Environmental satellite models for ADAM

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Climate change, Acidification and Eutrophication

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Preface

For the purposes of national planning and policy development there is a need for forecasts and analyses of environmental indicators; such work should be made consistent with current economic forecasts and analyses. However, environmental issues are often linked to specific physical activities that are not directly specified in economic models.

This report presents satellite models to be used with the macroeconomic model ADAM. Using a macroeconomic scenario from ADAM as a starting point, the satellite models determine the physical activities of environmental importance in argriculture, sewage treatment, waste handling and landfills. Combined with ADAM and the energy model EMMA (Energy- and emission models for ADAM) the satellite models presented constitute a system that links emissions of all major substances relevant for the environmental themes climate change, acidification and eutrophication to economic activities. For illustrative purposes the entire system of models is put to work in the final chapter of the report.

The models are developed as a part of the research within the AMOR-centre of the Strategic Environmental Research Programme. The institutions involved in the research are:

Statistics Denmark
Risø National Laboratory
National Environmental Research Institute
Danish Institute of Agricultural and Fisheries Economics

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1. Introduction and summary

1.1 Background and objectives of the report

The state of the environment sets conditions for economic activities, and economic activities affect the environment through the use of natural resources and emissions related to the production and consumption of goods, transport etc. Among the more important environmental themes related to economic development at a national level are climate changes, acidification and eutrophication. Each of these environmental areas has been the subject of national environmental plans, and national standards have been put forward for each of these areas.

For each of the themes, there is a close relationship between economic activity and environmental pressure. For example, economic growth leads to increased use of energy, transport etc., which in turns leads to increased emissions of energy-related pollutants (e.g. carbon dioxide, CO_2). On the other hand, environmentally-motivated policy regulations (e.g. restrictions on livestock production in the agricultural sector) have an impact on economic development. Thus, for macroeconomic planning etc., there is a significant need for quantification of the interactions between economic activity and the effects on central environmental factors, in relation to projections as well as analyses of policy regulations.

The approach used in the modelling of interactions between economic activities and environmental pressure is the development of satellite models that attach specific emissions to the specific economic activities. The approach enables the disaggregation of economic activities and calculation of emissions under various assumptions concerning relevant economic activities. Examples of such model systems are the E3ME model (An Energy-Environmental-Economy Model for Europe) (European Commission Directorate-General XII, 1995) and the Norwegian MSG-EE model.

A Danish example of an environmental satellite model is the EMMA model (Andersen et al., 1997), which focuses on the energy-related emissions of carbon dioxide (CO_2), sulphur dioxide (SO_2) and nitrous oxides (NO_X) in relation to the macroeconomic model ADAM.[1] The emissions described in EMMA constitute major shares of the Danish contribution to climate change and acidification respectively. However, other emissions also play significant roles in climate change, as well as acidification. In relation to climate change, emissions of methane (CH_4) and nitrous oxides (N_2O) are important, and in relation to acidification, ammonia (NH_3) is a significant contributor.

The satellite models presented in this report aim at expanding the ADAM-EMMA framework to include these emissions, along with models for eutrophication, thus improving the possibilities for taking into account the impacts of economic activities on the environment at the macro level. The objectives of the satellite models are:

- To facilitate forecasts and policy analyses, where environmental themes/emissions are evaluated in line with standard economic variables, e.g. gross national income, employment, balance of payments

[1] ADAM (Annual Danish Aggregate Model) is a macro-econometric model of the Danish economy. The model is used for official economic planning. Furthermore, the model is used by various firms, institutions, organisations etc. (Statistics Denmark, 1996)

- To generate consistency between macroeconomic forecasts and forecasts concerning various environmental themes. For instance, if the use of energy is changed, emissions of several substances (not just CO_2) change.

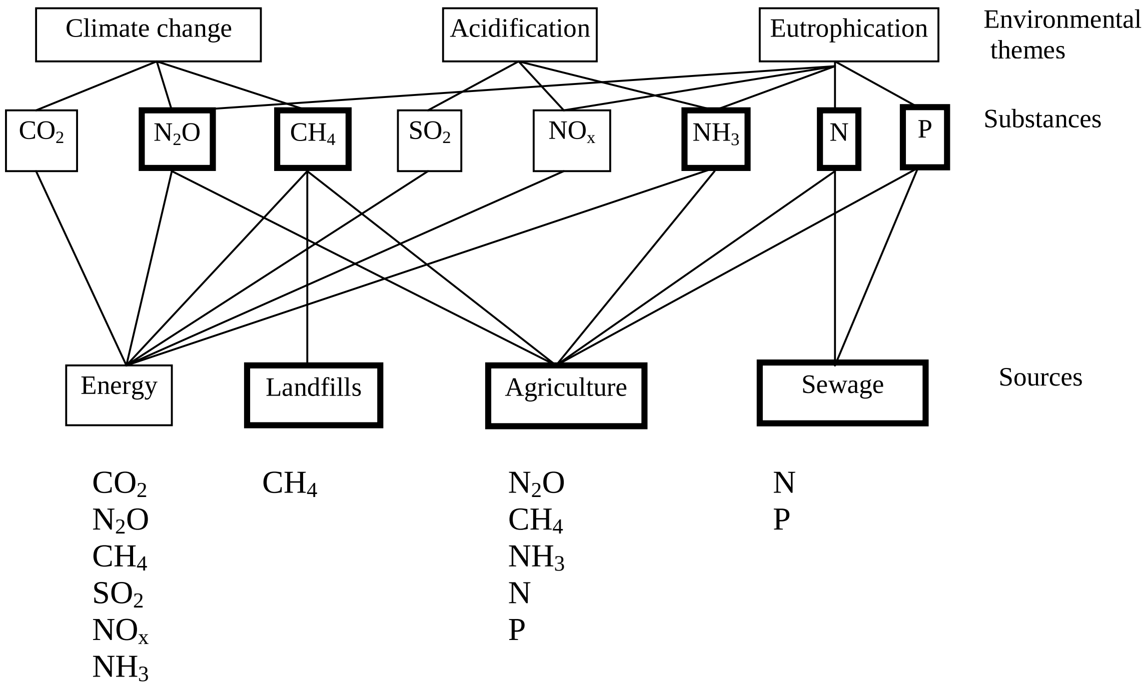
1.2 Modelling impacts of economic activities on climate, acidification and eutrophication

As indicated above, the models developed in the current project comprise emissions relevant for the environmental themes: climate change, acidification and eutrophication.

1.2.1 Climate change, acidification and eutrophication and relations to economic activities

The major links between environmental themes, emissions of substances and major economic sectors are illustrated in figure 1.1. (Bold frames indicate the focus in the present report).

Figure 1.1 Environmental themes, emissions of substances and economic sources.[2]



As is seen from the figure, the links between environmental themes, emissions of substances and economic activities are fairly complex. The environmental themes discussed here originate from the emissions of a number of substances (for example, climate change is caused by emissions of CO_2, N_2O and CH_4) and some of the substances contribute to several of the environmental themes (for instance, NH_3 contributes to both acidification and eutrophication). Furthermore, individual economic activities cause emission of several substances (agriculture emits N_2O, CH_4, NH_3, N and P), and individual substances are emitted from several activities (CH_4 from energy, landfills and agriculture). Linking emissions of the different substances to the same economic model ensures consistency between analyses of the individual substances. However, in a few cases minor spill-over effects between emissions of the different substances are not modelled endogenously e.g. removing SO_2 at powerplants by

[2] CO_2: carbon dioxide, N_2O: nitrous oxide, CH_4:methane, SO_2: sulphur dioxide, NO_x: nitrous oxides, NH_3: ammonia, N: nitrogen, P: phosphorus.

the production of gypsum emits CO_2, and the link between changed power production and required SO_2 removal is not modelled endogenously. Thus, to a certain extent the models of individual substances are separate models using the same basic data, and complete consistency requires consistent exogenous input data. Major spill-over effects like evaporation of ammonia (NH_3) and emissions of nitrous oxides (N_2O) in agricultural production are modelled endogenously.

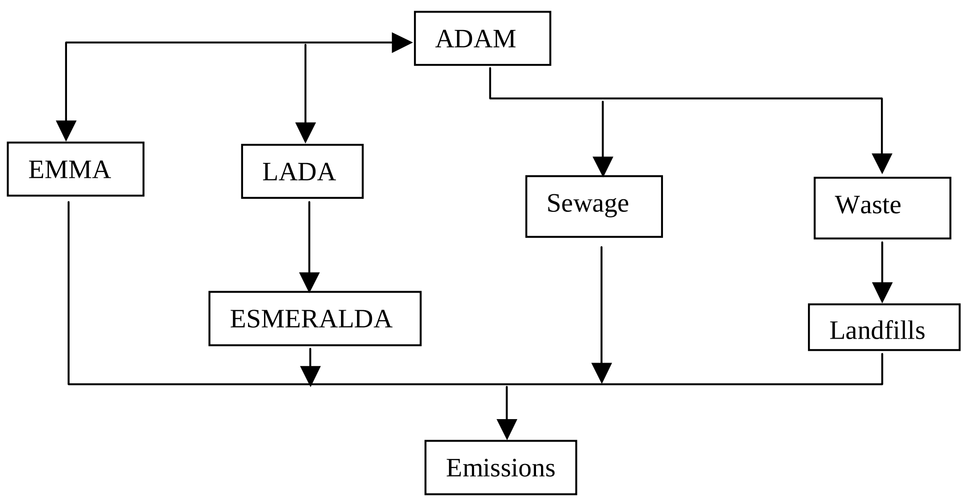
1.2.2 Modelling emissions in a macroeconomic framework

As illustrated in figure 1.1, the emissions of relevant substances are linked to energy consumption, landfills (deposition of organic waste), agricultural production and sewage treatment. Further, emissions of substances are often linked to specific physical activities, which must be specified at a lower level of aggregation than that used in the ADAM model. For example, the emissions of methane from agriculture depends on the number of animals in different categories (cattle, pigs, etc.), whereas in ADAM agriculture is described as only one activity. Therefore, in order to link emissions to ADAM it is necessary to:

- disaggregate the relevant economic activities
- establish a correspondence between economic and physical activities
- link emissions of substances to the relevant physical activities

An illustration of the system of environmental satellite models developed for ADAM is shown in figure 1.2.

Figure 1.2. The structure of environmental satellite models for ADAM



ADAM is a medium-term econometric model of the Danish economy, distinguishing 19 production branches and 12 categories of private consumption, and it also includes a determination of total energy use by households and branches. In ADAM, agriculture is represented by one branch, where production is determined from the demand side, as is the case in all ADAM's branches. For environmental modelling, a special version of ADAM has been developed, where the agricultural production is determined from the supply side, assuming that the export price is exogenous to the agricultural sector.

EMMA is a detailed energy model disaggregating the total energy use by households and industries from ADAM into seven types of energy: electricity, natural gas, district heating, solid fuels, fuels for transport, other fluid fuels and bio-fuels. Further, energy consumption is determined in the physical quantity TJ (Tera Joule), and emissions of CO2, SO2 and NOx are linked to the individual uses of energy measured in TJ. A detailed documentation of EMMA including emissions is given in Andersen et al., (1997) and Andersen and Trier, (1995).

LADA is a satellite model containing a disaggregation of ADAM's aggregated agricultural sector into 5 subsectors: crops, cattle, pigs, poultry and other. This disaggregation allows the possibility of taking into account changes in the composition of agricultural activity. As emissions of various substances differ significantly across agricultural subsectors, disaggregation is necessary for an appropriate modelling of agriculture-related emissions.

The basis for the LADA-disaggregation is the ESMERALDA-model, which is an econometric model describing producer behaviour in 16 agricultural lines of production, including 8 cash crops, 3 roughage crops, 2 cattle sectors, 1 pig sector, 1 poulty sector and a fallow land sector. This level of detail enables: a) fairly precise linkages between economic variables and physical quantity variables, and b) fairly detailed assessments of the impacts of changes in the composition of agricultural production. The latter enables refinement and adjustments of parameters for the 5 more aggregated LADA-subsectors.

In the area of agriculture, ESMERALDA is more detailed than LADA, which in turn is more detailed than ADAM. Hence, linkage to physical quantities is most straightforwardly established in the ESMERALDA-model, and linkage to the overall economy is more straightforward in ADAM, whereas LADA establishes the correspondence between the two models. The distinction between different lines of agricultural production in LADA and ESMERALDA gives the possibility of taking into account composition effects on economy and emissions at two different levels of detail. The set of agricultural models may be used in two ways:

a) detailed ESMERALDA scenarios/projections are implemented in LADA, making it possible to analyse policies affecting the agricultural sector at a fairly detailed level in ESMERALDA, and thereafter analyse the macro-economic effects of these policies in ADAM by aggregating the detailed ESMERALDA results through LADA

b) ADAM projections are utilised in LADA, giving projections of production, factor demands and land use in 5 subsectors. Data for these subsectors are disaggregated into 16 lines of production and linked to physical quantities, by means of ESMERALDA.

Finally, in relation to waste and sewage, two simple models are developed. In relation to the emission of methane (CH_4), a simple model for the generation of waste and the deposition of organic waste is developed. The generation of waste is linked to the individual categories of private and industrial activities in ADAM, and the deposition by type of waste is calculated assuming exogenous deposition rates. In relation to discharge of nitrogen (N) and phosphorus (P) from point sources, the amount of sewage is linked to the population and industries in ADAM.

Emissions are calculated from the definition:

$$Emission = Activity\ level \cdot emission\ coefficient$$

where *Activity level* is defined by variables in the economic model (including satellite models) and *emission coefficients* are defined relative to the specific variable in the economic model. Examples of activity levels may be the number of animals in specific livestock categories, tonnes of crops harvested, number of vehicles, tonnes of waste, etc. That is, emission coefficients are physical measures related to specific physical or economic variables modelled in the economic – or satellite – models.

1.3 Overview of the report

The following provides an overview of the report. This overview should provide the reader with an overall understanding of the model concept presented in this report, as well as of the individual elements of the concept.

Chapter two describes some of the relevant issues related to the ADAM-model, focusing on the changes in ADAM necessary for the current modelling. These changes include: introducing supply-side determined agricultural production into the model, integrating food processing industries with the agricultural sector, and changing domestic price formation in light of the exogenous export prices.

Chapter 3 describes the LADA model. As mentioned above, LADA consists of 5 agricultural subsectors: crops, cattle, pigs, poultry and other (horticulture, fish farming, etc.). The chapter describes the data underlying LADA, the model's representation of the 5 subsectors, and the incorporation of detailed ESMERALDA projections of the agricultural sector into the model.

Chapter 4 gives a short introduction to ESMERALDA, focusing on the detailed data underlying the model and the disaggregation of LADA-subsectors into individual lines of production to establish a correspondence between economic variables and relevant physical quantities in agricultural lines of production.

The modelling of emissions related to climate changes is described in chapter 5. This includes methane (CH_4) and nitrous oxide (N_2O) from agriculture as well as from waste, landfills and energy production. Agricultural emissions of methane are linked to the numbers of animals in different livestock categories, and agricultural emissions of nitrous oxide are linked to numbers of animals and numbers of hectares with different crops. Methane emissions from waste and landfills are linked to the amounts of deposited organic waste of different categories.

Chapter 6 treats acidification, with focus on the emissions of ammonia (NH_3). The agricultural emission of ammonia is linked to the numbers of animals in different livestock categories (distinguishing between grazing and stable animals), as well as the area with different crop categories. Other NH_3 emissions include emissions from road transport (emissions are linked to the numbers of vehicles and the corresponding shares of vehicles with catalytic converters.

Emission of nitrogen (N) and phosphorus (P) related to the environmental theme "eutrophication of the aquatic environment" and a simple model of sewage is described in chapter 7. Eutrophication from agriculture is related to the surplus of nitrogen and phosphorus respectively. The surplus depends on input from animal manure, synthetic fertilisers, wastewater sewage and industrial waste used as fertiliser, fixation and deposition, and removals in terms of crop harvest and evaporation. Other sources of nitrogen and phosphorus include various specific point sources.

Finally, the satellite models developed in this report are combined with the modelling of CO_2, SO_2 and NO_X emissions in the EMMA model. Use of the combined model framework is illustrated by a number of examples. One example is a baseline projection, where an ESMERALDA projection is used for modifying the agricultural part of an ADAM forecast, using LADA for this modification. The modified ADAM forecast yields projected macro-economic variables as well as projections for the considered emissions (CO_2, CH_4, N_2O, SO_2, NO_X, NH_3, N and P) at a national level. The established model framework can also be applied for policy scenario analyses. This is demonstrated by three different scenarios, which could be considered as alternatives to the baseline projection:

- change in government expenditure (traditional fiscal policy experiment)
- restrictions on animal density in agricultural production
- changes in agricultural feed practices, and hence changed emissions coefficients.

2. The agricultural sector in ADAM

In the current version of the ADAM model, production in the agricultural sector is determined from the demand side, while the output price is considered exogenous. It can be argued that this is not an appropriate description, because the agricultural sector in Denmark is small relative to a large world market and supply is restricted by land availability. This leads to the hypothesis that production is determined by the producer, who chooses the output level contingent on the export price.

This section presents the modelling of the agricultural production as determined in a modified version of ADAM. The modified version incorporates the hypothesis of exogenous prices of agricultural products in the export market, and describes the pricing behavior of the sector in the domestic market. At the same time the model makes the importance of quotas etc. more visible within the model, and the link between the agricultural sector and the associated industry *manufacturing of food*, the *nf*-industry, is modelled explicitly. The model is made to facilitate a better description of agricultural production with and without underlying LADA-scenarios. Supply-side determined production in the agriculture is also discussed in Werner (1999).

Section 2.1 solves the theoretical problem of a sector selling to both the domestic and the export market facing an exogenous price at the export market. Section 2.2 describes the structure of the food producing industries in ADAM. Equations describing supply-side determined production are introduced in section 2.3, while section 2.4 describes equations for exports, export prices and subsidies. In section 2.5 equations for domestic prices are estimated.

2.1 Supply-side determined production

This section describes the behaviour of a profit maximizing sector or industry producing one output which is sold in two markets. In the first market it is assumed that the industry knows some downward sloping demand curve and faces competition from competing goods. In this market, which will be refered to as the *domestic market*, the sector chooses an output price. In the other market, the output price is exogenous and the sector faces a horizontal demand curve. This market is referred to as the *export market*.

The above implies that the sector is solving the problem:

$$\max_{X,p^d} \Pi = p^d \cdot D\left(\frac{p^d}{p^c}\right) + p^e \cdot \left(X - D\left(\frac{p^d}{p^c}\right)\right) - TC(X) \qquad \textbf{(2.1.1)}$$

where X is the level of production, while p^d is the price of the sector's output and p^c is the prices of the competing goods in the domestic market. p^e is the exogenous price received by the sector in the export market. $D(p^d/p^c)$ is the domestic demand for the product produced by the industry given prices p^d and p^c. It is assumed that $D'(p^d/p^c)<0$ and that the priceelasticity, ξ, is constant and numerically larger than 1; $TC(X)$ is the cost minimizing total costs of producing X. Finally, it is assumed that $MC'(X)>0$, where $MC(X)=TC'(X)$.

