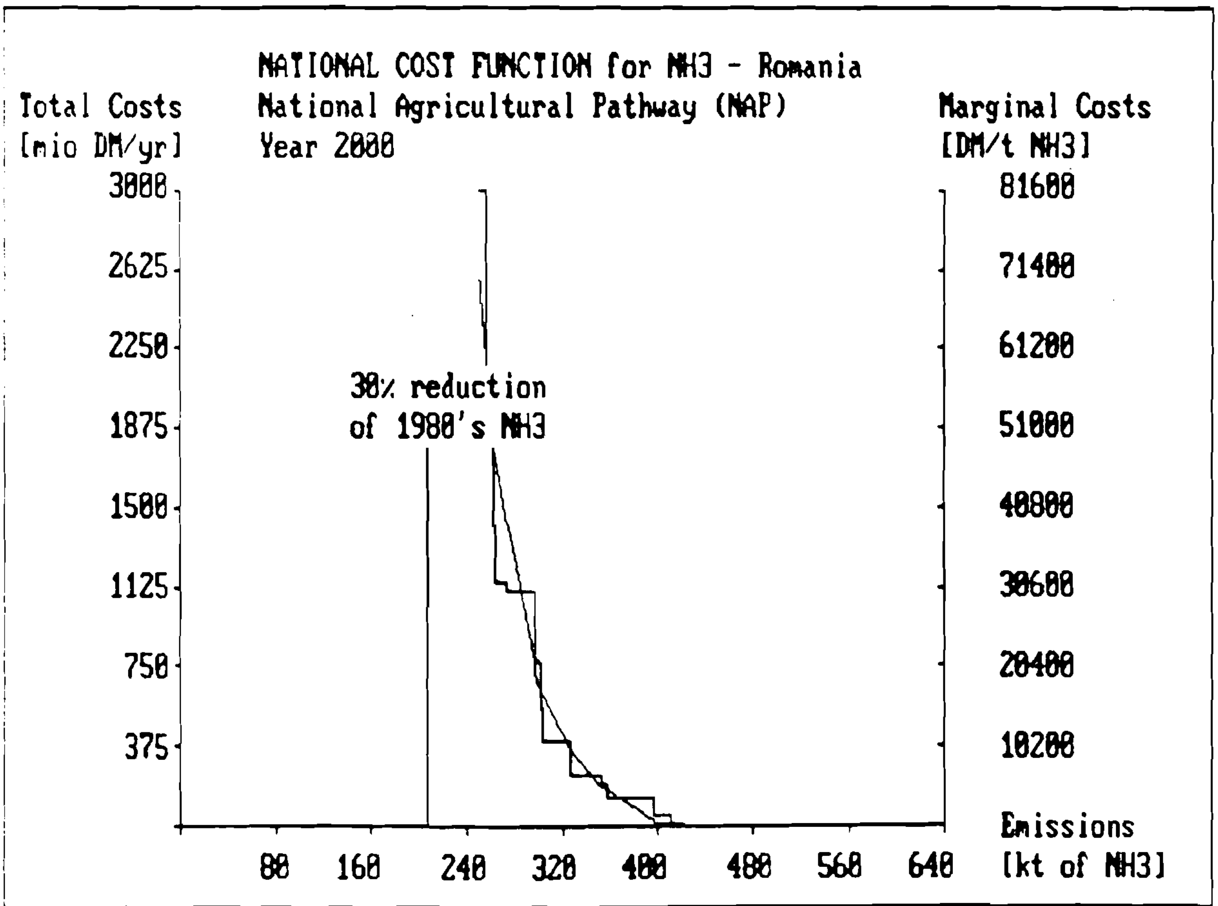

NATIONAL COST FUNCTION for NH3 - Luxembourg
National Agricultural Pathway (NAP)
Year 2000
Total Costs
[mio DM/yr]
Marginal Costs
[DM/t NH3]
80
70
60
50
40
30
20
10
72300
63300
54200
45200
36100
27100
18100
9000
30% reduction
of 1980's NH3
2
4
6
8
10
12
14
16
Emissions
[kt of NH3]

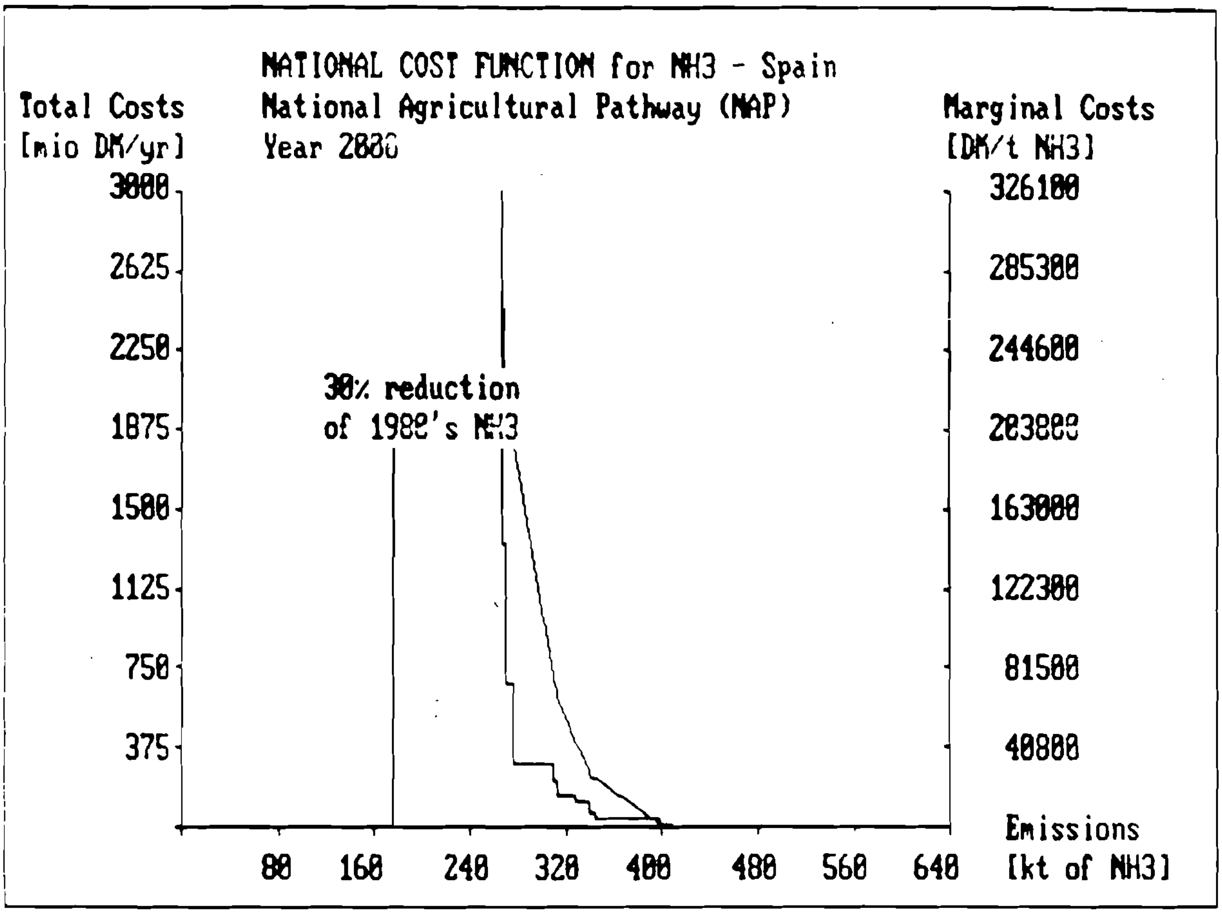

NATIONAL COST FUNCTION for NH3 - Netherlands
National Agricultural Pathway (NAP)
Year 2000
Total Costs
[mio DM/yr]
Marginal Costs
[DM/t NH3]
2000
1750
1500
1250
1000
750
500
250
214800
188000
161100
134300
107400
80600
53700
26900
30% reduction
of 1980's NH3
50
100
150
200
250
300
350
400
Emissions
[kt of NH3]