Solving the problem leads to the following first order conditions:

$$p^e = MC(X) \qquad \textbf{(2.1.2)}$$

and

$$p^d = (1+\mu)\cdot p^e \qquad \textbf{(2.1.3)}$$

Equation (2.1.2) is a supply function for the sector stating that the level of production is chosen so that the marginal cost of production equals the export price. Equation (2.1.3) shows that the industry chooses its domestic market price, p^d, as a mark-up on the export price, p^e. This is due to the fact that the export price can be seen as the alternative price of selling in the domestic market, since the industry can always sell to the export market at the price p^e. The constant mark-up follows from the assumptions on the elasticity[3] in the demand function.[4] Note from (2.1.3) that

$$\frac{\partial p^d}{\partial p^e} = (1+\mu) \leftrightarrow \frac{\partial p^d}{\partial p^e}\cdot\frac{p^e}{p^d} = (1+\mu)\cdot\frac{p^e}{(1+\mu)\cdot p^e} = 1 \qquad \textbf{(2.1.4)}$$

that is, a 1 % change in the export price leads to a 1 % change in the domestic price. This is the feature of equation (2.1.3) which is used in the empirical model.

Finally, it is noticed from equation (2.1.1) that total exports from the sector are determined residually from production and domestic demand for *X*.

2.2 The agricultural and related sectors

The agricultural sector in ADAM, denoted the *a*-sector or *a*-industry below, is an aggregate of 5 industries from the most detailed level of the National Accounts. The industries are *agriculture*, *horticulture etc.*, *agricultural services*, *forestry* and *fishing*. However, the ADAM industry denoted *manufacturing food*, the *nf*-industry, which consists mainly of slaughterhouses but also dairies, bakeries and mills etc., relies heavily on the agricultural sector for inputs. This section discusses the interdependency of the *a*-sector and the *nf*-industry and the assumptions which are made in the modelling of the production in these two industries.

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[3] The price elasticity of demand with respect to p^d is

$$\xi = \frac{D'\left(\frac{p^d}{p^c}\right)\cdot\frac{p^d}{p^c}}{D\left(\frac{p^d}{p^c}\right)}$$

[4] The first order condition with respect to p^d *is*

$$D\left(\frac{p^d}{p^c}\right) + p^d\cdot D'\left(\frac{p^d}{p^c}\right)\cdot\frac{1}{p^c} - p^e\cdot D'\left(\frac{p^d}{p^c}\right)\cdot\frac{1}{p^c} = 0 \leftrightarrow \frac{p^e}{p^d} = 1 + \frac{D\left(\frac{p^d}{p^c}\right)}{D'\left(\frac{p^d}{p^c}\right)\cdot\frac{p^c}{p^d}} \leftrightarrow \frac{p^e}{p^d} = 1+\frac{1}{\xi} \leftrightarrow$$

$$p^d = \left(\frac{\xi}{1+\xi}\right)\cdot p^e \leftrightarrow p^d = \left(1-\frac{1}{1+\xi}\right)\cdot p^e \leftrightarrow p^d = (1+\mu)\cdot p^e$$

where $\mu=-1/(1+\xi)$ as ξ is constant and $|\xi|>1$ it follows that μ is a positive constant.

If one looks at the fixed price input-output table describing 1997 at the ADAM aggregation level, one finds that about 55% of output from the agricultural sector is used as input in the *nf*-industry, 15% is used by the agricultural sector itself, about 20% is sold directly to the export market, mainly as exports in SITC-group *0*, *E0*, while the remaining approximately 10% is used directly for consumption (7%) or inputs in other domestic industries. The *nf*-industry sells approximately 55% of its output in the export market, mainly *E0*, about 20% of total production is used for private consumption of food, while just over 10% of production is used by the industry itself. Looking at the *nf*-industry from the input side it is seen that 38% of the total production stems from the agricultural sector.

The very low proportion of agricultural products used by final domestic demands indicates that a large proportion of agricultural output must be processed before it is consumed. This implies that one could think of agriculture as producing two goods, one which needs processing and one that can be consumed directly. This suggests that agriculture can sell the part of its production which must be processed, either to the *nf*-industry or to foreign plants. Likewise, the sector can sell the part of its production that does not need processing to either domestic or foreign consumption. In the model presented in the following section, it will be assumed that the proportion of agricultural output which is processed in the *nf*-industry is exogenous.[5] For simplicity, it is furthermore assumed that the remainder of the agricultural production can be sold either to domestic demands or exported at the exogenous export price.

The proportion of agricultural production used as input in the *nf*-industry has been relatively stable since the mid 1970s, varying between 34% and 39% of total production in the *nf*-industry. This amounts to between 55% and 60% of agricultural production. One can think of the input of agricultural semi-manufactured products as the basic input in the *nf*-industry, while other inputs such as labour, capital, energy and other materials are gross complements to the agricultural input in the *nf*-production function. It is assumed that the *nf*-industry will in fact buy and manufacture the agricultural output in question. In principle, the *nf*-industry can buy agricultural input in the *a*-sector or on the world market. The current version of ADAM already allows for this via substitution between input of products from the *a*-sector and inputs from imported agricultural products from SITC groups *0* and *2*, *M0* and *M2*. Approximately 55% of output from the *nf*-industry is exported, while 20% is used in private consumption of food. This implies that the *nf*-industry can be considered a one-output industry, in the sense that it produces for consumption only.

The determination of production in the *nf*-industry in the modified version of ADAM rests upon the two assumptions concerning production in the *a*- and *nf*-industries discussed above:

1) A proportion of the agricultural output must and will be processed in the *nf*-industry before it can be sold to final demands

2) Agricultural semi-manufactured products from the *a*-industry are the basic input in the *nf*-industry

Assumption 1) states that selling live pigs, raw milk etc. directly to households is not custom and that a proportion of these goods is in general not exported. The hypothesis implies that a constant proportion of the agricultural production is processed in the *nf*-industry; this proportion is assumed to change only with the composition of agricultural output. The

[5] This assumption could be justified by an argument that some proportion of agricultural production is not fit for transportation over long distances. In this case the proportion of agricultural output which needs processing in the *nf*-industry is determined by, for instance, the underlying composition of agricultural production.

objection to 1) is that it might be possible for the *a*-sector to sell some of these goods in the export market.

Assumption 2) states that if there is no agricultural production, then there is no production in the *nf*-industry. The objection to 2) is that the *nf*-industry could alternatively import *M0* and *M2* products for processing.[6]

2.3 Modelling production in the a-sector and nf-industry

The starting point for modelling the determination of agricultural production is the solution to the theoretical problem described in section 2.1. Two additional features are taken into account: 1) a scenario concerning production and prices in the *a*-sector might be known from the LADA-model. 2) the dependency between the *a*- and *nf*-industries discussed in section 2.2.

Concerning 1) the model is constructed such that some exogenous benchmark scenario, typically derived from some ESMERALDA/LADA scenario, determines the initial level of production in the agricultural sector, given some scenario describing factor prices and the price obtained in the export market. If the export price or the factor prices change compared to the benchmark scenario, the first order condition (2.1.2) comes into play, altering the production.

The cost of production in the baseline scenario is given from the LADA scenario, or alternatively from the factor demand system in ADAM. In both cases the production function exhibits constant returns to scale, implying that the marginal cost is constant. This introduces a problem of indeterminacy to the model, since production will be infinite if the export price is above the marginal costs, and undetermined if the export prices equals the marginal costs. There will be no export if the export price is below the marginal costs.[7]

The problem is solved by assuming that the reaction of exports of *E0* to price changes is unaltered compared to the current version of ADAM, implying that some price elasticities of production can be derived using the estimated export price elasticities used in the current version of ADAM. This practice implicitly assumes that the marginal cost depends positively on the level of production, which can be justified by assuming, for instance, that land is a fully fixed and crucial factor in agricultural production in all subsectors (despite this not being explicitly modelled in neither LADA nor ADAM), or that for instance some costs of respecting rules in agricultural production rise when production is increased.

Given the above, and assuming some sluggishness in adjusting production to a new level, the production in the agricultural sector can be written in error correction form as in equations (2.3.1) and (2.3.2) below:

$$\log(fXaw) = \log(fXae) + \xi_l^a \cdot \log\left(\frac{pne0}{pwaw} \cdot kfXa\right)$$

$$kfXa = \frac{pwawe}{pne0e} \qquad \textbf{(2.3.1)}$$

[6] The objections to 1) and 2) could be objects for future research.

[7] In this case the level of production in the theoretical problem (2.1.1) will be determined by the domestic demand when the sector choses some profit maximizing domestic prices according with (2.1.3)

where ξ_l^a is the long run price elasticity of production in the *a*-sector, *fXaw* is the profit maximizing level of production in the long run. *fXae*, *pne0e* and *pwawe* are agricultural production, the price received by the producer when exporting to *E0* and costs of production in the baseline scenario. *pne0* is the actual price received by the exporter and *pwaw* is the actual costs of production. Note from (2.3.1) that if *pne0=pne0e* and *pwaw=pwawe* then *fXaw* is equal to the agricultural production in the baseline scenario.

The dynamics of production are given by

$$d\log(fXa) = d\log(fXae_t) + \xi_s^a \cdot d\log\left(\frac{pne0_t}{pwaw_t} \cdot kfXa_t\right) + \gamma \cdot \left(\log(fXaw_{t-1}) - \log(fXa_{t-1})\right) \quad \textbf{(2.3.2)}$$

where ξ_s^a is the short run price elasticity of production in the *a*-sector while γ is the speed of adjustment. Note from (2.3.2) that the actual profit maximizing level of production also in the short run is equal to the corresponding variable in the baseline scenario, as long as the actual export price and costs are unchanged relative to the baseline scenario.

The elasticities ξ_l^a and ξ_s^a are regarded as exogenous variables in the modified ADAM. This allows changing the elasticity of production, which is an advantage when analysing the effects of changing rules and quotas, since changes in rules can reduce or expand the sectors' possibilities of reacting to price changes. Especially new rules or quotas can hinder expansion of production through restrictions or higher costs of production, thereby lowering the elasticities. Furthermore it allows the user of the model to introduce the hypothesis that the elasticities are decreasing in production as a result of land scarcity. As a benchmark the output elasticities are chosen such that the price elasticities of exports, *E0*, are identical in the partial models of *E0* in the current and the modified version of ADAM.[8]

The starting point in the modelling of production in the *nf*-industry is hypothesis 1) and 2) in section 2.2. If one assumes that the underlying composition of agricultural production is unchanged, these assumptions imply that a one % increase in agricultural production raises the production of products which need processing in the *nf*-industry by 1%, thereby increasing the material inputs in the *nf*-industry by 1%.[9] In ADAM production and material inputs are proportional, hence a 1 % increase in agricultural production leads to a 1% increase in production in the *nf*-industry.

[8] In the current version of ADAM exports of *E0* are determined by a downward sloping demand curve in the world market and the relative price of *E0* produced domestically (which is a mark-up on average unit costs) and elsewhere. In both models a higher world market price will increase Danish exports. In the modified ADAM this is due to increased production and higher domestic prices, and in the current version of ADAM due to the increased competitiveness of domestically produced goods. The benchmark output elasticities are choosen such that the effect on fixed price *E0* of a one percent increase in the world market price is identical in the two models.

[9] Agricultural products are a part of material input, *fVmnf*, in the *nf*-industry. The total material input is proportional to input of agricultural production when it is assumed that *fVmnf* is produced from inputs from various industries and import groups by Leontief technology. This is almost the case in ADAM. However, there is some substitution between energy and material as well as substitution between domestically produced and imported inputs; this leads to small deviations from the Leontief assumption. These deviations will result in minor deviations from the hypothesis of proportionality between agricultural and *nf* production when using the model.

It follows that production in the *nf*-industry is given as:

$$d\log(fXnf) = d\log(fXa) \qquad \textbf{(2.3.3)}$$

This equation states that the growth rates in production in the *a*- and *nf*-industry are equal.

For forecasting purposes, equation (2.3.3) can be used directly, as long as there are no changes in the composition of agricultural output. If one, for instance, in a policy analysis based on ESMERALDA and LADA observes changes in the composition of agricultural output, one should consider whether this is likely to change the proportion of total agricultural prodution which must be processed before sold to the final demands. This is the case in the experiment in section 8.2.2, where the production of pigs and cattle is reduced, while crop production etc. is unchanged. In this experiment it is assumed that the entire change in production is due to change in the part of production, which must be processed in the *nf*-industry and corrections are introduced into equation (2.3.3).

The pricing behaviour in the *nf*-industy is given by (2.1.3), as the pricing behaviour in the domestic market is independent of the production level.

2.4 Export, export price and subsidies

Having determined the production in the agricultural sector and the corresponding production in the *nf*-industry, the exported volume of *E0* from these industries is found residually from production and demands other than *E0*:

$$f<i>E0 = fX<i> - \left(\sum_h a<i><h>\, fX<h> + \sum_i \left(a<i><j> \cdot D\left(\frac{p<j>}{pcp}\right)\right)\right) \qquad \textbf{(2.4.1)}$$

where $i = a$, *nf* and indexes *h*, *j* denote industries and final demands (other than E0) respectively, *faE0* and *fnfE0* are exports of SITC 0 from the *a*- and *nf*-industry respectively. The prices *p<j>* are prices of final demand. These are functions of domestic prices in the *a*- and *nf*-industries. From equation (2.4.1) it is especially noted that industry pricing behaviour in the domestic market affects the level of exports.

An intermediate variable describing the exported volume from the *a*- and *nf*-industry is defined as:

$$fE0k = faE0 + fnfE0 \qquad \textbf{(2.4.2)}$$

The SITC0 export from the *a*- and *nf*-industry, *fE0k*, amounts to approximately 90% of total SITC0 exports, and the total exported volume *fE0* is assumed to be proportional to exports from the *a*- and *nf*-industry:

$$fE0 = fE0(-1) \cdot \frac{fE0k}{fE0k(-1)} \qquad \textbf{(2.4.3)}$$

The remaining 10% of the exported volume originates from trade, *qh*, the *nn*-industry "manufacturing of beverage and tobacco" and finally, imports from SITC0, *M0*. Equation (2.4.3) implies an assumption of constant properties among the input-output coefficients *aae0*, *anfe0*, *anne0*, *aqhe0* and *am0e0*. In this way modelling of input-output coefficients is avoided, and due to the large proportion of *fE0* originating from the *a*- and *nf*-industries the assumption seems reasonable.

Returning to the problem (2.1.1) and the actual production in the agricultural sector (2.3.2), it can be seen that production is determined by some export price and the marginal costs of producing. The export price in question is the price received by the producer when exporting goods in SITC0.

In ADAM variable terms, the price received by the exporter is:

$$pne0 = pe0 - \frac{Sipe0}{fE0} \qquad \textbf{(2.4.4)}$$

where *pe0* is the price received by the exporter less subsidies, while *Sipe0/fE0* is the subsidy received per exported unit.[10] The price, *pe0*, could be considered the price of Danish products in the world market. In the modified model *pe0* is considered to be exogenous and it is a compound price determined by world market prices, exchange rates and the composition of the Danish sub-SITC0 exports. Note that *pe0* cannot be considered a genuine world market price of *fE0*, since other countries might have other compositions for their SITC0 exports. That is, the price *pne0* is made up of three major components: some world market price and exchange rates, which together equal *pe0* and subsidies received by the sector. In the current version of ADAM *pe0* is calculated from the cost side.

The subsidy received by exporters of SITC0 is given from different schemes such as *Sipe0* = *Sipee* + *Sipaa* + *Sipeq*, where *Sipeq* is a residual and *Sipaa* is compensatory payments for arable crops. *Sipee* is export subsidies. In principle *Sipee* is received when exporting to markets outside the EU, and implies obtaining a price lower than some guaranteed price. Here, however, we are only looking for some rate, *tpe0*, as an approximation of the export subsidy obtained per unit exported.

It is found that:

$$\begin{aligned} &Sipee = \tau \cdot (p^{EU} - p^{W}) \cdot (1-\alpha) \cdot fE0 + Sipeem \rightarrow \\ &tpe0 = \frac{Sipee - Sipeem}{fE0} = \tau \cdot (p^{EU} - p^{W}) \cdot (1-\alpha) \end{aligned} \qquad \textbf{(2.4.5)}$$

where τ is the proportion of the price difference received as a subsidy, α is the proportion of exports to EU countries and p^{EU} is the price guaranteed by the EU, while p^{W} is the world market price. *Sipeem* is monetary equalization amounts. Equation (2.4.5) tends to lead to a rather rough estimate of the subsidy rate *tpe0*. Since τ, α, p^{W} and p^{EU} are unknown, the rate is determined simply as (*Sipee-Sipeem*)/*fE0*.

In the modified version of ADAM

$$Sipe0 = Sipaa + tpe0 \cdot fE0 - Sipeem + Sipeq \qquad \textbf{(2.4.6)}$$

is the modelling of the total subsidy received by the exporters of *E0*.

[10] In ADAM Sipe0 is taxes on specific goods net of subsidies to specific goods. Sipe0 is negative as agriculture is a net reciever of subsidies. This implies that the price received by the sector when exporting, pne0, is higher than the price received at the border, pe0.

2.5 Domestic prices

Solving the problem (2.1.1) leads to the first order condition (2.1.3), where the price in the domestic market will be chosen as a mark-up on the price the exporter can obtain in the export market, *pne0*.

In order to determine the pricing behaviour in the two industries, the following equations are estimated:

$$d\log(px < i >) = \beta^i_1 d\log(pne0) + \beta^i_2 d\log(pne0_{-1}) + \beta^i_0 \qquad \textbf{(2.5.1)}$$

i=a,nf. The model is estimated to be unrestricted and under the joint restriction $\beta_1^i + \beta_2^i = 1$ and $\beta_0^i = 0$. When these restrictions are imposed (2.5.1) has the property of (2.1.3) that a 1% increase in the price received when selling in the export market, *pne0*, implies a 1% increase in domestic prices chosen by the *a*- and *nf*-industry. The change of domestic prices take place within two years.

The equations have been estimated using data for the period 1968 – 1997. The results can be read in Table 2.5.1 and Table 2.5.2 below. The restrictions have been tested using the usual F statistic based on the RSS. When testing at a 5% significance level comparing the F statistic to the *F(2,29)*-distribution the restriction cannot be rejected, and the magnitude of the coefficients are generally understandable.

Table 2.5.1 Estimation of *pxa*

Parameter	No restrictions		$\beta_1^a + \beta_2^a = 1$ and $\beta_0^a = 0$	
	coefficient	s.d.	coefficient	s.d.
β_0^a	0.00265	(0.004609)		
β_1^a	0.85308	(0.052883)	0.89219	(0.041201)
β_2^a	0.06969	(0.052255)	0.10781	
R^2	0.9152			
RSS	0.0109		0.0115	
DW	2.3402		2.3310	

Table 2.5.2 Estimation of *pxnf*

Parameter	No restrictions		$\beta_1^{nf} + \beta_2^{nf} = 1$ and $\beta_0^{nf} = 0$	
	coefficient	s.d.	coefficient	s.d.
β_0^{nf}	0.00583	(0.003083)		
β_1^{nf}	0.79091	(0.035325)	0.83994	(0.029378)
β_2^{nf}	0.11309	(0.034907)	0.16006	
R^2	0.9559			
RSS	0.0049		0.0059	
DW	2.9664		2.7100	

In the modified version of the ADAM model, the effect of this description of domestic prices of goods from the *a*- and *nf*-industries is that world market prices will affect the domestic price level through the supply side.

The main problem when using price equations like (2.5.1) to determine domestic prices is that the *nf*-industry will be buying inputs for use in production at the price *pxa*, even though these inputs need manufacturing, as argued in section 2.3. However, there are possible ways of avoiding this problem. One way could be to disaggregate the domestic market of the agricultural sector into two sectors: the *nf*-industry and the rest. Another way could be to avoid looking at the internal deliveries among the *a*- and *nf*-industries.

3. The LADA model

The LADA model describes production in five agricultural subsectors constituting the agricultural sector in ADAM. These subsectors are *crops, cattle and milk production, pigs, poultry* and a sector defined residually, named the *q*-sector. The LADA model has two main purposes. First, the model can be used as a translation and aggregation module which translates ESMERALDA scenarios into LADA scenarios,and aggregates these scenarios into a scenario describing the agricultural sector in ADAM. Secondly, the model can be used to analyse simple and small changes in the agricultural subsectors of the model compared to some baseline scenario. For this purpose LADA has a simple description of factor demand and land use in the subsectors. In both cases the LADA-model provides a complete scenario, describing the agricultural sector in ADAM as well as projections of the physical production in ESMERALDAs 16 lines of production which are used as input in the environmental satellite model describing emissions from agriculture.

Section 3.1 describes the data construction methods and sources which have been used during data construction. In section 3.2 the transformation of the ESMERALDA scenario into LADA scenarios is described, while section 3.3 contains a description of the modelling of the subsectors production and factor demand. Section 3.4 comments on different ways of using the model.

3.1 Data construction

The five LADA subsectors: *crops*, *cattle and milk production*, *pigs*, *poultry* and the *q*-sector are a disaggregation of the ADAM agricultural sector, the *a*-sector. The objective in the data construction is to obtain subsector series for *crops, cattle and milk production, pigs* and *poultry* which are consistent with an appropriate aggregation of the ESMERALDA lines of production. The consistency of the series is crucial when ESMERALDA scenarios are used for projection of the LADA subsectors.

The historical data concerning production and output prices in the five subsectors are published in The Agricultural Statistics and National Accounts from Statistics Denmark. Data on production and output prices describing 29 subsectors can be found in the Agricultural Statistics. These series are aggregated to the LADA subsectors crops, cattle, pigs and poultry. Data from the National Accounts are mainly used to construct data describing the *q*-subsector. Table 3.1.1 below shows the connections of the LADA subsectors, the Agricultural Statistic, The National Accounts and the ESMERALDA lines of production. In Table 3.1.1 note the residual component of the *q*-subsector. This residual contains the difference between the definition of the agricultural sector in the Agricultural Statistics and the National Account compared to the agricultural sector in ADAM. Accordingly the *q*-subsector contains for instance fishing and forestry, besides what is shown in Table 3.1.1.

Data concerning the input side of production i.e. use of energy and materials, labour and capital are constructed based on a disaggregation of the agricultural sector from the input-output tables published by Statistics Denmark into the five subsectors. The disaggregation has been performed for one year by the SJFI. Data for the remaining years have been constructed based on information on production and total input in the *a*-sector, assuming that the production structure is fixed. Other sources in the data construction are historical data from SJFI and historical data from the ADAM model. Although the input side data series cannot be claimed to be historical, they constitute a reasonable basis for projections of input use in the five subsectors based on ESMERALDA scenarios. A detailed description of the data and data constrution can be seen in Nielsen (2000) and Werner (2000a).

Table 3.1.1 Construction of production and output prices

LADA subsector	Agricultural Statistics and National Account	ESMERALDA, lines of production
Crops *av*-subsector	Total cereals, pulses ripened, seeds for sowing, seeds for manufacturing, sugar beets, potatoes	spring barley etc., winter barley, wheat, pulses, rape, seeds for sowing, potatoes, sugar beets, fallow
Cattle *ak*-subsector	Milk, cattle, grass and green fodder, other crop products	dairy cattle, nurse cows, rearing cattle, calves, fodder beets, grass rotation
Pigs *as*-subsector	Pigs	sows, baconers
Poultry *ao*-subsector	Eggs for human consumption, poultry	Poultry
Others *aq*-subsector	Vegetables, mushrooms, fruit and berries, flowers, potted plants, nusery products, horses, sheep, furred animals, game, other livestock, residual	

3.2 Projections based on ESMERALDA scenarios

One of the main purposes of the LADA model is to be able to translate forecasts and policy scenarios from the ESMERALDA model into scenarios of the agricultural sector in ADAM, thereby enabling forecasts from ADAM to be based on SJFI scenarios for the agricultural sector and derivation of macroeconomic effects of agricultural and environmental policies affecting the agricultural subsectors. The ESMERALDA scenarios involve projections in both fixed and current prices. The linkage between the ESMERALDA and LADA series is modelled in a submodel of the LADA model. In the following discussion, this submodel will be referred to as *the transformation module*. The purpose of the module is to transform an ESMERALDA scenario into a projection of production and factor demand in the five LADA subsectors, using as much information from the ESMERALDA scenario as possible. The transformation module is described in detail in Werner (2000b).

The methods of projecting the variables in the LADA subsectors based on ESMERALDA scenarios differ for different categories of variables. The *aq*- subsector has to be handled separately as there is no information about this subsector in the ESMERALDA scenario.

The main categories are:

1) Production
2) Input of energy and material and gross value added
3) Labour force
4) Capital input and investment
5) Taxes etc.
6) q-subsector
7) Physical units

The projection of the *production* series is straightforward, as aggregation of ESMERALDA production series across lines of production and types of output causes no problems. The

LADA subsector productions are obtained using the last historical observation in a given production series from LADA as a base, and then projecting this series using the growth rate in the corresponding series from the aggregated ESMERALDA scenario. This is done in fixed and current prices and the output prices are derived.

Projecting the use of *energy and material* in the LADA subsectors based on the ESMERALDA scenario is somewhat more difficult. The reason is that the ESMERALDA input structure is based on the costs of different material and energy inputs while the LADA input structure - like the input structure in ADAM - is based on an input-output model. The inputs are then aggregated to energy or material costs.

Table 3.1.2 shows the ESMERALDA cost structure and how it is linked to the LADA input structure. The first column shows the ESMERALDA costs. The second column shows the components at the input-output level in LADA which are affected by the different ESMERALDA cost components. The third column shows the cost component, which is finally affected by the ESMERALDA costs.

In the transformation module the projection of the LADA energy and material demand is carried out at the level found in the ADAM input-output system, involving supplies from 19 industries and 15 import groups. This implies that the composition of the aggregated material use changes over time in each of the agricultural subsectors in LADA. Macroeconomic effects from environmental policies aimed at certain inputs in agricultural production, for example fertilizers or pesticides, are thereby easier to derive. Again, growth rates from an aggregation of the ESMERALDA forecast are used for projecting LADA series. Inputs at the disaggregated LADA level which are not affected by any ESMERALDA cost component are projected using the observed value in the last historical year.

Gross Value Added is determined residually from production, energy and material use and some tax variables commented on below.

Table 3.1.2 Linking ESMERALDA costs to LADA costs

ESMERALDA	Input from sector	LADA cost
Seeds	*av, M0*	*Material*
Fertilizer / manure	*ak, as, nk, M2, M5*	-
Concentrated feeds	*av, nf , M0*	-
Fodder roots	*ak*	-
Pesticides	*nk, M5*	-
Energy	*ng, ne, M3k, M3q*	*Energy*
Other services	*qt, qq*	*Material*
Contract operations	*aq*	-
Green fodder	*ak*	-
Labour		*Labour costs*
Insurance	*qq*	*Material*
Other costs	*aq, qq*	-
Maintenance, equipment	*nm*	-
Costs equipment		*Capital costs, equipment*
Maintenance, buildings	*b*	*Material*
Costs building		*Capital costs, buildings*
Maintenance, land	*qq*	*Material*

Abbreviations: *av* – crop subsector, *ak* – cattle and milk subsector, *as* – pig subsector, *aq* – other agricultural, *ng* – petroleum refineries, *ne* – public energy supply, *nf* – manufacturing of food, *nm* – manufacturing of macinery, *nt* – Shipyards etc., *nk* – manufacturing of chemicals, *b* – construction, *qh* – trade, *qt* - miscellaneous transport, *qq* – miscellaneous services, *M0* – imports from SITC group 0, *M3k* – imports of coal, *M3q* – Imports from SITC 3 other than coal and crude oil, *M5* imports from SITC 5

The ESMERALDA model projects the use of *labour*, measured in hours worked, as well as labour cost in each line of production. These series are used for projecting the corresponding LADA series using growth rates from the aggregated ESMERALDA scenario. From these projections further series concerning the use of labour in LADA such as hourly compensation and persons employed are derived. The partition of total employment into self-employed and wage earners is derived using ADAM assumptions on the development in hours worked per year and the share of self-employed within total employment.

The projections of series concerning *capital stocks* of buildings and machinery are the least reliable due to two particular circumstances. First, it is rather difficult to split the aggregated capital stock of equipment and buildings in the agricultural sector in ADAM into the corresponding series concerning the five LADA subsectors. Consequently, the levels of capital stocks in the subsectors might not be appropriate. Secondly, the corresponding series for the use of equipment and buildings in ESMERALDA is difficult to link to the stock series in LADA. Nevertheless, these series are important as they describe the assumptions on technological development underlying the ESMERALDA scenarios.

Despite the problems, an attempt is made to derive projections of the LADA capital stock series from the ESMERALDA scenario. Again the level of capital stocks in the last historical year in the LADA data is projected using growth rates from ESMERALDA series on the total cost of using equipment and buildings respectively. Knowing the capital stocks, gross investment is determined using a relation describing the accumulation of capital and ADAM assumptions on capital depreciation. Investment prices are derived from the ESMERALDA forecast. Based on these investment prices and assumptions on interest rates etc., the user-costs of capital are determined.

One way of avoiding the problems involved in linking the capital series could be to ignore the use of capital in the LADA model, and use the ADAM factor demand equations to determine the development of the stock of equipment and buildings in the agricultural sector contingent on the production determined in ESMERALDA. However, crucial information on the assumptions on technological development underlying the ESMERALDA scenario might be lost unless this information is extracted from the ESMERALDA scenario and introduced in the ADAM equations in some other way.

ESMERALDA provides forecasts of the subsidies received by the subsectors. The LADA model describes value added *taxes*, custom, taxes and subsidies on products and other taxes and subsidies. When projecting the subsidies the growth rate of the subsidies is used. Taxes are by and large projected using assumptions from the ADAM model.

The ESMERALDA scenario contains no information on what is happening in the *q*-sector, which is the residual between the agricultural sector in ADAM and agriculture as defined by SJFI. Historically, the production in the *aq*-sector constitutes approximately 40%. of total volume produced in the agricultural sector in ADAM. The transformation module per default projects the production in this sector as keeping its relative importance unchanged, compared to the last historical year. However, this procedure will not always be appropriate. For instance, this practice will exaggerate the effects of the policy when studying effects of an agricultural policy aimed at reducing pig production, the explanation being that the growth rate in the *aq*-production will be affected by changed pig production. In such an analysis, one solution could be to project activity in the *aq*-subsector using the changes in the remaining subsectors.

Finally, the series describing the production in 14 of the ESMERALDA subsectors in *physical units* are copied unaltered to the LADA scenario. These series that are used in the emission models are measured in tons of production in the crop subsectors and number of animals in the animal subsectors.

3.3 The LADA subsectors

Besides the transformation module, the LADA model contains a description of production and factor demand in the five subsectors. This feature can be used when one wants to study environmental and macroeconomic effects following simple and small changes in agricultural production at the subsector level compared to some baseline scenario. This part of the model is described below; however, only main features and key equations of the model are explicitly commented. The entire model is found in Annexes 3.1 and 3.2.

It is assumed that technology in the five subsectors can be described by a Leontief production function, but the determination of the production level differs among the subsectors. In the *as*-, *ao*- and *aq*-subsectors, production is considered to be exogenous, while production in the *av*- and *ak*-subsectors is determined by the land available to the sectors.

In the *as*-, *aq*- and *ao*-subsectors, it is assumed that equipment, buildings, labour, material and energy are used as inputs in production. Combined with the technology assumption, the production in these subsectors can be written:

$$fX<k> = \min\left(\frac{fKm<k>}{bkm<k>}, \frac{fKb<k>}{bkb<k>}, \frac{Hq<k>}{bhq<k>}, \frac{fVm<k>}{bvm<k>}, \frac{fVe<k>}{bve<k>}\right) \quad \textbf{(3.3.1)}$$

where $k=as, aq, ao$ and $fX<k>$ is production in subsector k measured in fixed prices. $fKm<k>$ is use of machinery, $fKb<k>$ is use of buildings, $Hq<k>$ is labour input measured in hours, $fVm<k>$ is input of materials and $fVe<k>$ is energy inputs. Both energy and material inputs are measured in fixed prices. $bkm<k>$, $bkb<k>$, $hq<k>$, $bvm<k>$ and $bve<k>$ are technological coefficients of equipment, buildings, labour, material and energy respectively.

Keeping in mind that production is considered to be exogenous, equation (3.3.1) and an assumption of cost minimization yield the factor demands. Note especially, that the input coefficients concerning input of material and energy are not explicit variables in the model, but are determined as sums of input-output coefficients from the disaggregated level, as:

$$bve<k> = ang<k> + ane<k> + am3k<k> + am3q<k> \quad \textbf{(3.3.2)}$$

and

$$bvm<k> = \sum_j a<j><k> \quad \textbf{(3.3.3)}$$
$$j = av, ak, as, ao, aq, nf, nm, nt, nk, b, qh, qt, qq, m0, m2, m3k, m3q, m5, si$$

where the $a<j><k>$ are input-output coefficients at the disaggregated level of inputs. As an example, the coefficient *anmas* shows how much of the input to the pig-subsector originates from the *nm*-industry, *manufacturing of machinery*.

Determination of production in the *av*- and *ak*-subsectors is different, since it is assumed that land is used as an input in production and that the land available to the subsectors is the limiting factor in production.

Again the technology assumption implies that production is given by:

$$fX<h> = \min\left(\frac{nv<h>}{bnv<h>}, \frac{fKm<h>}{bkm<h>}, \frac{fKb<h>}{bkb<h>}, \frac{Hq<h>}{bhq<h>}, \frac{fVm<h>}{bvm<h>}, \frac{fVe<h>}{bve<h>}\right) \quad \textbf{(3.3.4)}$$

where $h=av, ak$ and $nv<h>$ is the land available to subsector h measured in hectares and $bnv<h>$ is the technological coefficients associated with land in subsector h. The remaining notation is as above. Since the amount of land available to each subsector is the limiting factor, the production in subsector h is determined as

$$fX<h> = \frac{nv<h>}{bnv<h>} \quad \textbf{(3.3.5)}$$

Demands for the remaining factors are determined from equations (3.3.4), (3.3.5) and the assumption of cost minimization. Equations (3.3.2) and (3.3.3) also apply to material and energy coefficents, $bvm<h>$ and $bve<h>$, in the *av*- and *ak*-subsectors.

The total amount of land available, *nv*, is considered to be exogenous. In the land allocation between the *av*- and *ak*-subsector it is assumed that land lying fallow, *nvbr,* is exogenous and the use of land in the *ak*-subsector, *nvak*, is given by

$$nvak = nvsh + nvvg + nvrf \tag{3.3.6}$$

where *nvsh*, *nvvg* and *nvrf* are land used for rotation grass, permanent grass and fodder roots respectively.

The land available to the *av*-subsector, *nvav*, is determined residually as

$$nvav = nv - (nvak + nvbr) \tag{3.3.7}$$

This modelling of production and land used by the subsectors *av* and *ak* implies that increasing land use and thereby production in one sector leads to a decline in land use and thereby production in the other subsector given the total amount of land available and the amount of land lying fallow. This property of the LADA model mimics a corresponding property in the ESMERALDA model. Of course one can also change production by changing the total amount of land available or the area lying fallow. In these cases, however, one has to keep in mind that changing the area laid fallow will affect the subsidies received by the sector, and a change in the total area available to agricultural production will influence the economy through various channels.

Given the land available to the *av*- and *ak*-subsectors, the production volumes are determined from (3.3.5) and, assuming cost minimization, the demand for capital, labour, material and energy is easily derived from equation (3.3.4).

From equation (3.3.1) and (3.3.4) it can be seen that all production factors except for land in the *av*- and *ak*-subsector are modelled as fully flexible. This is not an appropriate description of the demand for equipment and buildings, and implies that only small changes in production can be appropriately analysed directly in the LADA model. If the changes are sufficiently small it can be argued (at least regarding equipment) that most of the desired change in the capital stock can be gained by instantly changing investments. If one wants to analyse larger changes in production it is recommended that demand for capital is either determined by the factor demand equations in ADAM or that explicit assumptions concerning the reduction or growth of the capital stock are made.

The necessary investments consistent with the capital stocks are determined by the accumulation identity:

$$fI<q><k> = fK<q><k> - (1 - bfi<q>va)\, fK<q><k>_{-1} \tag{3.3.8}$$

where *q=m,b* denotes equipment and buildings respectively, and *bfi<q>va* is the depreciation rate for capital of type *q* obtained from the relevant ADAM scenario. Finally, the user-cost of capital is determined for each subsector and each type of capital. The user-cost describes the cost of using one unit of capital for one period of time and is endogenous depending on investment prices.

The employment, $Q<k>$, $k=$ av,ak,as,ao,aq, in each subsector is derived from the labour demand measured in hours per year, $Hq<k>$, as

$$Q<k>=\frac{Hq<k>}{Hgn}\cdot 1000 \qquad \textbf{(3.3.9)}$$

where *Hgn* is the agreed number of working hours per year in the manufacturing industries in ADAM. This equation yields a rather rough estimate of the number of persons employed, because the number of hours in manufacturing and agriculture are not necessarily the same.

The taxes paid and subsidies received are modelled in four groups. As mentioned above, the modelling of taxes is by and large identical to the modelling of these variables concerning the aggregated agricultural sector in ADAM. Subsidies on production are considered exogenous, whereas the subsidies on products are modelled as a subsidy-rate times the production in fixed prices.[11]

In general, output prices as well as factor prices except user-cost of capital are exogenous in the model. Current price projections are easily derived by inflating fixed price scenarios.

To enable the calculation of emissions from the agricultural sector, the production in the subsectors is disaggregated to production measured in physical units at the ESMERALDA level, that is tons of crops in the *av*-subsector and number of animals in the *ak*-, *as*-, *ao*-subsectors. It is assumed that the tons produced and number of animals per volume of production is constant, implying that physical production is proportional to production in fixed prices.

Finally, the LADA model contains some equations used to aggregate the subsector projections to a projection describing the agricultural sector in ADAM. This part of the model is referred to as *the aggregation module*. This module has two important properties

1) When using the LADA model for simulation in historical years on the constructed data, the results from the aggregation module concerning the entire agricultural sector in ADAM are in fact the historical observations of this sector

2) When using the model for aggregation of ESMERALDA scenarios, the subsector scenarios remain unaltered through simulation

The first property implies that the aggregation module and the data are consistant with the ADAM *a*-sector. The second property implies that it is in fact the LADA subsector scenarios based on the ESMERALDA scenarios that are aggregated even though the LADA model has to simulate to derive the scenario describing the aggregated agricultural sector in ADAM.

[11] The taxes modelled in LADA correspond with the indirect taxes in the ADAM input-output system. These are value added taxes, Siga<j>, taxes and subsidies on specific goods, Sipa<j>, and taxes and subsidies on production, Siqa<j>.

3.4 Using the LADA model

Regardless of the use of the LADA model the output provided by the model is:

1) A scenario describing the activity in the agricultural sector in ADAM

2) Projections of the production in the ESMERALDA lines of production counted in produced tons in the crop lines and number of animals in the animal lines of production

The scenario describing the agricultural sector is used to analyse macroeconomic effects of some development in the agricultural sector. The productions in the ESMERALDA lines of production counted in physical units are used as input to the emission model calculating the emissions of N_2O, CH_4 etc.; see Figure 1.1.