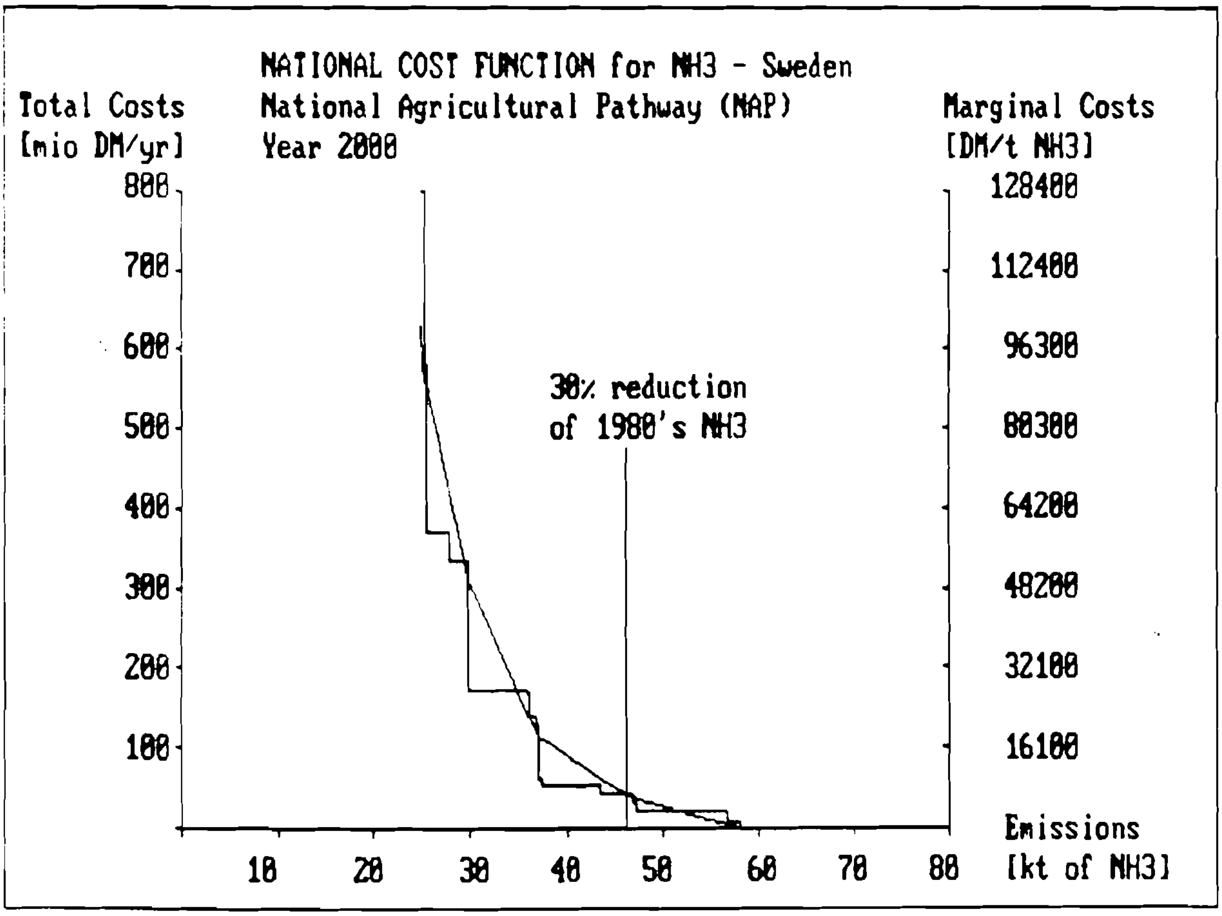

NATIONAL COST FUNCTION for NH3 - Norway
National Agricultural Pathway (NAP)
Year 2000
Total Costs
[mio DM/yr]
Marginal Costs
[DM/t NH3]
400
350
300
250
200
150
100
50
161300
141100
120900
80600
60500
40300
20200
30% reduction
of 1980's NH3
Emissions
[kt of NH3]
5
10
15
20
25
30
35
40

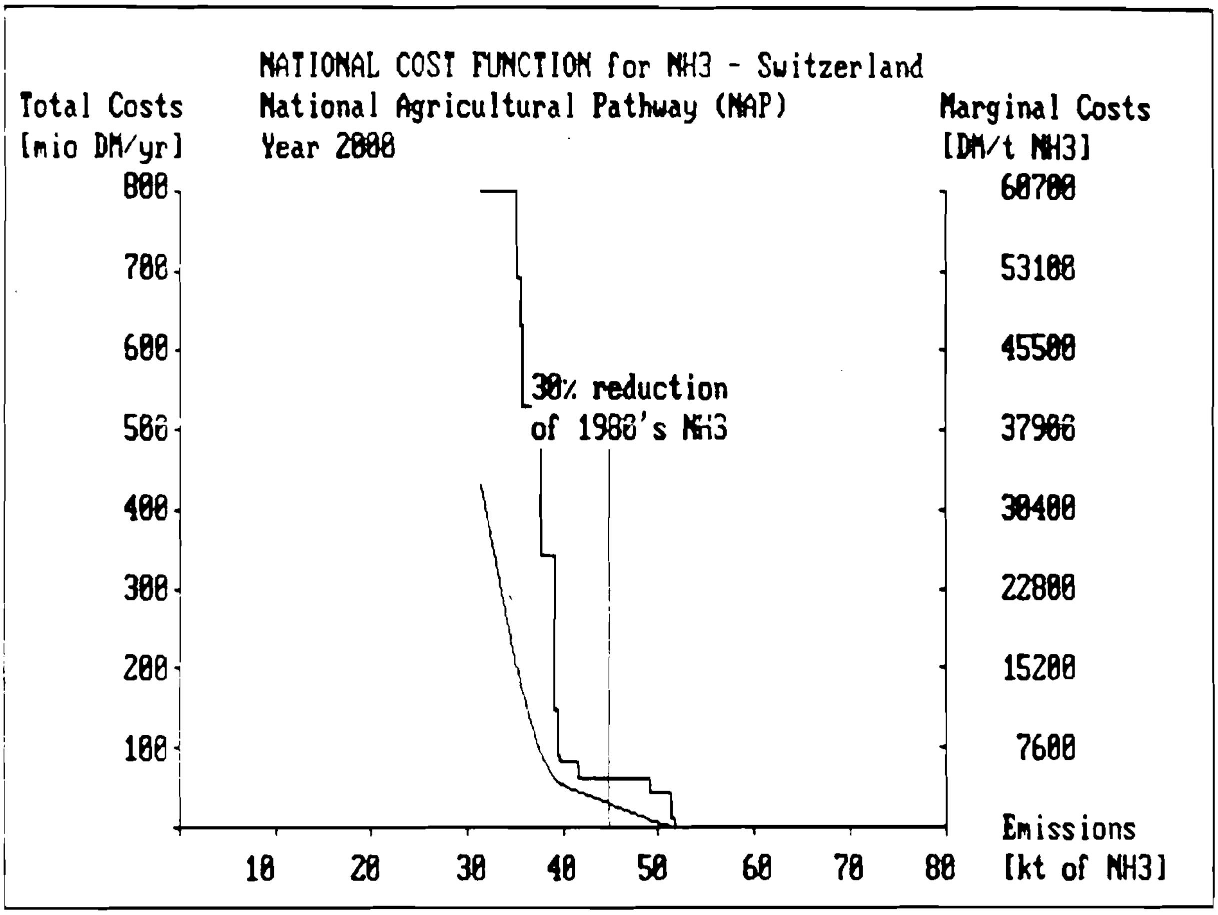

NATIONAL COST FUNCTION for NH3 - Poland
National Agricultural Pathway (NAP)
Year 2000
Total Costs
[mio DM/yr]
Marginal Costs
[DM/t NH3]
3000
2625
2250
1875
1500
1125
750
375
107900
94400
80900
67500
54000
40500
27000
13500
30% reduction
of 1980's NH3
Emissions
[kt of NH3]
80
160
240
320
400
480
560
640