There are three different ways of using the LADA model:

1) Some ESMERALDA baseline scenario is aggregated to the ADAM level and used in an ADAM forecast

2) Given an ESMERALDA baseline scenario and one or more alternative scenarios, macroeconomic and environmental effect of policies studied in ESMERALDA can be evaluated

3) Given an ESMERALDA baseline scenario, the macroeconomic and environmental effects of restricting production in one or more of the subsectors: crops, cattle and milk, pigs and poultry can be studied using the LADA model only

Looking at case 1) the only task of the LADA model is to aggregate the five subsectors into a scenario describing ADAMs agricultural sector and pass series on production in physical terms to the emission model. Thereafter, the environmental effects of the ESMERALDA forecast are calculated in the emission model, while some macroeconomic forecast based upon the ESMERALDA forecast of the agriculture can be made in ADAM.

In case 2) the objective will typically be to evaluate the environmental benefits and economic costs of introducing some policy aimed at the agricultural sector. The ESMERALDA baseline scenario is used to construct consistent scenarios describing emissions and the macroeconomy. Alternative emission and macroeconomic scenarios can then be constructed, consistent with the alternative ESMERALDA scenario. The environmental benefits can be assessed by comparing the baseline emission scenario to the alternative emission scenario, while economic costs in agriculture can be evaluated by comparing the two ESMERALDA scenarios, and derived macroeconomic effects can be found by comparing the macroeconomic baseline scenario to the alternative scenarios.

Case 3) is similar to case 2) except for the fact that only simple and small changes in subsector production can be analysed using the LADA model alone, and that the economic influence from the change on the agriculture must be evaluated at the LADA or ADAM level.

Annex 3.1 List of variables for LADA

The notation is standard ADAM notation, so the only news for those familiar with ADAM is the subsectors. A variable *X* appears normally in current prices, fixed prices, and as a deflator, the notation is then *X, fX,* and *pX* respectively. The disaggregation of ADAM's a-sector implies that to the usual *a* for agriculture in ADAM the following suffixes will be added: *v, k, s, f,* and *q* for crops, cattle, pigs, poultry, and other agriculture respectively. Hence *fXas* is *X* in fixed prices for the pigs subsector.

io-coefficients have the prefix *a* followed by supplying sector or import, and recipient sector, e.g. *anmas* the coefficient for supply from the *nm*-sector to subsector *s*.

Variables
a<i><j> i=av, ak, as, af, aq, ng, ne, nf, nm, nt, nk, b, qh, qt, qq, m0, m2, m3k, m3q, m5, si, yw, yf
j=av, ak, as, ao, aq
coefficient for supply from sector *i* to use in sector *k*

Supplies are the same as standard ADAM-supply, except for the disaggregation of sector *a*.

av	crops
ak	cattle
as	pigs
ao	poultry
aq	others
ng	petroleum refineries
ne	energy suppliers
nf	manufacturing of food
nm	manufacturing of machinery
nt	transportation equipment
nk	chemical industry
b	construction
qh	trade
qt	other transport
qq	other services
m0	import of SITC 0: foodstuff
m2	import of SITC 2: unmanufactured goods, non food, except fuel
m3k	import of SITC 32: coal and coke
m3q	residual import of SITC 3: petroleum, electricity, and gas
m5	import of SITC 5: chemicals
si	indirect taxes, total
yw	compensation of employees
yf	gross value added

bhqa<j> j=v, k, s, o, q
necessary input of hours per unit produced in sector *j*

bivp<k> k=b, m
present value of expected fiscal depreciation from an investment in capital type *k*

bkba<j> j=v, k, s, o, q
necessary input of buildings per unit produced in sector *j*

bkma<j> j=v, k, s, o, q
necessary input of equipment per unit produced in sector *j*

bnva<j> j=v, k, s, o, q
necessary input of land per unit produced in sector *j*

bqsa
ratio of self-employed in ADAM's *a*-sector

bqsa<j> j=v, k, s, o, q
ratio of self-employed in subsector *j*

btgxa
degree of charging VAT on ADAM's *a*-sector

fIba<j> j=v, k, s, o, q
gross fixed capital formation in buildings and civil engineering projects in subsector *j*, 1995 prices

fIma<j> j=v, k, s, o, q
gross fixed capital formation in machinery, transport equipment and
other equipment in subsector *j,* 1995 prices

fKba<j> j=v, k, s, o, q
gross capital stock of buildings etc. in subsector *j*

fKma<j> j=v, k, s, o, q
gross capital stock of machinery etc. in subsector *j*, 1995 prices

fKnba<j> j=v, k, s, o, q
net capital stock of buildings etc. in subsector *j*

fKnma<j> j=v, k, s, o, q
net capital stock of machinery etc. in subsector *j*

fVa<j> j=v, k, s, o, q
use of energy and material in subsector *j*, 1995 prices

fVea<j> j=v, k, s, o, q
use of energy in subsector *j*, 1995 prices

fVma<j> j=v, k, s, o, q
use of materials in subsector *j*, 1995 prices

fXa<j> j=v, k, s, o, q
gross output in subsector *j,* 1995 prices

fYfa
gross value added in ADAM's *a*-sector, 1995 prices

fYfa<j> j=v, k, s, o, q
gross value added in subsector *j*, 1995 prices

hgn
average working hours in manufacturing, hours per year

hqa<j> j=v, k, s, o, q
volume of hours worked in subsector *j*

Iba<j> j=v, k, s, o, q
gross fixed capital formation in buildings and civil engineering projects in subsector *j*, current prices

Ima<j> j=v, k, s, o, q
gross fixed capital formation in machinery, transport equipment, and other equipment in subsector *j*, current prices

iwbz
redemption yields on bonds

iwlo
banks interest rate on advances

la<j> *j=v, k, s, o, q*
implicit hourly compensation per wage earner in subsector *j*

n<j> *j=km, ko, ka, kl, ss, sl, oe*
size of livestock in ESMERALDA subsector *j*

n<j>e *j=km, ko, ka, kl, ss, sl, oe*
size of livestock in ESMERALDA in subsector *j*, initial estimate for agruculture

nv
total land available

nva<j> *j=v, k*
land available to subsector *j*

nvbr
land lying fallow

nv<j> *j=sh, vg, rf*
hectares used in ESMERALDA subsector *j*

nv<j>e *j=sh, vg, rf*
hectares used in ESMERALDA subsector *j*, initial estimate for agriculture

pwa<j> *j=v, k, s, o, q*
average unit costs in subsector *j*

pwaw
average unit cost in ADAM's *a*-sector

pIba
price of buildings and civil engineering projects in ADAM's *a*-sector

pIma
price of machinery, transport equipment and other equipment in ADAM's *a*-sector

pVa<j> *j=v, k, s, o, q*
deflator for use of energy and materials in subsector *j*

pVea<j> *j=v, k, s, o, q*
deflator for use of energy in subsector *j*

pVma<j> *j=v, k, s, o, q*
deflator for use of materials in subsector *j*

pXa<j> *j=v, k, s, o, q*
deflator for gross output in subsector *j*

pYfa<j> *j=v, k, s, o, q*
deflator for gross value added in subsector *j*

qsa<j> *j=v, k, s, o, q*
number of self employed in subsector *j*

qwa<j> *j=v, k, s, o, q*
number of wage earners in subsector *j*

rpi<k>ae *k=b, m*
expected growth in *pi<k>a*

Sigxa
VAT revenue from gross output in ADAM’s *a*-sector

Sigxa<j> j=v, k, s, o, q
VAT revenue from gross output in subsector *j*

Sipvea
revenue from duties on use of energy in ADAM’s *a*-sector

Sipvea<j> j=v, k, s, o, q
net revenue from duties on use of energy in subsector j

Sipxa
net revenue from taxes on specific goods in ADAM’s *a*-sector, total

Sipxa<j> j=v, k, s, o, q
net revenue from taxes on specific goods in subsector *j*, total

Siqa
net revenue from taxes on production in ADAM’s *a*-sector, total

Siqa<j> j=v, k, s, o, q
net revenue from taxes on production in subsector *j*, total

Siqal
revenue from duties paid by employers on wage and salary costs in ADAM’s *a*-sector

Siqal<j> j=v, k, s, o, q
revenue from duties paid by employers on wage and salary costs in subsector *j*

tg
VAT rate

tsdsu
expected marginal rate of corporation tax

t<j> j=vf, vv, vh, vb, vo, vk, vr
production in ESMERALDA subsector *j*, tons

t<j>e j=vf, vv, vh, vb, vo, vk, vr
production in ESMERALDA subsector *j*, tons, initial estimate for agriculture

tvea
rate of duty on *fVea*

tvea<j> j=v, k, s, o, q
rate of duty on *fVea<j>*

ui<k>a k=b, m
user-cost on capital stock of type *k,* in ADAM’s *a*-sector

ui<k>a<j>   k=b, m   j=v, k, s, o, q
user-cost on capital stock of type *k,* in subsector *j*