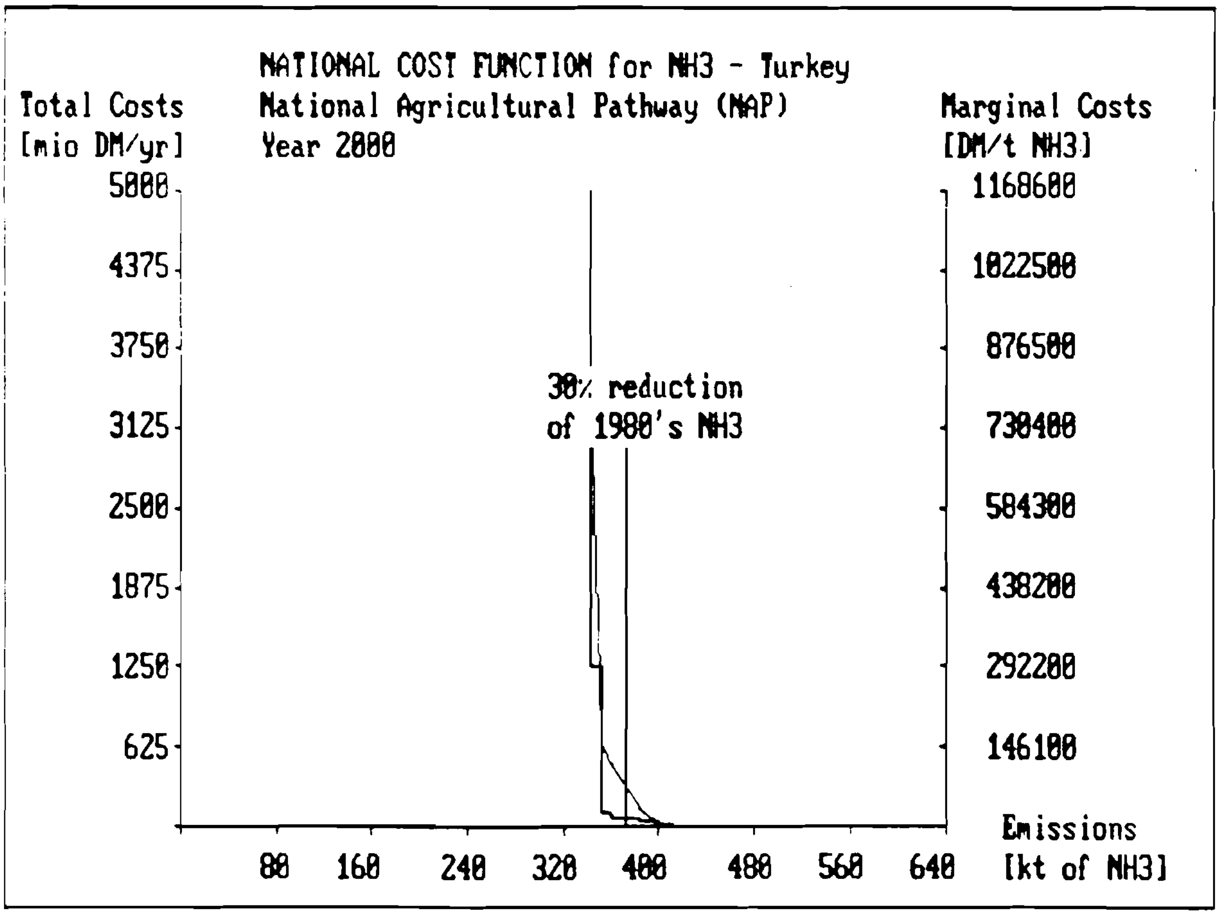

NATIONAL COST FUNCTION for NH3 - Portugal
National Agricultural Pathway (NAP)
Year 2000
Total Costs
[mio DM/yr]
Marginal Costs
[DM/t NH3]
800
700
600
500
400
300
200
100
288200
252100
216100
180100
144100
108100
72000
36000
30% reduction
of 1980's NH3
10
20
30
40
50
60
70
80
Emissions
[kt of NH3]