Va<j>j=v, k, s, o, q
Use of energy and material in subsector *j*, current prices

Vea<j>   j=v, k, s, o, q
Use of energy in subsector *j*, current prices

Vma<j>   j=v, k, s, o, q
Use of materials in subsector *j*, current prices

Xa<j>   j=v, k, s, o, q
gross output in subsector *j,* current prices

Yfa
gross value added in ADAM's *a*-sector, current prices

Yfa<j>   j=v, k, s, o, q
gross value added in subsector *j*, current prices

Ywa
compensation of employees in ADAM's *a*-sector

Ywa<j>   j=v, k, s, o, q
compensation of employees in subsector *j*

Annex 3.2 The LADA-model

```
() equations forming the LADA model

() ************
() SUB-SECTORS
() ************

() PRODUCTION

FRML _D    fXav = (nv-(nvsh+nvvg+nvrf)-nvbr)/bnvav $
FRML _D    fXak = nvak/bnvak                       $

FRML _I     Xav = pXav*fXav  $
FRML _I     Xak = pXak*fXak  $
FRML _I     Xas = pXas*fXas  $
FRML _I     Xao = pXao*fXao  $
FRML _I     Xaq = pXaq*fXaq  $


() ENERGY CONSUMPTION

FRML _GJR   fVeav  =  (angav+aneav+am3kav+am3qav)*fXav  $
FRML _GJR   fVeak  =  (angak+aneak+am3kak+am3qak)*fXak  $
FRML _GJR   fVeas  =  (angas+aneas+am3kas+am3qas)*fXas  $
FRML _GJR   fVeao  =  (angao+aneao+am3kao+am3qao)*fXao  $
FRML _GJR   fVeaq  =  (angaq+aneaq+am3kaq+am3qaq)*fXaq  $


FRML _I     Veav  =  pVeav*fVeav   $
FRML _I     Veak  =  pVeak*fVeak   $
FRML _I     Veas  =  pVeas*fVeas   $
FRML _I     Veao  =  pVeao*fVeao   $
FRML _I     Veaq  =  pVeaq*fVeaq   $


() MATERIAL CONSUMPTION

FRML _GJR   fVmav  =  (aavav+aakav+aasav+aaoav+aaqav+anfav+
                       anmav+antav+ankav+abav +aqhav+
                       aqtav+aqqav+am0av+am2av+am5av+
                       asiav)*fXav                           $

FRML _GJR   fVmak  =  (aavak+aakak+aasak+aaoak+aaqak+anfak+
                       anmak+antak+ankak+abak +aqhak+
                       aqtak+aqqak+am0ak+am2ak+am5ak+
                       asiak)*fXak                           $

FRML _GJR   fVmas  =  (aavas+aakas+aasas+aaoas+aaqas+anfas+
                       anmas+antas+ankas+abas +aqhas+
                       aqtas+aqqas+am0as+am2as+am5as+
                        asias)*fXas                           $

FRML _GJR   fVmao  =  (aavao+aakao+aasao+aaoao+aaqao+anfao+
                       anmao+antao+ankao+abao +aqhao+
                       aqtao+aqqao+am0ao+am2ao+am5ao+
                       asiao)*fXao                           $
```

```
FRML _GJR   fVmaq  =  (aavaq+aakaq+aasaq+aaoaq+aaqaq+anfaq+
                       anmaq+antaq+ankaq+abaq +aqhaq+
                       aqtaq+aqqaq+am0aq+am2aq+am5aq+
                       asiaq)*fXaq                          $

FRML _I     Vmav  =  pVmav*fVmav $
FRML _I     Vmak  =  pVmak*fVmak $
FRML _I     Vmas  =  pVmas*fVmas $
FRML _I     Vmao  =  pVmao*fVmao $
FRML _I     Vmaq  =  pVmaq*fVmaq $


() ENERGY- OG MATERIAL CONSUMPTION

FRML _I     fVav   =  fVmav + fVeav  $
FRML _I     fVak   =  fVmak + fVeak  $
FRML _I     fVas   =  fVmas + fVeas  $
FRML _I     fVao   =  fVmao + fVeao  $
FRML _I     fVaq   =  fVmaq + fVeaq  $

FRML _I     Vav    =  Vmav + Veav  $
FRML _I     Vak    =  Vmak + Veak  $
FRML _I     Vas    =  Vmas + Veas  $
FRML _I     Vao    =  Vmao + Veao  $
FRML _I     Vaq    =  Vmaq + Veaq  $

FRML _I     pVav    =  Vav/fVav  $
FRML _I     pVak    =  Vak/fVak  $
FRML _I     pVas    =  Vas/fVas  $
FRML _I     pVao    =  Vao/fVao  $
FRML _I     pVaq    =  Vaq/fVaq  $


() GROSS VALUE ADDED


FRML _I     Yfav   =  pYfav*fYfav  $
FRML _I     Yfak   =  pYfak*fYfak  $
FRML _I     Yfas   =  pYfas*fYfas  $
FRML _I     Yfao   =  pYfao*fYfao  $
FRML _I     Yfaq   =  pYfaq*fYfaq  $


() WAGES AND EMPLOYMENT


() bhqa<k> er det nødvendige timeinput pr. producerede enhed, er endnu ikke
dannet i banken
FRML _GJR  HQav = bhqav*fXav   $
FRML _GJR  HQak = bhqak*fXak   $
FRML _GJR  HQas = bhqas*fXas   $
FRML _GJR  HQao = bhqao*fXao   $
FRML _GJR  HQaq = bhqaq*fXaq   $

FRML _GJR  Qwav = HQav*(1-bqsav)*(1/hgn)*1000  $
FRML _GJR  Qwak = HQak*(1-bqsak)*(1/hgn)*1000  $
FRML _GJR  Qwas = HQas*(1-bqsas)*(1/hgn)*1000  $
FRML _GJR  Qwao = HQao*(1-bqsao)*(1/hgn)*1000  $
FRML _GJR  Qwaq = HQaq*(1-bqsaq)*(1/hgn)*1000  $

FRML _GJR  Qsav = HQav*bqsav*(1/hgn)*1000  $
FRML _GJR  Qsak = HQak*bqsak*(1/hgn)*1000  $
FRML _GJR  Qsas = HQas*bqsas*(1/hgn)*1000  $
FRML _GJR  Qsao = HQao*bqsao*(1/hgn)*1000  $
FRML _GJR  Qsaq = HQaq*bqsaq*(1/hgn)*1000  $

FRML _GJR  Ywav = lav*(1-bqsav)*hqav-Siqalv  $
FRML _GJR  Ywak = lak*(1-bqsak)*hqak-Siqalk  $
FRML _GJR  Ywas = las*(1-bqsas)*hqas-Siqals  $
FRML _GJR  Ywao = lao*(1-bqsao)*hqao-Siqalo  $
FRML _GJR  Ywaq = laq*(1-bqsaq)*hqaq-Siqalq  $
```

```
() CAPITAL, COSTS OF CAPITAL AND GROSS CAPITAL FORMATION

() GROSS CAPITAL STOCKS
FRML  _GJR  fKmav  =  fXav*bkmav $
FRML  _GJR  fKmak  =  fXak*bkmak $
FRML  _GJR  fKmas  =  fXas*bkmas $
FRML  _GJR  fKmao  =  fXao*bkmao $
FRML  _GJR  fKmaq  =  fXaq*bkmaq $

FRML  _GJR  fKbav  =  fXav*bkbav $
FRML  _GJR  fKbak  =  fXak*bkbak $
FRML  _GJR  fKbas  =  fXas*bkbas $
FRML  _GJR  fKbao  =  fXao*bkbao $
FRML  _GJR  fKbaq  =  fXaq*bkbaq $

() CAPITAL FORMATION
FRML  _I    fImav  =  fKmav-(1-bfimva)*fKmav(-1)  $
FRML  _I    fImak  =  fKmak-(1-bfimva)*fKmak(-1)  $
FRML  _I    fImas  =  fKmas-(1-bfimva)*fKmas(-1)  $
FRML  _I    fImao  =  fKmao-(1-bfimva)*fKmao(-1)  $
FRML  _I    fImaq  =  fKmaq-(1-bfimva)*fKmaq(-1)  $

FRML  _I    fIbav  =  fKbav-(1-bfibva)*fKbav(-1)  $
FRML  _I    fIbak  =  fKbak-(1-bfibva)*fKbak(-1)  $
FRML  _I    fIbas  =  fKbas-(1-bfibva)*fKbas(-1)  $
FRML  _I    fIbao  =  fKbao-(1-bfibva)*fKbao(-1)  $
FRML  _I    fIbaq  =  fKbaq-(1-bfibva)*fKbaq(-1)  $


FRML  _I    Imav  =  pImav*fImav  $
FRML  _I    Imak  =  pImak*fImak  $
FRML  _I    Imas  =  pImas*fImas  $
FRML  _I    Imao  =  pImao*fImao  $
FRML  _I    Imaq  =  pImaq*fImaq  $

FRML  _I    Ibav  =  pIbav*fIbav  $
FRML  _I    Ibak  =  pIbak*fIbak  $
FRML  _I    Ibas  =  pIbas*fIbas  $
FRML  _I    Ibao  =  pIbao*fIbao  $
FRML  _I    Ibaq  =  pIbaq*fIbaq  $


() NET CAPITAL STOCK
FRML _GJR   fKnmav =  fImav+(1-bfinmva)*fKnmav(-1) $
FRML _GJR   fKnmak =  fImak+(1-bfinmva)*fKnmak(-1) $
FRML _GJR   fKnmas =  fImas+(1-bfinmva)*fKnmas(-1) $
FRML _GJR   fKnmao =  fImao+(1-bfinmva)*fKnmao(-1) $
FRML _GJR   fKnmaq =  fImaq+(1-bfinmva)*fKnmaq(-1) $

FRML _GJR   fKnbav =  fIbav+(1-bfinbva)*fKnbav(-1) $
FRML _GJR   fKnbak =  fIbak+(1-bfinbva)*fKnbak(-1) $
FRML _GJR   fKnbas =  fIbas+(1-bfinbva)*fKnbas(-1) $
FRML _GJR   fKnbao =  fIbao+(1-bfinbva)*fKnbao(-1) $
FRML _GJR   fKnbaq =  fIbaq+(1-bfinbva)*fKnbaq(-1) $

FRML  _I    bfknmav = fKnmav/fKmav   $
FRML  _I    bfknmak = fKnmak/fKmak   $
FRML  _I    bfknmas = fKnmas/fKmas   $
FRML  _I    bfknmao = fKnmao/fKmao   $
FRML  _I    bfknmaq = fKnmaq/fKmaq   $

FRML  _I    bfknbav = fKnbav/fKbav   $
FRML  _I    bfknbak = fKnbak/fKbak   $
FRML  _I    bfknbas = fKnbas/fKbas   $
FRML  _I    bfknbao = fKnbao/fKbao   $
FRML  _I    bfknbaq = fKnbaq/fKbaq   $
```

```
() USER-COST
() MACHINERY
FRML  _GJR  uimav=bfknmav*pimav*(1-tsdsu*bivpm)
                        /(1-tsdsu)*((1-tsdsu)*iwlo+bfinmva-0.5*rpimae)  $
FRML  _GJR  uimak=bfknmak*pimak*(1-tsdsu*bivpm)
                        /(1-tsdsu)*((1-tsdsu)*iwlo+bfinmva-0.5*rpimae)  $
FRML  _GJR  uimas=bfknmas*pimas*(1-tsdsu*bivpm)
                        /(1-tsdsu)*((1-tsdsu)*iwlo+bfinmva-0.5*rpimae)  $
FRML  _GJR  uimao=bfknmao*pimao*(1-tsdsu*bivpm)
                        /(1-tsdsu)*((1-tsdsu)*iwlo+bfinmva-0.5*rpimae)  $
FRML  _GJR  uimaq=bfknmaq*pimaq*(1-tsdsu*bivpm)
                        /(1-tsdsu)*((1-tsdsu)*iwlo+bfinmva-0.5*rpimae)  $

() BUILDINGS
FRML  _GJR  uibav=bfknbav*pibav*(1-tsdsu*bivpb)
                        /(1-tsdsu)*((1-tsdsu)*iwbz+bfinbva-0.5*rpibae)  $
FRML  _GJR  uibak=bfknbak*pibak*(1-tsdsu*bivpb)
                        /(1-tsdsu)*((1-tsdsu)*iwbz+bfinbva-0.5*rpibae)  $
FRML  _GJR  uibas=bfknbas*pibas*(1-tsdsu*bivpb)
                        /(1-tsdsu)*((1-tsdsu)*iwbz+bfinbva-0.5*rpibae)  $
FRML  _GJR  uibao=bfknbao*pibao*(1-tsdsu*bivpb)
                        /(1-tsdsu)*((1-tsdsu)*iwbz+bfinbva-0.5*rpibae)  $
FRML  _GJR  uibaq=bfknbaq*pibaq*(1-tsdsu*bivpb)
                        /(1-tsdsu)*((1-tsdsu)*iwbz+bfinbva-0.5*rpibae)  $


() COSTS OF PRODUCTION

FRML _GJR  pwav=(uimav*fKmav+uibav*fKbav+lav*Hqav+Veav+Vmav+siqav-
siqalv)/fXav  $
FRML _GJR  pwak=(uimak*fKmak+uibak*fKbak+lak*Hqak+Veak+Vmak+siqak-
siqalk)/fXak  $
FRML _GJR  pwas=(uimas*fKmas+uibas*fKbas+las*Hqas+Veas+Vmas+siqas-
siqals)/fXas  $
FRML _GJR  pwao=(uimao*fKmao+uibao*fKbao+lao*Hqao+Veao+Vmao+siqao-
siqalo)/fXao  $
FRML _GJR  pwaq=(uimaq*fKmaq+uibaq*fKbaq+laq*Hqaq+Veaq+Vmaq+siqaq-
siqalq)/fXaq  $


() TAXES AND DUTIES

FRML  _GJR  Sigxav = tg*btgxa*(1-tg*btgxa)*Vav $
FRML  _GJR  Sigxak = tg*btgxa*(1-tg*btgxa)*Vak $
FRML  _GJR  Sigxas = tg*btgxa*(1-tg*btgxa)*Vas $
FRML  _GJR  Sigxao = tg*btgxa*(1-tg*btgxa)*Vao $
FRML  _GJR  Sigxaq = tg*btgxa*(1-tg*btgxa)*Vaq $

FRML _GJR   Sipveav =  tveav*fVeav  $
FRML _GJR   Sipveak =  tveak*fVeak  $
FRML _GJR   Sipveas =  tveas*fVeas  $
FRML _GJR   Sipveao =  tveao*fVeao  $
FRML _GJR   Sipveaq =  tveaq*fVeaq  $

FRML _GJR   Sipxav = tvmav*fVmav + tveav*fVeav  $
FRML _GJR   Sipxak = tvmak*fVmak + tveak*fVeak  $
FRML _GJR   Sipxas = tvmas*fVmas + tveas*fVeas  $
FRML _GJR   Sipxao = tvmao*fVmao + tveao*fVeao  $
FRML _GJR   Sipxaq = tvmaq*fVmaq + tveaq*fVeaq  $

FRML _GJ_   Siqalv = Siqal*Qwav/(Qwav+Qwak+Qwas+Qwao+Qwaq)  $
FRML _GJ_   Siqalk = Siqal*Qwak/(Qwav+Qwak+Qwas+Qwao+Qwaq)  $
FRML _GJ_   Siqals = Siqal*Qwas/(Qwav+Qwak+Qwas+Qwao+Qwaq)  $
FRML _GJ_   Siqalo = Siqal*Qwao/(Qwav+Qwak+Qwas+Qwao+Qwaq)  $
FRML _GJ_   Siqalq = Siqal*Qwaq/(Qwav+Qwak+Qwas+Qwao+Qwaq)  $
```

```
() ******************************
() AGGREGATION TO THE AGRICULTURAL SECTOR IN ADAM
() ******************************

() PRODUCTION

FRML _I  fXa = fXav + fXak + fXas + fXao + fXaq  $
FRML _I  Xa  =  Xav +  Xak +  Xas +  Xao + Xaq  $
FRML _I  pXa =  Xa/fXa $


() ENERGY- og MATERIAL CONSUMPTION

FRML _I  fVea  =  fVeav + fVeak + fVeas + fVeao + fVeaq  $
FRML _I   Vea  =   Veav +  Veak +  Veas +  Veao + Veaq  $
FRML _I  pVea  =  Vea/fVea $

FRML _I  fVma  =  fVmav + fVmak + fVmas + fVmao + fVmaq  $
FRML _I   Vma  =   Vmav +  Vmak +  Vmas +  Vmao +  Vmaq  $
FRML _I  pVma  =  Vma/fVma $

FRML _I  fVa   =  fVav + fVak + fVas + fVao + fVaq  $
FRML _I   Va   =   Vav +  Vak +  Vas +  Vao + Vaq  $
FRML _I  pVa   =   Va/fVa $


() GROSS VALUE ADDED


FRML _I  fYfa  =  fYfav + fYfak + fYfas + fYfao + fYfaq  $
FRML _I   Yfa  =   Yfav +  Yfak +  Yfas +  Yfao + Yfaq  $
FRML _I  pYfa  =  Yfa/fYfa  $
() WAGE AND EMPLOYMENT

FRML _I  HQa   =  HQav + HQak + HQas + HQao+ HQaq  $
FRML _I  Qwa   =  Qwav + Qwak + Qwas + Qwao+ Qwaq  $
FRML _I  Qsa   =  Qsav + Qsak + Qsas + Qsao+ Qsaq  $
FRML _I  Ywa   =  Ywav + Ywak + Ywas + Ywao+ Ywaq  $


() CAPITAL, CAPITAL COSTS AND GROSS CAPITAL FORMATION

FRML _I  fKma  =  fKmav + fKmak + fKmas + fKmao + fKmaq  $
FRML _I  fKba  =  fKbav + fKbak + fKbas + fKbao + fKbaq  $

FRML _I  fKnma  =  fKnmav + fKnmak + fKnmas + fKnmao + fKnmaq  $
FRML _I  fKnba  =  fKnbav + fKnbak + fKnbas + fKnbao + fKnbaq  $

FRML _I  fIma  =  fImav + fImak + fImas + fImao + fImaq  $
FRML _I  fIba  =  fIbav + fIbak + fIbas + fIbao + fIbaq  $
FRML _I   Ima  =   Imav +  Imak +  Imas +  Imao +  Imaq  $
FRML _I   Iba  =   Ibav +  Ibak +  Ibas +  Ibao +  Ibaq  $
FRML _I  pIma  =  Ima/fIma  $
FRML _I  pIba  =  Iba/fIba  $

FRML _I  bfknma = fKnma/fKma $
FRML _I  bfknba = fKnba/fKba $

FRML _I  uima   = bfknma*pima*(1-tsdsu*bivpm)/(1-tsdsu)
                        *((1-tsdsu)*iwlo+bfinmva-0.5*rpimae)  $
FRML _I  uiba   = bfknba*piba*(1-tsdsu*bivpb)/(1-tsdsu)
                        *((1-tsdsu)*iwbz+bfinbva-0.5*rpibae)  $

FRML _I  la     =(lav*Hqav+lak*Hqak+las*Hqas+lao*Hqao+laq*Hqaq)/hqa $

() COSTS OF PRODUCTION

FRML _GJR pwaw= (uima*fKma+uiba*fKba+la*hqa+Vea+Vma+Siqa-siqal)/fXa $
```

```
() TAXES AND DUTIES

FRML _I  Sigxa  =  Sigxav + Sigxak + Sigxas + Sigxao + Sigxaq  $
FRML _I  Sipxa  =  Sipxav + Sipxak + Sipxas + Sipxao + Sipxaq  $
FRML _I  Sipvea =  Sipveav+ Sipveak+ Sipveas+ Sipveao+ Sipveaq $

FRML _I  tvma   =  (Sipxa-Sipvea)/fVma $
FRML _I  tvea   =  Sipvea/fVea $

FRML _I  Siqal  =  Siqalv + Siqalk + Siqals + Siqalo + Siqalq  $
FRML _I  Siqa   =  Siqav  + Siqak  + Siqas  + Siqao  + Siqaq   $

() **********************************************
() DISAGGREGATION TO PHYSICAL ESMERALDA VARIABLES
() **********************************************


FRML _GJR  nkm  =  nkme*(fXak/fXake)          $
FRML _GJR  nko  =  nkoe*(fXak/fXake)          $
FRML _GJR  nka  =  nkae*(fXak/fXake)          $
FRML _GJR  nkl  =  nkle*(fXak/fXake)          $
FRML _GJR  nss  =  nsse*(fXas/fXase)/1.9      $
FRML _GJR  nsl  =  nsle*(fXas/fXase)/1.9      $
FRML _GJR  noe  =  noee*(fXas/fXase)*6.421   $
FRML _GJR  tvf  =  tvfe*(fXav/fXave)          $
FRML _GJR  tvv  =  tvve*(fXav/fXave)          $
FRML _GJR  tvh  =  tvhe*(fXav/fXave)          $
FRML _GJR  tvb  =  tvbe*(fXav/fXave)          $
FRML _GJR  tvo  =  tvoe*(fXav/fXave)          $
() FRML _GJR  tvg  =  tvg*(fXav/fXave)          $
FRML _GJR  tvk  =  tvke*(fXav/fXave)          $
FRML _GJR  tvr  =  tvre*(fXav/fXave)          $
() FRML _GJR  tvrf = tvrf*(fXav/fXave)          $
() FRML _GJR  tvsh = tvsh*(fXav/fXave)          $
() FRML _GJR  tvvg = tvvg*(fXav/fXave)          $
() FRML _GJR  tvoc = tvoc*(fXav/fXave)          $
() FRML _GJR  nvg  = nvge*fXav/fXave $
FRML _GJR  nvsh = nvshe*nvak/nvake  $
FRML _GJR  nvvg = nvvge*nvak/nvake  $
FRML _GJR  nvrf = nvrfe*nvak/nvake  $
```

4. The ESMERALDA model

4.1 Introduction

As mentioned above, ESMERALDA[12] is an econometric behavioural model representing the Danish agricultural sector. The model describes production, input application and land use etc. in 16 of the most significant agricultural lines of production (spring barley, winter barley, wheat, peas, rape, seeds for sowing, potatoes, sugar beets, fodder beets, green fodder in rotation, permanent grasslands, dairy cattle, beef cattle, pigs and poultry as well as the fallow area) as functions of e.g. exogenous agricultural product and input prices, quantitative restrictions etc. Green fodder in rotation, dairy cattle, beef cattle and pigs can also be considered as aggregates. Hence, dairy cattle comprises dairy cows and rearing cattle, beef cattle comprises nurse cows and slaughtering calves, pigs comprise sows and baconers, and green fodder in rotation includes grass and silage cereals. In total 19 lines of production are distinguished. However, the proportions within the aggreates dairy cattle, beef cattle, pigs and green fodder are assumed to be constant in the simulations with ESMERALDA. The model is based on econometrically estimated cost and profit functions for different farm types, where prices are among the explanatory variables. Simulations with the model are combined with an aggregation procedure to aggregate farm type results to e.g. a national level. Among the output variables from the model can be mentioned areas with different crops, numbers of animals in different livestock categories, revenues from sales of agricultural productions, input costs etc. Aggregated revenues and costs are in principle comparable with corresponding official agricultural gross factor income figures, although there are some differences in the definition of the agricultural sector, cf. below.

4.2 Data

Main data sources underlying the ESMERALDA model are:

- official aggregated data from Agricultural Statistics, Statistics Denmark
- more detailed farm accounts data from Danish Institute of Agricultural and Fisheries Economics (SJFI)
- detailed data concerning the economy of individual lines of agricultural production from SJFI

The LADA-data are consistent with official aggregated data from Statistics Denmark. For various reasons the more detailed SJFI-data are not strictly consistent with these official figures. Hence, a number of data compatibility issues arise, including differences in the degree of representativity in the two data samples, differences in sector and variable definitions and differences in the level of detail in the available data. These problems will be handled in the following.

The agricultural accounts statistics database comprises data from a sample of approximately 2000 farms on an annual basis. The sample represents farms with at least 5 hectares. Based on data from the full-time farms in this sample (around two thirds of the sample), a statistic for the economy of individual lines of agricultural production is also provided. By contrast, the

[12] Econometric Sector Model for Evaluating Resource Allocation and Land use in Danish Agriculture (Jensen, 2000, Jensen et al., 2001).

official data from Statistics Denmark are based on a sample of approximately 24000 enterprises, which also includes horticulture as well as a larger number of very small farms.

Data concerning individual lines of production

An overview of data concerning individual lines of production can be obtained from Table 4.1 below. The figures are supplemented by official data for total activity levels in the respective lines of production.

The number of baconers represents a stock measure, i.e. the number of pigs except for sows at a given point in time. In contrast, the output and input figures in the baconer sector represent revenues and costs per produced baconer. In general, the stock of baconers can be converted to the number of produced baconers per year by multiplying by a factor of 1.9.

For example, table 4.1 shows that in cereals, pulses and rape an average of 14-17 hours of labour is applied per hectare per year. The value of equipment is estimated as the technical replacement value, whereas the value of buildings is estimated on the basis of cash value according to the general assessment of real property. Figures concerning gross yields represent the total output value for each of the production lines, including output used on-farm, such as for example cereals used for feeding animals. For dairy cows, gross yield represents the value of milk whereas the yield of beef is given in the beef yield row of the table.

Input applications in the subsequent three blocks of the table are ordered according to variability. The first section includes the most variable costs, the second section contains semi-variable inputs, and the lower section represents fixed costs. Among the most variable costs are seeds for sowing, fertilisers, chemicals, feeds etc., whereas semi-variable costs include labour and equipment costs. Labour costs include the stipulated value of the labour delivered by the farm family. In general, the most variable costs are most easily related to the individual lines of production than is the case for capacity costs (labour, capital etc.) Furthermore, capital costs are based on standardised assumptions concerning depreciation, interests etc. Hence, the validity of the variable costs can be considered as more reliable than those for less variable costs, at least as far as the distribution on lines of production is concerned.

Relation between line-of-production data and agricultural gross factor income data

The above data represent the gross yields and input applications of each individual line of production without specifically taking into account the interrelations between different lines of production. Thus, gross yield figures represent the economic value of the total yield of the considered product, including the share used internally on the farm. Correspondingly, input costs represent the total use of an input including deliveries from other lines of production on the farms. By contrast, the official gross factor income statistics only represent net output and input use, i.e. marketed outputs and inputs net of on-farm deliveries. The gross figures are, however, important if the model user wants to analyse changes in the composition of agricultural production.

The figures in Table 4.2.1 can be aggregated to the national level using the total activity levels in the first line of the table. The resulting figures can be compared with the official gross factor income figures. This comparison as well as a decomposition of the differences is presented in Table 4.2.2.

The first figure in Table 4.2.2 represents the total output value of cereals amounting to 9.2 billion DKK. when SJFI-figures are aggregated. By comparison, the official figure is 6.3 billion DKK. The main reason for the difference is on-farm deliveries which are not included in the official statistics. Differences in the average physical yield level in each of the data samples from SJFI and Statistics Denmark also contribute slightly to explaining the difference between the two figures for cereals. Concerning ”other cattle” and pigs, the official figures only include the value of produced meat whereas the SJFI-figures also include the gross value of gains (in weight or value) in live animals.[13] The latter component is however more or less offset by depreciations on live animals at the aggregate level, especially for dairy cows and sows (not included in the table).

[13] Including changes in stocks.

Table 4.2.1 Economic data concerning individual lines of production, DKK/ha or DKK/animal, 1995/96

	Spring barley	Winter barley	Wheat	Pulses	Rape	Seeds for sowing	Pota-toes	Sugar beets	Fodder beets	Grass in rotation	Silage cereals	Perm. grass	Fallow	Dairy cows	Heifers	Nurse cows	Bulls and calves	Sows with piglets	Baco-ners	Poultry
Activity level, 1000 ha or animals	655.4	185.4	606.6	74.2	154.2	61.6	42.4	67.8	52.8	238.4	137.5	181.1	216.5	702.4	862.3	122.4	403.2	1015.0	11084.0	186.0
Labour, hours per unit	15.1	17.1	17.6	15.5	14.1	17.3	48.0	41.7	44.6	11.5	13.1	5.8	2.7	42.3	7.5	24.6	8.3	17.0	0.7	5.0
Equipment	3149	4571	4806	3676	3652	4151	8314	6619	9738	4098	4500	2297	778	3100	500	1225	500	2494	102	925
Buildings	9456	13725	13042	3667	3681	4368	11818	9408	11481	4004	4350	2244	761	10700	3575	7650	3575	8225	491	4100
Gross yield I	5277	6077	7601	3427	2866	5854	22612	16702	0	0	0	0	0	15791	0	0	0	7071	758	6463
Gross yield beef	0	0	0	0	0	0	0	0	0	0	0	0	0	1708	2139	854	4949	-	-	-
By-products	477	468	590	0	0	213	0	528	0	0	0	0	0	970	319	970	0	557	41	-
Subsidies	2170	2175	2181	3170	3688	3073	31	13	0	0	0	0	2787	194	56	818	666	79	4	0
Seeds	446	435	414	620	294	226	2431	941	726	348	662	25	78	0	0	0	0	-	-	-
Fertilisers	970	1115	1044	520	1209	578	1741	1162	1881	1531	1585	1000	0	-501	-193	-361	-141	-155	-13	0
Concentrate feeds	0	0	0	0	0	0	0	0	0	0	0	0	0	3037	929	1030	2056	3033	251	4920
Chemicals	319	421	534	425	509	420	1158	1612	1579	135	312	5	0	0	0	0	0	-	-	-
Energy	140	172	176	140	147	162	942	310	298	193	263	85	18	175	38	0	39	188	6	0
Services	566	576	580	462	620	482	1277	590	2384	1223	1753	435	111	844	217	318	127	595	14	235
Labour	1895	2097	2171	1941	1736	2115	5879	5191	5571	1435	1605	732	335	5223	936	2595	1039	2047	82	577
Maintenance, equipment	348	483	538	353	380	449	1555	1273	1712	555	668	281	62	473	78	315	77	284	12	83
Depreciations, equipment	630	774	901	646	653	715	1743	1338	1750	672	786	387	92	538	83	0	81	452	18	118
Interest, equipment	141	194	192	147	146	166	412	265	390	152	180	82	20	124	20	49	20	100	4	37
Land tax	230	289	305	212	274	316	242	427	197	216	234	156	251	0	0	0	0	0	0	0
Insurance + miscellaneous	378	363	408	347	346	410	707	877	704	261	303	152	160	431	125	190	118	222	13	144
Buildings, maint. + deprec.	325	340	395	155	152	213	209	349	522	187	212	68	54	443	136	249	133	391	22	177
Amelior., maint. + deprec.	135	150	152	142	149	152	167	144	130	114	123	80	137	0	0	0	0	-	-	-

Note: “Spring barley” includes rye, oats and mixed grains etc.
Source: ESMERALDA database

Table 4.2.2 Relations between aggregated SJFI figures and official gross factor income figures, 1995

million DKK	Aggregated SJFI-figures	Excluded lines of production	On-farm deliveries	Rest	Official figures
Cereals total	9196	0	2903	-18	6311
Pulses	254	0	0	-32	286
Industrial seeds	442	0	0	-48	490
Potatoes	959	0	0	96	863
Sugar beets	1132	0	0	103	1029
Raw milk	11092	0	0	-69	11161
Other cattle	6172	0	2695	277	3200
Pigs	22360	0	7040	-945	16265
Eggs/poultry meat	726	0	0	-982	1708
Seeds for sowing	1070	-	131	64	875
Fertilisers	2745	59	1034	-76	1845
Chemicals	1040	63	0	-9	1112
Feeds	12735	14	2857	-1350	11241
Energy	871	303	0	-386	1560

Source: Statistics Denmark, Agricultural Statistics 1995

On the input side, a major explanation for differences between the aggregated SJFI-figures and the official figures is differences in the definition of the agricultural sector. As an example, Statistics Denmark includes horticulture in the agricultural figures, whereas the SJFI figures do not. Furthermore, since a significant amount of cereals is used on-farm for feeding, this also explains a large share of the difference in feed cost figures. Aggregated SJFI figures for fertiliser represent the sum of commercial fertilisers and the utilised share of animal manure (represented by on-farm deliveries), whereas the official figures only represent purchased fertilisers.

To a large extent there seems to be a reasonable correspondence between the SJFI line-of-production data and the official gross factor income figures, taking the differences in definitions of the agricultural sector and specific variables into account. In a few cases, however, there exist significant differences. This is the case for marketed differences in the value of poultry production, seeds for sowing and feeds.

4.3 Links between economic data and physical quantities

The above line-of-production data focus on economic issues in different production lines. Direct quantitative data concerning individual lines of production (i.e. quantities of inputs per hectare or animal) are accordingly only available to a limited extent in the SJFI data material. However, in many environmental analyses there is a need for this kind of information. Therefore, supplementary data on physical quantities are taken from various data sources. These data are not strictly consistent with those related to the economy in the different lines of production, but they are considered to provide a reasonable basis for assessments of the order of size for the relevant physical effects in connection with the above SJFI-data. Key quantity variables for 1995 are given in Table 4.3.1.

Table 4.3.1 Quantities per hectare or animal, 1995

	Crop yield		Nutrients per hectare		
	Dkr/ha	hkg/ha	Fertilisers Dkr/ha	Nitrogen kg/ha	Phosphoru s kg/ha
Spring barley etc.	5277	51.9	970	125	20
Winter barley	6077	60.8	1115	160	25
Wheat	7601	75.9	1044	180	25
Pulses	3427	38.0	520	0	20
Rape	2866	20.5	1209	170	25
Seeds for sowing	5854	389.0	578	110	20
Potatoes	22612	375.0	1741	160	30
Sugar beets	16702	461.0	1162	130	35
Fodder beets	-	602.0	1881	200	35
Grass in rotation	-	397.0	1531	350	35
Permanent grass	-	222.0	1000	100	20
Commercial fertilisers total, million kg				291	22
Animal manure total, million kg				302	49

Source: Statistics Denmark, Agricultural Statistics 1995; Håndbog for Driftsplanlægning 1995-96, 1998

Data concerning average crop yields per hectare, as well as total amounts of fertilisers and animal manure are provided by Statistics Denmark, whereas the quantitaties of nitrogen and phosphorus per hectare as well as the nutrient contents in animal manure are obtained from the "Handbook of Farm Management" (Håndbog for Driftsplanlægning). In each line of production, crop yield data reflect actually obtained crop yields, whereas the fertiliser data represent norms which are not necessarily consistent with actual applications of fertilisers. Hence, the estimated nutrient quantities per hectare or animal in Table 4.3.1 are not necessarily consistent with the total figures in the bottom of the table. Some of the deviation is however also due to the fact that total official use of fertilisers includes the use of fertilisers in horticulture.

The figures in Table 4.3.1 are applied to assess changes in the physical quantities of e.g. nitrogen or phosphorus due to changes in land use or animal density. However, in the case of price changes, there must be expected changes in crop yield levels as well as the composition of inputs in the respective lines of production. In such cases, the changes in physical quantities per hectare are determined on the basis of changes in the corresponding value terms (measured in fixed price level). Hence, a given percentage change in the value of e.g. wheat per hectare in fixed prices is assumed to represent the percentage change in the physical crop yield per hectare of wheat.

Substitution between nutrients in commercial fertilisers and animal manure is assumed. For nitrogen, the rate of utilisation is assumed to be 40%, whereas the corresponding utilisation rates for phosphorus and potassium are assumed to be 70% and 85% respectively.

The economic-focused SJFI data (and presently also the ESMERALDA model) only contain one fertiliser element for each line of production – the total value of fertilisers. Hence, this observation includes the total costs of nitrogen, phosphorus and potassium per hectare, including valued nutrients in animal manure. In order to enable quantitative assessments of nutrient quantity changes due to price changes, we assume that the quantities of phosphorus and potassium per hectare are fixed, whereas the quantity of nitrogen is the variable fertiliser component. Given an initial distribution of the fertiliser cost per hectare according to nutrients (based on data from Table 4.3.1), and information on the change in the total costs of fertilisers in fixed prices, we calculate the change in the quantity of nitrogen per hectare in each line of production.

4.4 Disaggregating aggregate data to LADA subsectors and individual lines of production

The above SJFI line-of-production data are aggregated to the 4 subsectors of LADA: crop, cattle pig and poultry farming. As there are differences between the aggregated SJFI-data and the official figures, the information from the SJFI-data is incorporated in terms of disaggregation parameters which can be attached to the official aggregated variables. In this way the official figures from Statistics Denmark provide the basis for the current data work as mentioned above.

The distribution of the official aggregate figures on four of the five LADA sectors is shown in Table 4.4.1. The official figures have been adjusted for on-farm deliveries across subsectors (e.g. feeds from the cash crop sector to the livestock sectors and manure from the livestock sectors to crop production).

Table 4.4.1 Official aggregate figures distributed on LADA subsectors, 1995/96

million DKK	Cash crops	Cattle (including roughage)	Pigs and poultry	Poultry
Cash crops, total	11882	0	0	0
Raw milk	0	11161	0	0
Other cattle	0	3200	0	0
Pigs	0	0	16265	0
Eggs and poultry	0	0	0	1708
Seeds for sowing	733	142	0	0
Fertilisers	2281	286	-781	0
Chemicals	913	136	0	0
Feeds*	0	3169	10458	448
Energy	440	362	455	0
Net contribution to total fertiliser use				
Nitrogen, million kg	249	96**	-63**	0
Phosphorus,million kg	50	6**	-35**	0

Source: Statistics Denmark, Agricultural Statistics 1995
* The figures are gross-figures, i.e. including on-farm deliveries between subsectors
** Net ab storage

The amount of feed used in the pig sector is about three times that used in the cattle sector, as a large share of feed use in the cattle sector is covered by roughage which is produced internally in the cattle/roughage subsector. By contrast, feed use in the pig sector is covered by cash crops or external sources including imports.

Distribution of subsector figures on individual lines of production

The constructed data at the subsector level may imply a need for subsequent disaggregation of these data into individual lines of production, e.g. in relation to environmental assessments. In Tables 4.4.2-4.4.4, sets of disaggregation coefficients for this purpose are shown. The coefficients represent the situation in 1995/96 and are based on the data in Table 4.2.1. In general, the coefficients are constructed according the formula

$$d_{ij} = \frac{z_i \cdot x_{ij}}{\sum_{hj} z_h \cdot x_{hj}} \quad \textbf{(4.4.1)}$$

where z_i is the activity level (e.g. number of hectares), and x_{ij} is the application of input j per activity unit in production line i. For value data, these x_{ij}-figures are provided in Table 4.2.1, whereas for physical quantity data, they are provided in Table 4.3.1.

Table 4.4.2 Disaggregation coefficients for cash crops

	spring barley	winter barley	wheat	pulses	rape	seeds for sowing	potatoes	sugar beets
Production value	0.280	0.091	0.374	0.021	0.036	0.029	0.078	0.092
Seeds for sowing	0.326	0.090	0.280	0.051	0.051	0.016	0.115	0.071
Fertilisers	0.337	0.109	0.335	0.020	0.099	0.019	0.039	0.042
Chemicals	0.231	0.086	0.358	0.035	0.087	0.029	0.054	0.121
Energy	0.275	0.095	0.319	0.031	0.068	0.030	0.119	0.063
Nitrogen quantity	0.304	0.110	0.405	0.000	0.097	0.025	0.025	0.033
Phosph. quantity	0.304	0.107	0.352	0.034	0.089	0.029	0.029	0.055

Source: Esmeralda database

Assuming that the composition of activities in the cash crop subsector is constant, 28% of a change in the total subsector output value (including production of on-farm deliveries) will be spring barley, 9.1% will be winter barley etc. Measured in cost terms, 33.7% of a change in the use of fertilisers in the cash crop subsector will be in spring barley, whereas 10.9% will be in winter barley. However, considering the quantities of the respective nutrients yields slightly different figures. For example, 30.4% of a change in the quantity of nitrogen in the cash crop sector will be in spring barley.

Table 4.4.3 Disaggregation coefficients for the cattle/roughage subsector

	fodder beets	grass in rotation	permanent grass	dairy cows	heifers	nurse coes	bulls/ calves
Output value	0.000	0.000	0.000	0.757	0.114	0006	0.123
- of which milk	0.000	0.000	0.000	0.683	0.000	0.000	0.000
Seeds for sowing	0.221	0.753	0.026	0.000	0.000	0.000	0.000
Fertilisers	0.420	2.433	0.766	-1.488	-0.704	-0.187	-0.240
Chemicals	0.618	0.375	0.007	0.000	0.000	0.000	0.000
Feeds	0.000	0.000	0.000	0.548	0.206	0.032	0.213
Energy	0.057	0.264	0.056	0.447	0.119	0.000	0.057
Nitrogen quantity	0.102	1.265	0.174	-0.316	-0.129	-0.027	-0.068
Phosphorus quantity	0.345	2.453	0.675	-1.467	-0.563	-0.128	-0.316

Source: Esmeralda database

Of the total net use of fertilisers in the cattle sector, the major part goes to grass and green fodder, but a large share of this is delivered internally in the subsector in terms of animal manure, mainly from dairy and nurse cows. When it comes to chemicals the production of fodder beets requires the largest share within the cattle/roughage subsector.

Table 4.4.4 Disaggregation coefficients for the pigs/poultry subsector

	sows	baconers
Output value	0.206	0.794
Fertilisers	0.243	0.757
Feeds	0.252	0.748
Energy	0.484	0.516
Nitrogen quantity	0.160	0.840
Phosphorus quantity	0.234	0.766

Source: Esmeralda database

In the pigs/poultry subsector 79% of the output value stems from baconers, which also contributes with a corresponding share of the subsector's production of fertilisers/manure. Poultry accounts for 2% of output value, but requires 4% of total feed costs. As all the contributions of nutrients have the same sign, we ignore the signs, in contrast to the cattle sector above.

4.5 Need for recalculation of disaggregation matrices

In general, the disaggregation coefficients in Tables 4.4.2-4.4.4 are less robust to changes in relative output prices than relative input prices. A change in output prices affects competition between individual lines of production and accordingly the composition of the activities within the subsector. A change in input prices also affects the competition between lines of production, but the composition of the activities within the subsectors is affected to a smaller extent, as an input price change in general affects all lines of production within a subsector.

The need for updating the disaggregation matrices has been evaluated by investigating the responses to a 10% change on each of the output and input prices in turn. The results of such an evaluation are presented in Table 4.5.1 for the cash crop subsector. For example, spring barley's share of total yield in the cash crop sector is 0.34 if the barley price increases by 10% and 0.24 if the wheat price increases by 10%. For 10% price increases on any of the other crops as well as on any of the individual inputs, the resulting share lies closely around 0.28 as in Table 4.4.2.

The table shows some variation in the disaggregation coefficients due to price changes in the crop subsector. The major contribution to this variation stems from variations in the barley and wheat prices respectively. A price increase on barley leads to a larger barley area, mainly at the cost of wheat area, and vice versa. These effects on land allocation naturally have consequences for the distribution of various inputs on these crops. For pulses and rape, the largest coefficients occur as an own-price effect, whereas the lowest coefficients occur when cereal prices are changed. Disaggregation coefficients for the remaining cash crops are fairly robust to price changes. As the coefficients in the cattle and pig/poultry subsectors are also fairly robust to price changes, the sensitivity results from these subsectors are not presented.

A general impression from the sensitivity analysis is that the disaggregation coefficients in Tables 4.4.2-4.4.4 are fairly robust to price changes at 10% or less. As was clear in Table 4.5.1, there is some sensitivity within the crop subsector, however, if the price relation between barley and wheat changes significantly. Nevertheless, for most realistic scenarios, the prices of barley and wheat may be expected to be highly correlated. In such cases, the disaggregation matrix for the crop subsector will also be fairly robust to price changes at 10% or similar magnitudes. An implication of this result is that as long as price changes are moderate, the need for updating coefficients in the LADA-model is not dramatic.

Table 4.5.1 Sensitivity of disaggregation coefficients to price changes, crop subsector

Crop sector	Spring barley	Winter barley	Wheat	Pulses	Rape	Seeds	Pota-toes	Sugar beets
Yield								
minimum	0.24	0.09	0.36	0.01	0.01	0.03	0.06	0.08
maximum	0.34	0.10	0.46	0.05	0.06	0.03	0.09	0.11
Fertiliser cost								
minimum	0.30	0.10	0.31	0.01	0.04	0.02	0.03	0.04
maximum	0.41	0.12	0.43	0.05	0.15	0.02	0.04	0.05
Pesticide cost								
minimum	0.21	0.08	0.33	0.01	0.04	0.03	0.04	0.12
maximum	0.29	0.10	0.45	0.08	0.13	0.03	0.06	0.14
Energy cost								
minimum	0.25	0.09	0.30	0.01	0.03	0.03	0.09	0.06
maximum	0.35	0.11	0.41	0.07	0.10	0.03	0.13	0.08
Nitrogen quantity								
minimum	0.26	0.10	0.38	0.00	0.04	0.02	0.02	0.03
maximum	0.37	0.12	0.50	0.00	0.15	0.03	0.03	0.04
Phosphorus quantity								
minimum	0.27	0.10	0.33	0.01	0.04	0.03	0.02	0.05
maximum	0.38	0.12	0.45	0.07	0.13	0.03	0.03	0.07

Source: Esmeralda database
Note: Minimum and maximum disaggregation coefficients due to 10% price increases on individual outputs and inputs.

5. Climate change

As mentioned in the introduction, CO_2, CH_4 and N_2O are greenhouse gases that affect the climate. However, as different gases absorb radiation at different wavelengths and with different efficiencies and have different mean lifetimes in the atmosphere, one kilo of the different gases has quite different climatic effects. In order to weight the different gases in international negotiations a measure in Global Warming Potential (GWP) equivalents has been defined. GWP equivalents are defined as “the time-integrated warming effect due to an instantaneous release of 1kg of the gas in today’s atmosphere relative to the warming effect of 1kg CO_2 measured in W/m^2 with a lifetime of 150 years”. The effect of the various greenhouse gases can thereby be converted to an equivalent amount of CO_2, i.e. to the amount of CO_2 that will yield the same climatic effect (Holten-Andersen, J. et al 1998, p. 36). Dependent on the horizon of the analyses, the relative weights of the different gases change (the mean lifetimes of the various gases are different) and Table 5.0.1 shows the weights assuming time-horizons of 20, 100 and 500 years respectively. In international climate negotiations, gases are normally weighted according to a 100 years time horizon. In the Kyoto protocol a long list of fluoridised greenhouse gases (HFCs, PFCs and SF_6) are included, in addition to the pollutants listed in Table 5.0.1. However, for Denmark the total emissions of these pollutants never reach the equivalent of 1 Mt of CO_2 and are not treated in the present model. Further, according to the Kyoto Protocol, only emissions from anthropogenic sources are included in the national commitments to reduce emissions. Therefore, in the model GWP equivalents are calculated as:

$$GWP = CO_2dk + 21 \cdot CH_4dk + 310 \cdot N_2Odk$$

CO_2dk the total anthropogenic emission of CO_2 from Danish sources

CH_4dk the total anthropogenic emission of CH_4 from Danish sources

N_2Odk the total anthropogenic emission of N_2O from Danish sources

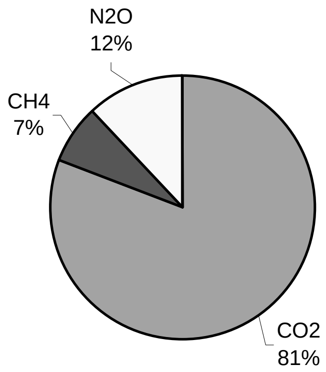
Table 5.0.1 GWP equivalents (mass basis).

Compound	Chemical formula	Lifetime	Global Warming Potential (Time Horizon)		
			20 years	100 years	500 years
Carbon dioxide	CO_2	Variable	1	1	1
Methane[1]	CH_4	12 +/-3	56	21	6.5
Nitrous oxide	N_2O	120	280	310	170

[1]The GWP for methane includes indirect effects of tropospheric ozone production and stratospheric water vapour production.
Source: Intergovernmental Panel on Climate Change (IPCC) (1996), p. 121.

For Denmark the contribution to the GWP of the three greenhouse gases for 1998 is shown in Figure 5.0.1 It should, however, be kept in mind that only emissions from anthropogenic sources are included.

Figure 5.0.1 Contribution to GWP in 1997



Source: Fenhan, J. (1999)

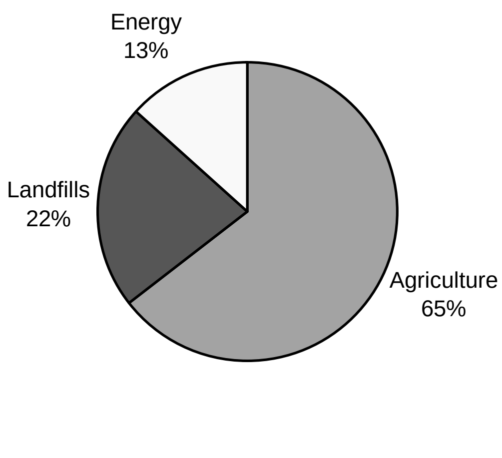
In this chapter the modelling of emissions of CH_4 and N_2O is treated. The modelling of CO_2 emissions is included in ADAM/EMMA and described in Andersen, F.M. et al (1997).

5.1 Emissions of methane (CH_4)

As is seen from Table 5.0.1, methane has a greenhouse effect that is substantially larger than CO_2. Taking a 100 years time horizon, 1kg of methane has a greenhouse effect equivalent to 21kg of CO_2. Of the total Danish greenhouse gas emissions, using a 100 years time horizon, about 8% of the effect is ascribed to anthropogenic emissions of methane. (Fenhann, 1999). In addition to the anthropogenic emissions, about an equal amount of methane is estimated to come from natural sources such as marsh gas from wetlands and ooze of natural gas from underground; this figure is however fairly uncertain.