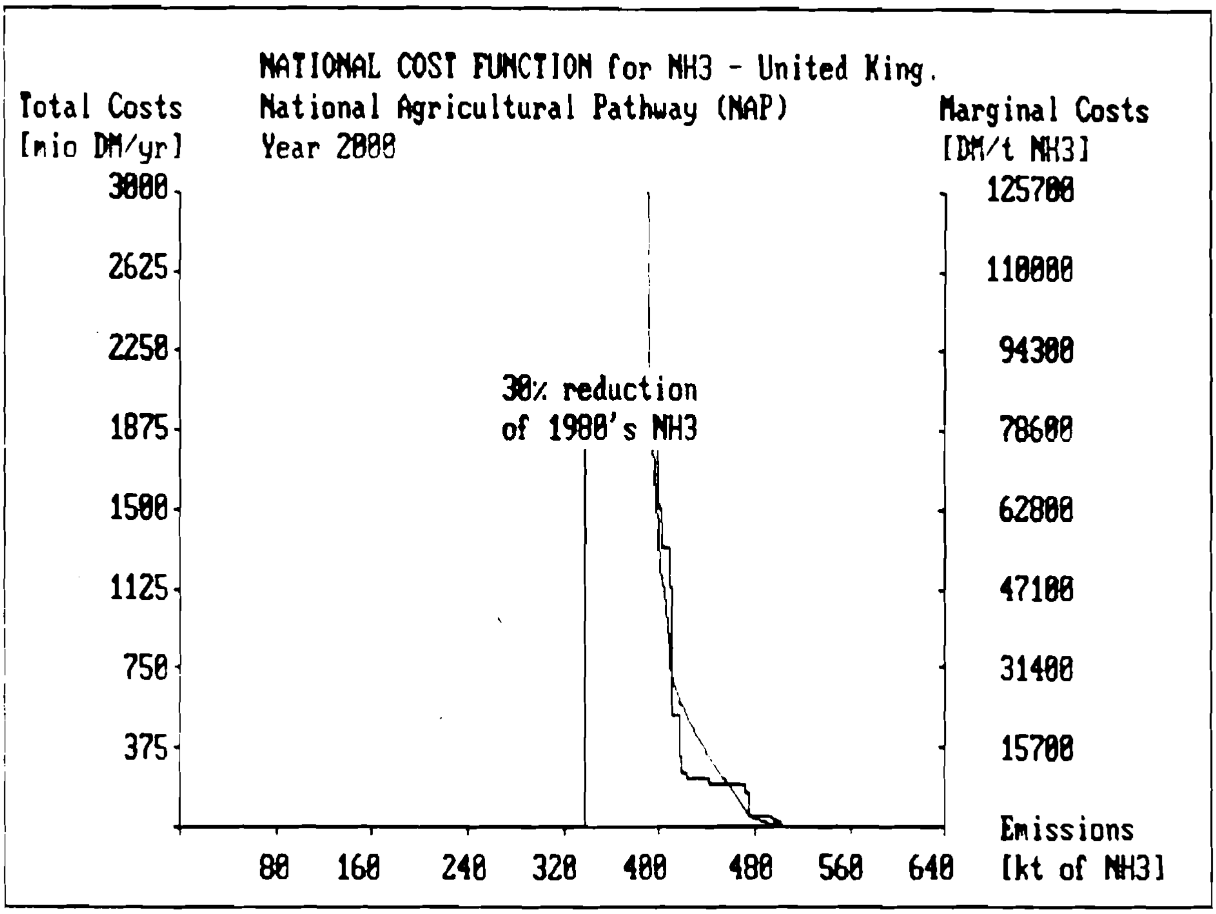

NATIONAL COST FUNCTION for NH3 - Romania
National Agricultural Pathway (NAP)
Year 2000
Total Costs
[mio DM/yr]
Marginal Costs
[DM/t NH3]
3000
2625
2250
1875
1500
1125
750
375
81600
71400
61200
51000
40800
30600
20400
10200
30% reduction
of 1980's NH3
80
160
240
320
400
480
560
640
Emissions
[kt of NH3]