Looking at the sources of methane emission, in 1997 total emissions from anthropogenic sources were 284 kt CH_4. As can be seen from Figure 5.1.1 and Table 5.1.1, agriculture accounts for the major part of the anthropogenic emissions (65%). These emissions are related to the size of the livestock and come from enteric fermentation and management of animal manure. Emissions from landfills account for about 22% and come from fermentation of deposited biological waste. As future depositing of biological waste is prohibited, emission of methane from landfills is expected to decrease. Other sources, mainly energy-related emissions, account for 13%. The energy-related emissions comprise both fugitive emissions from fuels and emissions from combustion.

Figure 5.1.1 Emissions of CH4 in 1997



Source. Fenhann, J. (1999)

Table 5.1.1 Emission of CH_4 in 1997.

	Ton CH_4
Agriculture	182731
Enteric fermentation	137678
Manure management	45053
Landfills	63261
Energy	37713
Combustion	23713
Fugitive emissions	14000
Total	283705

5.1.1 Emission from agriculture

Methane is produced as a by-product during the digestive processes in animals. All domestic animals emit methane, but the largest contribution is from ruminants (cows and cattle) due to their ability to break down cellulose. Emissions come from both enteric fermentation and the management of manure. About ¾ of the total emission is from enteric fermentation.

Emission from enteric fermentation mainly depends on the size and composition of the livestock and on the forage consumed by the individual animal groups. As is seen from Table 5.1.2 the major part of methane emission is from ruminants. Sows and fattening pigs contribute to some extent and horses and ovines are minor contributors. Emission coefficients differ among the different animal groups and are, except for dairy cows, assumed to be constant over time. For dairy cows the emission coefficient is evaluated to increase by 0.71% p.a. to 109 kg CH_4 per head in year 2003. This is due to a larger feed intake and an annual increase in the milk production per cow by 1.43% p.a., which is a continuation of the annual increase over the period 1985 to 1995. The calculation of emission coefficients for the four categories of cows is shown in Annex 5.1.1. Emission coefficients for the other animal categories are values from the IPCC-guidelines.

Table 5.1.2 CH_4 emissions from enteric fermentation by livestock in 1997

Animal	Heads in 1997	Year 1997		Year 2003	
		Emission coefficient kg CH_4/animal/year	Emission ton CH_4	Emission coefficient kg CH_4/animal/year	Emission ton CH_4
Dairy cows	670354	104,18	69837	108,70	72867
Slaught. calves	369028	42,83	15805	42,83	15805
Heifers	839744	33,39	28039	33,39	28039
Nurse cows	125085	48,47	6063	48,47	6063
Sows	1068473	1,50	1603	1,50	1603
Fattening pigs	10074609	1,50	15112	1,50	15112
Poultry	18993561	0,00	0	0,00	0
Fur animals	2212811	0,00	0	0,00	0
Horses	38862	18,00	700	18,00	700
Ovines	64820	8,00	519	8,00	519
Total			137678		140708

Source: CORINAIR 1997.

As for enteric fermentation, emission from manure management depends on the size and composition of the livestock. Emission coefficients mainly depend on the production of animal manure and the CH_4 production capacity of the manure. In addition, emission coefficients depend on the type of storage facility and the use of the manure. In the model, emission coefficients for manure management are assumed to be constant. Therefore, it is implicitly assumed that average uses and storage facilities are unchanged. The major part of the emission is from dairy cows, other cattle, sows and fattening pigs. Horses, ovine, chickens and fowls are minor contributors.

Table 5.1.3. CH_4 emissions from manure management in 1997

Animal	Heads in 1997	Year 1997 Emission coefficient kg CH4/animal/year	Emission ton CH4
Dairy cows	670354	21,86	14652
Slaught. calves	369028	1,63	602
Heifers	839744	1,57	1321
Nurse cows	125085	1,32	165
Sows	1068473	6,04	6450
Fattening pigs	10074609	2,07	20899
Poultry	18993561	0,05	893
Fur animals	2212811	0,00	0
Horses	38862	1,10	43
Ovines	64820	0,46	30
Total			45053

Source: CORINAIR 1997. The calculation of emission coefficients is shown in Annex 5.1.1.

The distinction between enteric fermentation and manure management is maintained in the model. Changes in manure management systems or the composition of races within the animal categories may change the average emission coefficient per head. However, emission coefficients are not determined within the model, but are assumed to be exogenous.

Therefore, emission of methane from agriculture is described by the equations 5.1.1 and 5.1.2 and the emission coefficients used in the model are given in Table 5.1.2 and 5.1.3.

$$CH_4^{ent} = \sum_i NH^i \cdot kCH_4^{i,ent} + k_0^{ent} \qquad \textbf{(5.1.1)}$$

$$CH_4^{man} = \sum_i NH^i \cdot kCH_4^{i,man} + k_0^{man} \qquad \textbf{(5.1.2)}$$

CH_4^{ent} and CH_4^{man}	total CH_4 emissions from enteric fermentation and manure management respectively
NH^i	heads of animal type i (dairy cows, heifers etc.)
$kCH_4^{i,ent}$ and $kCH_4^{i,man}$	the CH_4 emission coefficients for animal type i
k_0^{ent} , k_0^{man}	emissions from other livestock.

5.1.2 Emission from landfills

When organic material is deposited at landfills over time part of the carbon content is converted to methane. For categories of waste, Table 5.1.4 gives the amount of waste generated, waste deposited, emission coefficients and actual emission in 1997. Accounting for CH_4 collected by landfill gas plants, total emission from landfills for 1997 is estimated at 63261 ton CH_4.

Emission coefficients per ton waste deposited are calculated from evaluations of the carbon content in different types of waste, on the assumption that 50% of carbon content is converted to a gas containing 45% methane. Before emission to the air, 10% of the CH_4 is oxidised (in the topsoil layer) to CO_2. Concerning the rate of conversion, it is assumed that half of the organic material is converted within the first 10 years after the deposition.

The amount of solid waste generated and deposited is forecasted using a very simple scenario model distinguishing a few sources of waste.

Table 5.1.4 CH_4 emission from landfills in year 1997.

	Waste generated 1000 ton	Waste deposited 1000 ton	CH_4 emission coefficient kg CH_4/ton waste	CH_4 emission 1000 ton CH_4
Domestic waste	1621	83	67,8	10814
Bulky waste	588	248	93,6	19541
Garden waste	443	6	51,3	4028
Commercial	861	170	78,8	6860
Industrial	2736	707	22,1	15406
Building and construction	3427	264	7,6	6651
Sludge	1248	130	44,6	9361
CH_4 collection				9400
Total	10924	1608		63261

Note: CH_4 emission coefficients are total CH_4 emissions from waste over time, while CH_4 emissions are actual emissions in year 1997.

By source, the amount of waste generated is forecasted according to:

$$wg_t^s = wg_{t_0}^s \cdot \left[1 + \left(\frac{x_t^s - x_{t_0}^s}{x_{t_0}^s}\right)\right] \quad \textbf{(5.1.3)}$$

wg_t^s and $wg_{t_0}^s$ the amount of waste from source s generated in year t and the baseyear t_0, and x_t^s and $x_{t_0}^s$ are an activity variable in ADAM in year t and t_0.

The amount of waste deposited is calculated as:

$$wd_t^s = wg_t^s \cdot depsh_t^s \quad \textbf{(5.1.4)}$$

where $depsh_t^s$ is the share of waste from source s deposited in year t. $depsh_t^s$ is exogenous to the model.

The amount of waste generated and deposited by source, the deposition rate in 1997 and 2010 and the activity variables used for forecasts are given in Table 5.1.5.

Table 5.1.5 Waste generated and deposited in 1997.

Waste source	Waste generated $wg^s_{t_0}$ 1997	Waste deposited $wd_{t_0}^{\ s}$ 1997	Share deposited $depsh_t^{\ s}$ 1997	2010	Activity variable $x_t^{\ s}$
Domestic refuse	1621	83	5%	1,25%	fC
Bulky refuse	588	248	42%	10,00%	fCv
Garden refuse	443	6	1%	0,25%	Exogenous
Comm. & office	861	170	20%	10,00%	fXq
Industrial refuse	2736	707	26%	19,50%	fXn
Building & constr.	3427	264	8%	6,00%	fXb
Sludge	1248	130	10%	10,00%	Exogenous

Source: Data from Affaldsstatistik 1997, Annex 1 Table 1.

Emission coefficients are exogenous and basically calculated for types of waste and weighted to coefficients for waste from sources. For source s the emission coefficient is calculated as:

$$kCH_4^{waste,s} = \sum\nolimits_f sh_f^s (C\%_f \cdot dsr \cdot (1-or) \cdot CH_4 r \cdot {}^{16}\!/\!_{12}) \qquad \textbf{(5.1.5)}$$

$kCH_4^{waste,s}$	the methane emission coefficient in kg CH_4 per ton waste
sh_f^s	the share of type f in the amount of waste from source s
$C\%_f$	the carbon content in waste of type f
dsr	the rate of carbon dissimilated (set to 0.5)
or	the oxidation factor (set to 0.1)
CH_4r	the share of methane in the gas emitted from the deposit (set to 0.45)
16/12	the weight of methane (CH_4) divided by the weight of carbon (C)

The types of waste, the carbon content, weights in sources and the CH_4 emission coefficients are shown in Table 5.1.6.

Table 5.1.6 Calculation of $kCH_4^{waste,s}$ for landfills.

Type of waste	Waste food	Card Board&paper Dry	Wet	Plastics	Other comb.	Oth. Waste		$kCH_4^{waste, source s}$ kg CH_4/ton waste
Carbon content $C\%_f$	20	40	20	85	20-57	0		
$kCH_4^{waste, type f}$	54	108	54	229,5	54-155	0		
Waste source	Compositon of landfilled waste sh^s_f						Total	
Domestic refuse	0,37	0,15	0,26	0,07	0,03	0,12	1,00	67,8
Bulky refuse		0,31		0,05	0,45	0,19	1,00	93,6
Garden refuse					0,76	0,24	1,00	51,3
Comm.&office	0,24	0,35	0,11	0,05	0,10	0,15	1,00	78,8
Industrial refuse	0,06	0,09	0,01	0,01	0,06	0,77	1,01	22,1
Building & constr.					0,07	0,93	1,00	7,6
Sludge					0,29	0,71	1,00	44,6

Source: Data from Fenhann, J. (1999)

The total emission from landfills in year t is calculated as:

$$CH_4^{landfill,t} = \sum_s \sum_{i=t}^{i=t-25} kCH_4^{waste,s} \cdot wd_i^s \cdot dr_i + (kCH_4^{waste,s} \cdot wd_{t-26}^s \cdot drr) - CH_4coll \qquad \textbf{(5.1.6)}$$

$$dr_i = \exp(-dgr \cdot (i-1) - \exp(-dgr \cdot i) \qquad i = 1........25 \qquad \text{and}$$

$$drr = 1 - \sum_{i=t}^{i=t-25} dr_i$$

dr_i the share of the total methane emissions from one ton waste deposited in year i emitted in year t

dgr the degradation rate set to 0.069 so that 50% of the total emissions are emitted within the first 10 years after the deposition. The bracket in eq. 5.1.6 is the remaining emissions for waste deposited 25 years ago

CH_4coll the amount of methane collected by landfill gas plants. This collection is exogenous to the model.

Emission coefficients by sources and historical values for deposited amounts of waste are given in Annex 5.1.2.

5.1.3 Emission from energy

Emissions of methane from energy consist of emissions related to combustion of fuels and fugitive emissions related to the production, processing, handling and transport of fossil fuels. For 1997 energy related CH_4 emissions are given in Table 5.1.7.

Table 5.1.7 Energy related emissions of CH_4 in 1997.

Source	ton CH_4	Explanatory variable	Emission coef. kg CH_4/GJ
Combustion, total	23713		
Power plants	15930	Natural gas cons in dec power stations (qJgdece)	0,36
Residential	6283	Wood and straw consumption in househ. (qJsc1)	0,40
Road transport	1500	Gasoline cons. by households (qJtc1)	0,02
Fugitive emissions, total	14000		
Natural gas network	7900	Exogenous, constant	
Town gas network	600	Exogenous, constant	
Coal storage	5500	Coal import (qJscene+qJscenh+qJsdece+qJsdech)	

Source: Data from Fenhann, J. (1999). Emissions from road transport revised due to additional information.

As is seen from the table, the major sources for emission from combustion are the gas consumption in decentral power plants, wood and straw for residential uses and gasoline used for road transport.

Emission from power plants is related to gas engines used for power production in decentral plants. Of the total amount of natural gas used by decentral power plants in 1997 about 60% is used in gas engines and in these engines it is evaluated that 3% of the gas consumption is lost as methane emissions. For natural gas used by decentral power plants (forecasted as the variable qJgdece in EMMA) this gives an average emission coefficient of 0.36 kg CH_4/GJ.

Methane from residential sources is related to the burning of wood and straw. The emission coefficient is 0,40 kg CH_4/GJ. In the model this emission is linked to the consumption of solid fuels by households (EMMA variable qJsc1). However, as qJsc1 is only part of the residential use of wood and straw, emissions are scaled to give the emissions in 1997.

Concerning road transport, methane is emitted from vehicles using gasoline. In 1997 the emission coefficient is 0,018 kg CH_4/GJ. However, due to the introduction and improvements of catalytic converters the emission coefficient is reduced to 0,0025 kg CH_4/GJ in year 2010 and to 0,0003 kg CH_4/GJ in year 2030. In the model emissions are linked to consumption of transport fuels by households (EMMA variable qJtc1), and (as this is not the gasoline consumption) scaled to give the emissions in 1997.

Fugitive emissions are related to leakage from gas networks and evaporation from storage of coal.

Leakage from the gas network is mainly related to the size and physical conditions of the network and is assumed to be constant in the model.

Evaporation from coal storage depends on whether the coal is from surface or underground mines, where emission from underground mined coal is more than 20 times the emission from surface mined coal. As we do not know the future composition of coal consumption, in the model the composition in 1997 is kept constant. In addition, emission is linked to the consumption of coal in power plants (EMMA variables qJscene+qJscenh+qJsdece+qJsdech), and the emission coefficient is scaled to give the emission in 1997.

Annex 5.1.1 Calculation of CH4 emission coefficients for agriculture.

Enteric fermentation.

Emission coefficients for enteric fermentation depend on the amount of forage consumed, which again depends on the weight, growth, milk production, breeding and the type of forage consumed by the individual animals. According to IPCC guidelines, emission coefficients are calculated from the net energy consumption necessary to obtain the production of the animal, and this is then converted to gross energy consumption dependent on how digestible the forage is. Finally part of the gross energy consumption is converted to CH_4. The general equation for the emission coefficient is:

$$kCH_4^{i,ent} = GE^i \cdot sCH_4 \cdot \frac{365}{55.65} \quad \textbf{(A5.1.1)}$$

$kCH_4^{i,ent}$	the emission coefficient in kg CH_4/animal/year
GE^i	the gross energy consumption in MJ per animal per day
sCH_4	the share of the energy consumption emitted as CH_4 (set to 6%)
55.65	the calorific value of 1 kg CH_4 in MJ and the 365 is the number of days per year.

That is, the first two terms give the daily energy consumption per animal used for production of emitted CH_4, and the two constants are simply conversion factors from daily to annual energy use and from energy in MJ to emissions in kg CH_4.

The gross energy consumption GE^i is calculated from the net energy used by the animal, and empirical functions for the conversion from net energy usable by the animal to gross energy input via forage.
Due to differences in the conversion factors from net to gross energy, IPCC distinguishes between energy consumption for maintenance, lactation, pregnancy etc and for growth, that is, suppressing index i:

$$GE = \frac{NE_l}{cf_l} + \frac{NE_g}{cf_g} \quad \textbf{(A5.1.2)}$$

NE_l	the net energy consumption in MJ per day for maintenance, lactation, pregnancy etc.
NE_g	the net energy consumption in MJ per day for growth
cf_l, cf_g	the corresponding conversion factors from net to gross energy consumption

The net energy consumption for maintenance etc. is calculated according to:

$$NE_l = \left[k \cdot W^{0,75} \cdot (sS + sG \cdot 1{,}17)\right] + \left[L \cdot (1{,}47 + 0{,}40 \cdot F)\right] + \left[0{,}335 \cdot W^{0,75} \cdot 0{,}075 \cdot sB\right] \quad \textbf{(A5.1.3)}$$

W	the weight of the animal in kg
sS	the share of feed given as stall-feed
sG	the share of feed obtained by grazing (to obtain their food, grazing animals require more energy than do stall-fed animals)
L	the amount of milk produced measured in kg per day
F	the fat content in the milk measured in percent e.g. 4 for 4%
sB	the share of animal giving birth per year
k	a constant of 0,335 for dairy cows and 0,322 for other cattle

The net energy consumption for growth is calculated as:

$$NE_g = 4{,}18 \cdot \left[\left(0{,}035 \cdot W^{0,75} \cdot \partial W^{1,119}\right) + \partial W\right] \qquad \textbf{(A5.1.4)}$$

∂W the weight gain in kg per day.

The conversion factors cf_l and cf_g are estimated from empirical observations and depend on the digestibility of the feed. For the digestible energy rate sde respectively less than or greater than 65% of the gross energy in the feed the conversion factors are calculated as:

for $sde \le 0{,}65$ **(A5.1.5)**

$$cf_l = sde\left[0{,}298 + 0{,}335 \cdot sde\right]$$
$$cf_g = sde\left[-0{,}036 + 0{,}535 \cdot sde\right]$$

for $sde > 0{,}65$ $cf_l = sde \cdot \left[1{,}123 \div 0{,}4092 \cdot sde + 0{,}1126 \cdot sde^2 \div {}^{0,254}\!/_{sde}\right]$

$$cf_g = sde \cdot \left[1{,}164 \div 0{,}5160 \cdot sde + 0{,}1308 \cdot sde^2 \div {}^{0,374}\!/_{sde}\right]$$

sde the share of digestible energy relative to the gross energy content in the feed.

From these equations the emission coefficients for enteric fermentation from categories of cows are calculated in Table A5.1.1.

Table A5.1.1 Calculation of emission coefficients for enteric fermentation from cows and cattle.

Animals		Dairy cows 1997	Dairy cows 2003	Slaught.calves	Heifers/calves	Nurse cows
Weight	W	550	550	260	279	550
Weight gain	dW	0	0	1	0,5	0
Feed stall	sS	0,9	0,9	0,1	0,6	0,39
Feed grass	sG	0,1	0,1	0,9	0,4	0,61
Milk prod.	L	19,1	20,51	0	0	0
Milk fat %	F	4	4	0	0	0
Birth rate	sB	0,9	0,9	0	0	0,9
Constant	k	0,335	0,335	0,322	0,322	0,322
Net energy maint.	NE_l	99,90	104,23	24,04	23,48	42,93
Net energy growth	NE_g	0,00	0,00	13,65	6,69	0,00
Digestibility	sde	0,71	0,71	0,76	0,74	0,67
Conversion factor	cf_l	0,38	0,38	0,41	0,40	0,35
Conversion factor	cf_g	0,24	0,24	0,27	0,26	0,21
Gross energy	GE	264,74	276,21	108,83	84,84	123,16
Emission coefficient		104,18	108,70	42,83	33,39	48,47

Data Source: Andersen, J.M. (1999).

Manure management.
The emission coefficients for manure management depend on the amount of manure per animal, the CH_4 production capacity of the manure and the type of management/storage facilities. According to IPCC guidelines emission coefficients per animal are calculated as:

$$kCH_4^{i,man} = DW^i \cdot CH_4^i \max \cdot \sum_j ST^{i,j} \cdot sECH_4^j \qquad \textbf{(A5.1.6)}$$

DW^i	the dry-matter content of the manure from animal category i (measured in kg manure per animal per year)
CH_4^i max	the max. CH_4 production capacity for manure from animal category I measured in kg CH_4 per kg dry-matter manure)
$ST^{i,j}$	the share of manure from category i stored in system j
$sECH_4^j$	the share of CH_4^i max that is emitted when stored in system j

Employing equation A5.1.6 and parameter values recommended by IPCC, the calculated emission coefficients are given in Table A5.1.3.