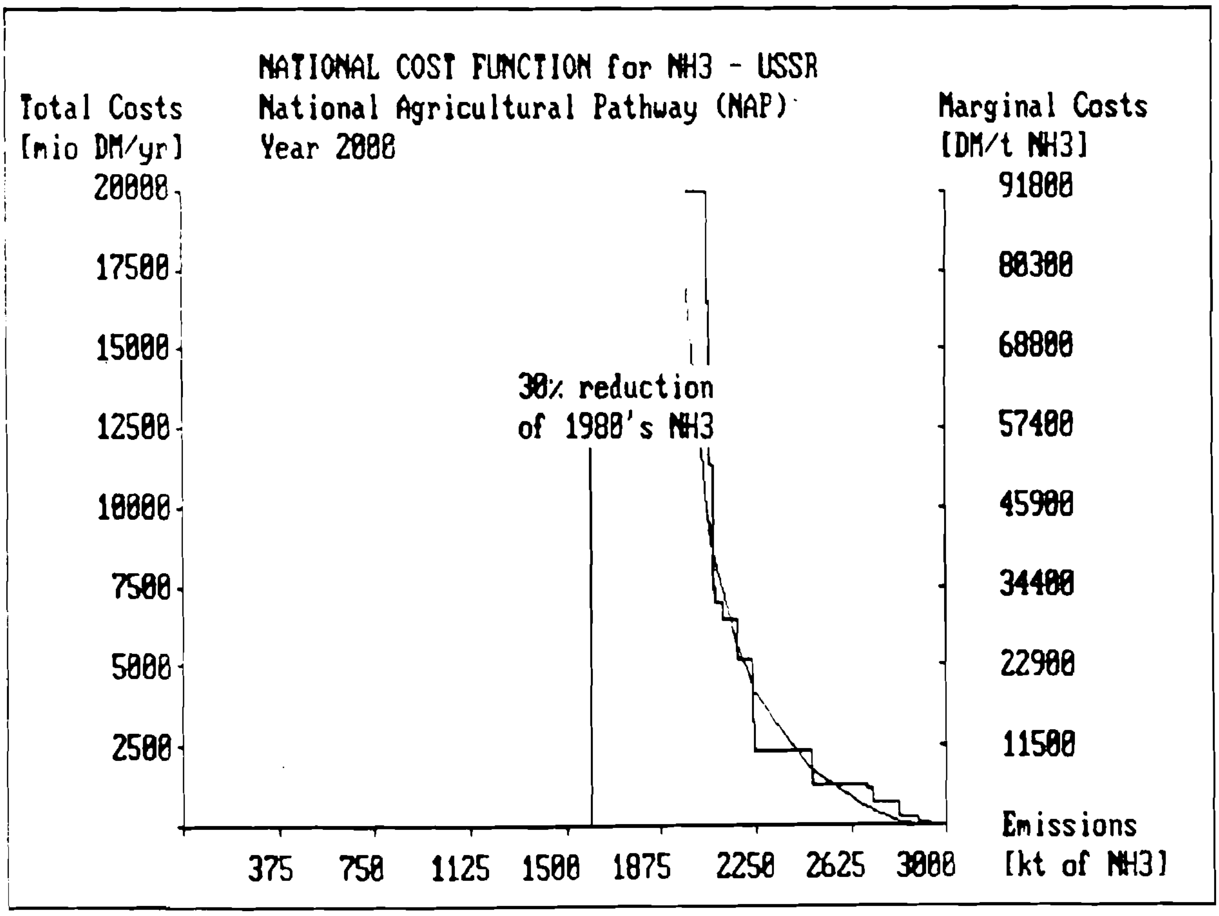

NATIONAL COST FUNCTION for NH3 - Spain
National Agricultural Pathway (NAP)
Year 2000
Total Costs
[mio DM/yr]
Marginal Costs
[DM/t NH3]
3000
2625
2250
1875
1500
1125
750
375
326100
285300
244600
203800
163000
122300
81500
40800
30% reduction
of 1980's NH3
80
160
240
320
400
480
560
640
Emissions
[kt of NH3]

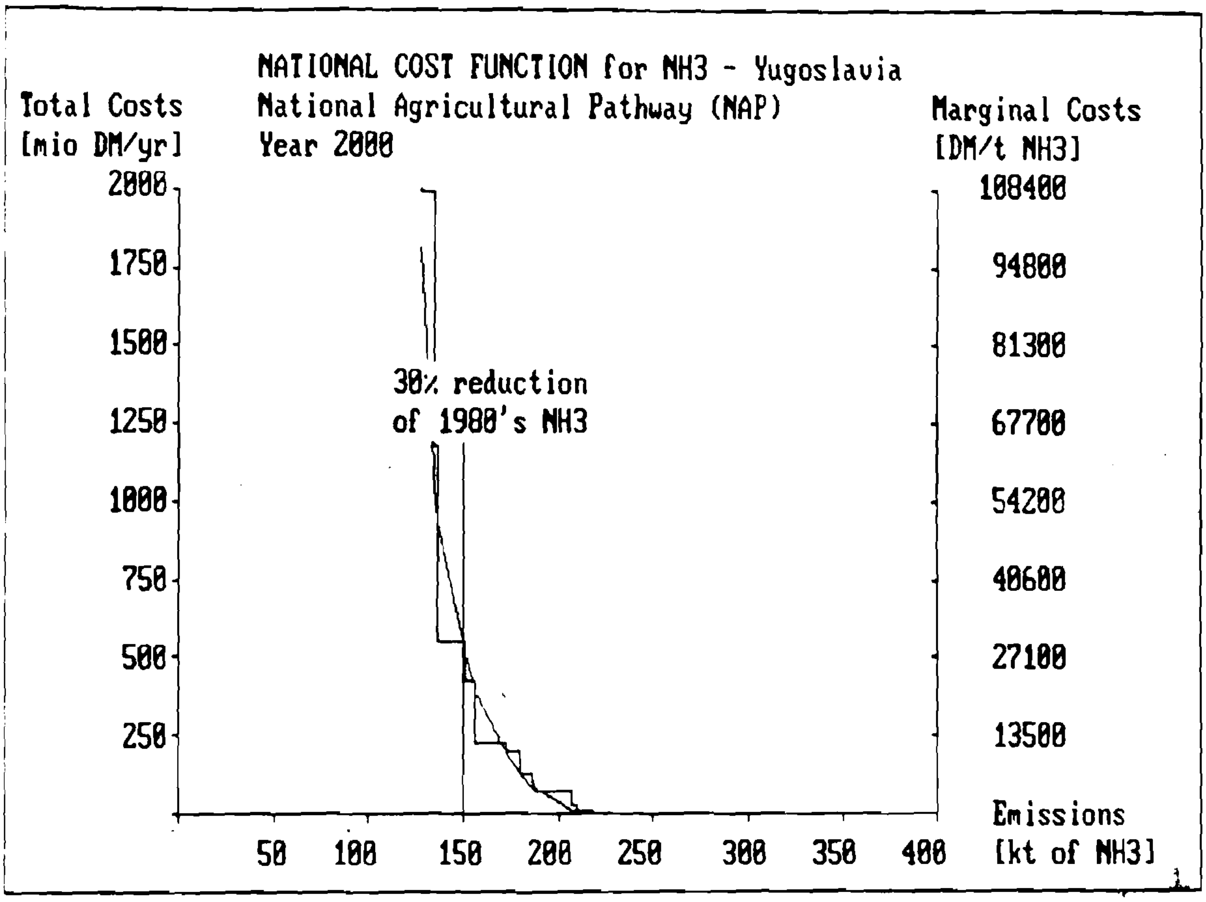

NATIONAL COST FUNCTION for NH3 - Sweden
National Agricultural Pathway (NAP)
Year 2000
Total Costs
[mio DM/yr]
Marginal Costs
[DM/t NH3]
800
700
600
500
400
300
200
100
128400
112400
96300
80300
64200
48200
32100
16100
30% reduction
of 1980's NH3
10
20
30
40
50
60
70
80
Emissions
[kt of NH3]


NATIONAL COST FUNCTION for NH3 - Switzerland
National Agricultural Pathway (NAP)
Year 2000
Total Costs
[mio DM/yr]
Marginal Costs
[DM/t NH3]
800
700
600
500
400
300
200
100
60700
53100
45500
37900
30400
22800
15200
7600
30% reduction
of 1980's NH3
10
20
30
40
50
60
70
80
Emissions
[kt of NH3]


NATIONAL COST FUNCTION for NH3 - Turkey
National Agricultural Pathway (NAP)
Year 2000
Total Costs
[mio DM/yr]
Marginal Costs
[DM/t NH3]
5000
4375
3750
3125
2500
1875
1250
625
1168600
1022500
876500
730400
584300
438200
292200
146100
30% reduction
of 1980's NH3
80
160
240
320
400
480
560
640
Emissions
[kt of NH3]


NATIONAL COST FUNCTION for NH3 - United King.
National Agricultural Pathway (NAP)
Year 2000
Total Costs
[mio DM/yr]
Marginal Costs
[DM/t NH3]
3000
2625
2250
1875
1500
1125
750
375
125700
110000
94300
78600
62800
47100
31400
15700
30% reduction
of 1988's NH3
80
160
240
320
400
480
560
640
Emissions
[kt of NH3]


NATIONAL COST FUNCTION for NH3 - USSR
National Agricultural Pathway (NAP)
Year 2000
Total Costs
[mio DM/yr]
Marginal Costs
[DM/t NH3]
20000
17500
15000
12500
10000
7500
5000
2500
91800
80300
68800
57400
45900
34400
22900
11500
30% reduction
of 1988's NH3
375
750
1125
1500
1875
2250
2625
3000
Emissions
[kt of NH3]



NATIONAL COST FUNCTION for NH3 - Yugoslavia
National Agricultural Pathway (NAP)
Year 2000
Total Costs
[mio DM/yr]
Marginal Costs
[DM/t NH3]
2000
1750
1500
1250
1000
750
500
250
108400
94800
81300
67700
54200
40600
27100
13500
30% reduction
of 1980's NH3
50
100
150
200
250
300
350
400
Emissions
[kt of NH3]