Table A5.1.3 Emission coefficients for manure management.

			Manure management			Emission coeff.
			Solid	Liquid	Grazing	$kCH_4^{i,man}$
Share of CH_4 max emitted ($sECH_4^j$)			0,01	0,1	0,01	
	Manure DW^i	Methane prod CH_4^i max				
Dairy cows	2115	0,1608	0,3	0,6	0,1	21,8
Slaught. calves	479	0,1139	0,77	0,23	0	1,7
Heifer calves	591	0,1139	0,4	0,15	0,45	1,6
Nurse cows	1156	0,1139	0,43	0	0,57	1,3
Sows	257	0,3015	0,23	0,75	0,02	6,0
Piglets	39	0,3015	0,13	0,87	0	1,0
Slaught. pigs	124	0,3015	0,32	0,68	0	2,7
Fattening pigs						2,1
Poultry/ 100 heads	1077	0,3015	0,95	0,05	0	4,7

Data Source: Jensen, T.S. (1999). The emission coefficient for Fattening pigs is a weighted average of piglets (35%) and Slaught. pigs (65%). The weights are the number of animals in each category relative to the total number of fattening pigs.

Annex 5.1.2 Landfilled waste.

Table A5.1.4 Time-series for the amount of landfilled waste and the collection of CH_4

	Domestic waste	Bulky waste	Garden waste	Commer-cial	Industrial waste	Building & Constr.	Sludge	Ash & slag	Total	kt CH_4 collected
	Emissioncoefficient kg CH_4/ton waste $kCH_4^{waste,s}$									
	67.8	***93.6***	***51.3***	***78.8***	***22.1***	***7.6***	***44.6***	***0.0***		
Year	1000 Tons waste									
1970	84.6	88.4	66.8	23.7	344.0	713.7	154.8	169.2	1645.3	0.0
1971	92.3	96.5	72.9	25.8	375.2	778.6	168.9	184.6	1794.9	0.0
1972	100.0	104.5	79.0	28.0	406.5	843.5	183.0	200.0	1944.5	0.0
1973	107.7	112.5	85.1	30.2	437.8	908.4	197.1	215.4	2094.1	0.0
1974	115.4	120.6	91.2	32.3	469.0	973.3	211.2	230.8	2243.7	0.0
1975	123.1	128.6	97.2	34.5	500.3	1038.2	225.2	246.2	2393.2	0.0
1976	130.8	136.7	103.3	36.6	531.6	1103.0	239.3	261.5	2542.8	0.0
1977	138.5	144.7	109.4	38.8	562.8	1167.9	253.4	276.9	2692.4	0.0
1978	146.2	152.7	115.5	40.9	594.1	1232.8	267.5	292.3	2842.0	0.0
1979	153.8	160.8	121.5	43.1	625.4	1297.7	281.5	307.7	2991.5	0.0
1980	161.5	168.8	127.6	45.2	656.7	1362.6	295.6	323.1	3141.1	0.0
1981	169.2	176.8	133.7	47.4	687.9	1427.5	309.7	338.5	3290.7	0.0
1982	176.9	184.9	139.8	49.5	719.2	1492.3	323.8	353.8	3440.3	0.0
1983	184.6	192.9	145.8	51.7	750.5	1557.2	337.8	369.2	3589.8	0.0
1984	192.3	201.0	151.9	53.8	781.7	1622.1	351.9	384.6	3739.4	0.0
1985	**200.0**	**209.0**	**158.0**	**56.0**	**813.0**	**1687.0**	**366.0**	**400.0**	3889.0	0.0
1986	199.8	217.3	143.4	66.7	814.9	1539.9	337.2	427.0	3746.2	0.4
1987	199.6	225.7	128.9	77.3	816.8	1392.8	308.4	454.0	3603.4	0.4
1988	199.3	234.0	114.3	88.0	818.7	1245.7	279.7	481.0	3460.7	0.4
1989	199.1	242.3	99.8	98.7	820.6	1098.6	250.9	508.0	3317.9	0.9
1990	198.9	250.7	85.2	109.3	822.4	951.4	222.1	535.0	3175.1	1.7
1991	198.7	259.0	70.7	120.0	824.3	804.3	193.3	562.0	3032.3	1.7
1992	198.4	267.3	56.1	130.7	826.2	657.2	164.6	589.0	2889.6	1.7
1993	198.2	275.7	41.6	141.3	828.1	510.1	135.8	616.0	2746.8	2.8
1994	**198.0**	**284.0**	**27.0**	**152.0**	**830.0**	**363.0**	**107.0**	**643.0**	2604.0	2.8
1995	**190.0**	**286.0**	**17.0**	**128.0**	**779.0**	**321.0**	**101.0**	**135.0**	1957.0	6.0
1996	**132.0**	**275.0**	**6.0**	**135.0**	**822.0**	**317.0**	**117.0**	**703.0**	2507.0	6.6
1997	**83.0**	**248.0**	**6.0**	**170.0**	**707.0**	**264.0**	**130.0**	**475.0**	2083.0	9.4
1998	74.1	221.4	5.4	157.9	681.8	254.6	130.0	475.0	2000.1	12.7
1999	65.2	194.9	4.7	145.7	656.5	245.1	130.0	475.0	1917.1	15.0
2000	56.3	168.3	4.1	133.6	631.3	235.7	130.0	475.0	1834.2	16.0
2001	47.4	141.7	3.4	121.4	606.0	226.3	130.0	475.0	1751.3	17.0
2002	38.5	115.1	2.8	109.3	580.8	216.9	130.0	475.0	1668.4	18.0
2003	29.6	88.6	2.1	97.1	555.5	207.4	130.0	475.0	1585.4	18.0
2004	**20.8**	**62.0**	**1.5**	**85.0**	**530.3**	**198.0**	**130.0**	**475.0**	1502.5	18.0
2005	20.8	62.0	1.5	85.0	530.3	198.0	130.0	475.0	1502.5	18.0
2006	20.8	62.0	1.5	85.0	530.3	198.0	130.0	475.0	1502.5	18.0
2007	20.8	62.0	1.5	85.0	530.3	198.0	130.0	475.0	1502.5	18.0
2008	20.8	62.0	1.5	85.0	530.3	198.0	130.0	475.0	1502.5	18.0
2009	20.8	62.0	1.5	85.0	530.3	198.0	130.0	475.0	1502.5	18.0
2010	20.8	62.0	1.5	85.0	530.3	198.0	130.0	475.0	1502.5	18.0
2011	20.8	62.0	1.5	85.0	530.3	198.0	130.0	475.0	1502.5	18.0
2012	20.8	62.0	1.5	85.0	530.3	198.0	130.0	475.0	1502.5	18.0

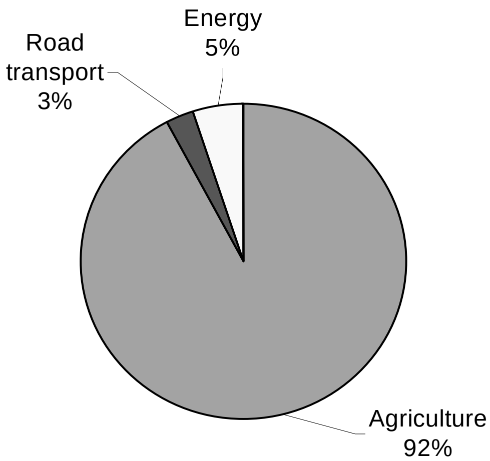
Source: Fenhann, J. (1999), p.54. Figures in bold are statistic figures or goals in the official waste plan.

5.2 Emissions of nitrous oxide (N_2O).

Assuming a 100 years time horizon, the global warming potential index for nitrous oxide (N_2O) is 310, i.e. one kg nitrous oxide has a greenhouse effect equivalent to 310 kg CO_2 (see Table 5.0.1). The total emission of N_2O from Danish sources was 32,3 kt in 1997, and this accounts for about 14% of the greenhouse effect of anthropogenic emissions from Danish sources.

Distribution by major sources is illustrated in Figure 5.2.1 Agriculture is by far the most important source, accounting for 92% (29,7 kt) of the total N_2O emission. Road transport contributes with 3% (1,0 kt) and energy, incl. other mobile sources, contributes with 5% (1,6 kt).

Figure 5.2.1 Emissions of N2O in 1997



Source: CORINAIR-database, 1997

5.2.1 Emission of N_2O from agriculture.

The sources of N_2O from agriculture are emissions from agricultural crops and emissions from manure management, accounting for 75% and 25% respectively.

Production of N_2O results primarily from the nitrification and denitrification processes involved in the degradation of organic material, by either aerobic microbial oxidation of ammonium to nitrate or by anaerobic microbial reduction of nitrate to dinitrogen gas. N_2O is a gaseous intermediate in the reaction sequences of both processes. These processes occur during decomposition of animal manure in manure storage systems, during decomposition of organic material in soil and during leaching of nitrogen.

According to IPCC (IPCC Guidelines, 1997), emission from animal manure includes the contribution from handling of manure, the use of animal manure as fertilisers and animal grazing. Emission from agricultural crops includes contributions from the application of synthetic fertilisers, crop residues, nitrogen fixation, deposition of ammonia, nitrogen leaching and run-off and the cultivation of histosols. Total emission from agriculture is the sum of these contributions.

At an aggregated level for 1997, total N_2O emissions from sources within agriculture are listed in Table 5.2.1. The N_2O emission from the different sources is calculated from the statements of the nitrogen input and a related emission coefficient. The nitrogen input data from animal fertiliser, animal grazing and synthetic fertiliser is reduced by the amount of nitrogen that evaporates as ammonia (NH_3).

That is, N_2O emissions are calculated as:

$$N_2O^{agr} = 44/28 \cdot \sum_i N^i \cdot (1 - sNH_3^i) \cdot sN^i \qquad \textbf{(5.2.1)}$$

N_2O^{agr}	the emission of N_2O from agriculture
N^i	the amount of N-input from category *i* in table 5.2.1
sNH_3^i	the share of the N-input that evaporates as NH_3
sN^i	the share of the N-input emitted as N_2O
44/28	the conversion factor from N to N_2O.

Table 5.2.1 shows that concerning emission from manure management, the handling and use of manure as fertilisers are the main sources and contribute by 43% and 45% respectively. Animal grazing contributes 12%.
From agricultural crops, the emission from crop residues as well as leaching and run-off are the main sources, each accounting for 32% of emission. Emission from the use of synthetic fertiliser contributes 25%.

Table 5.2.1 N_2O emission coefficients, N-input data, and total emission in 1997 (CORINAIR-database, 1997).

	N-input (kt N)	Share of N-input evaporated as NH_3	Share of N emitted as N_2O	Emission in 1997 (kt N_2O)
Manure management				**7,54**
Animal manure handling:				
Liquid	143,0		0,1%	0,22
Solid	97,8		2,0%	3,07
Animal fertilisers	240,8	28,5%	1,25%	3,38
Animal grazing	29,5	7,0%	2,0%	0,86
Agricultural crops				**22,18**
Synthetic fertilisers	287,6	2,3%	1,25%	5,52
Wastewater sludge used as fertilisers	8,1	1,9%	1,25%	0,16
Crop residues	361,3		1,25%	7,10
N-fixation	37,0		1,25%	0,73
Atmospheric N depostion	93,7		1,0%	1,47
Nitrogen leaching & runoff	181,2		2,5%	7,12
Histosols	18,4		3	0,09
Total				**29,72**

Source: Data from CORINAIR 1997 revised

In the model, the emission related to manure management is linked to categories of livestock, and the emission related to agricultural crops is linked to the use of fertilisers (both animal manure and synthetic fertilisers) and categories of vegetable production.

Emissions related to manure management.
Emissions of nitrogen oxides from manure management are calculated as a fraction of the nitrogen content of animal manure, and depend on the size and composition of the livestock and the handling and use of the manure.

Total emission related to manure management is calculated as:

$$N_2O^{man} = k_0 + \sum_i NH^i \cdot kN_2O^{i,man} \qquad \textbf{(5.2.2)}$$

N_2O^{man}	is the total N_2O emission from manure management
NH^i	is the number of heads of animal type i
$kN_2O^{i,man}$	is the aggregated N_2O emission coefficient for animal type i (kg N_2O/animal/year)
k_0	is a constant for emission from minor contributors not istinguished in the model

For each animal type, the aggregated emission coefficient is the sum of emissions related to the manure management types: manure handling of solid and fluid manure, the use of manure as fertilisers and emissions from grazing animals. That is:

$$kN_2O^{i,man} = \sum_j kN_2O^{i,man\,j} \qquad \textbf{(5.2.3)}$$

where $kN_2O^{i,man\,j}$ is the emission coefficient for animal type *i* and manure management type *j*

man j is the manure management types: manure handling of solid and liquid manure (*h*), use of manure as fertilisers (*f*) and animal grazing (*g*)

For manure handling of solid and fluid manure the emission coefficients $kN_2O^{i,manh}$ are calculated as:

$$kN_2O^{i,man\,h} = \left[N^i \cdot (1 - Frac^{\,i,man\,g}) \cdot (s_s^{\,i} \cdot sN_s^{\,manh} + s_l^{\,i} \cdot sN_l^{\,manh})\right] \cdot 44/28 \qquad \textbf{(5.2.4a)}$$

for the use of manure as fertilisers the coefficients are calculated as:

$$kN_2O^{i,man\,f} = \left[N^i \cdot (1 - Frac^{i,man\,g}) \cdot \left(1 - sNH_3^{\,i,man\,f}\right) \cdot sN^{\,man\,f}\right] \cdot 44/28 \qquad \textbf{(5.2.4b)}$$

and for grazing animals the coefficients are calculated as:

$$kN_2O^{i,mang} = \left[N^i \cdot Frac^{\,i,mang} \cdot \left(1 - sNH_3^{\,i,mang}\right) \cdot sN^{\,mang}\right] \cdot 44/28 \qquad \textbf{(5.2.4c)}$$

N^i	the nitrogen ab animal
$Frac^{i,man\,g}$	the share of N from grazing animals
$sNH_3^{\,i,man\,j}$	the share of N from animal *i* and manure type *j* evaporated as NH_3
$s_s^i\,, s_l^{\,i}$	the share of solid (*s*) and liquid manure (*l*) form animal *i*
$sN^{\,man\,j}$	the share of N emitted as N_2O

and the coefficient $44/28$ converts from a measure in kg N to a measure in kg N_2O (the ratio represents the weight of N_2O relative to N).

For individual categories of animals, emission coefficients for the years 1997 and 2003 for manure handling, the use of manure as fertilisers and grazing animals are calculated in Annex 5.2.1 and summarised in Table 5.2.2. Total emissions of N_2O from animals in 1997 are given in Table 5.2.3.

Table 5.2.2 N_2O emission coefficients for categories of animal in 1997 and 2003

Animal	Manure handling	Use as fertilisers		Grazing	Total	
		kg N_2O per animal per year				
Year	1997/2003	1997	2003	1997/2003	1997	2003
Dairy cows	1,287	1,758	1,848	0,366	3,411	3,501
Slaught. calves	0,837	0,459	0,5	0	1,296	1,337
Heifers	0,451	0,266	0,289	0,462	1,179	1,202
Nurse cows	0,771	0,319	0,351	0,951	2,041	2,073
Sows	0,213	0,343	0,371	0,015	0,571	0,599
Fattening pigs	0,086	0,110	0,119	0	0,196	0,205
Poultry	0,018	0,007	0,007	0	0,025	0,025
Fur animals	0,076	0,050	0,051	0	0,126	0,127
Horses	0,721	0,289	0,32	0,671	1,681	1,712
Ovines	0,213	0,085	0,095	0,442	0,740	0,750

See calculations in Annex A5.2.1

Table 5.2.3 N_2O emissions from animals in 1997

Animal	Heads in 1997	manure handling	use as fertilisers	grazing	total
			ton N_2O in 1997		
Dairy cows	670354	863	1178	245	2287
Slaught. calves	369028	309	169	0	478
Heifers	839744	379	223	388	990
Nurse cows	125085	96	40	119	255
Sows	1068473	228	366	16	610
Fattening pigs	10074609	866	1108	0	1975
Poultry	18993561	342	133	0	475
Fur animals	2212811	168	111	0	279
Horses	38862	28	11	26	65
Ovines	64820	14	6	29	48
Other animals		13	25	33	71
Total		3306	3371	856	7533

The projected N_2O emission coefficients are based on actions taken in the Danish Action Plan on the Aquatic Enivironment (I) in 1987, the Danish Action Plan on Sustainable Agriculture in 1991 and the Danish Action Plan on the Aquatic Environment (II) in 1998.

The effect on N_2O emissions is due to regulations of the handling of animal manure. The regulation aims at increasing the utilisation of animal manure and implies covering of slurry tanks, defining a limit of twelve hours between the addition of manure to un-vegetated soil and ploughing, and changing the manure addition practice. The effect of the regulation is a reduction of the evaporation of NH_3, and implies (as may be seen from eq. 5.2.4a-c) an increase in the N_2O emission coefficients. For the use of manure as fertilisers, the average evaporation of NH_3 is reduced from 28,5% to 23,6%, and for animal grazing NH_3 evaporation is assumed to be constant at 7%. As is seen from Table 5.2.2, this implies that the N_2O emission coefficients for the use of manure as fertilisers increase. The increase varies for the individual categories of animals between 0 and 12%. The coefficients for grazing animals are constant.

From Table 5.2.3 it is seen that the main contributors to N_2O emission from animal manure are the cattle sector, accounting for 54% of emissions, and the pig sector, accounting for 34%. The poultry sector accounts for 6%.

Emissions related to agricultural crops.
Emissions related to agricultural crops are calculated for the categories given in Table 5.2.1 and are linked to the production of crops and the use of fertilisers.

Emissions from synthetic fertilisers.
The use of synthetic fertilisers is determined within ESMERALDA and depends on the agricultural area cultivated within conventional farming and the composition of crops. Synthetic fertilisers are not used within organic farming. Emissions of N_2O are calculated at an aggregated level according to:

$$N_2O^{fert} = 44/28 \cdot \left(N^{fert} \cdot (1 - sNH_3^{fert}) \cdot sN_2O^{fert}\right) \quad \textbf{(5.2.5)}$$

N_2O^{fert}	the emission of N_2O from the use of synthetic fertilisers
N^{fert}	the amount of N-input from synthetic fertilisers
sNH_3^{fert}	the share of the N-input that evaporate as NH_3 (2,3% in 1997, expected to be reduced to 1,7% in year 2005, see Table 3.1.4)
sN_2O^{fert}	the share of the N-input emitted as N_2O (1,25%, see Table 5.2.1)

In 1997 the total use of fertilisers was 287,6 kt. N. Of this 5,8 kt N was used at golf courses, institutions etc. and 281,8 kt. N was used on 2,3 mill. ha. conventionally farmed agricultural land with permanent, arable land crops and market gardening. (Grant, R. 1999) This corresponds to 120,3 kg N/ha. or an emission of 2,36 kg N_2O/ha on average. According to the Action Plan on the Aquatic Environment I and II and the Danish Action Plan for Sustainable Agriculture the use of synthetic fertilisers shall be reduced by about 40% by the year 2003. However, in the model the amount of N in synthetic fertilisers used for agricultural crops is determined in ESMERALDA. Due to the required reduction of the nitrogen manure standard, it is evaluated that fertilisers with relatively large evaporation rates are substituted by fertilisers with lower rates, and on average the evaporation rate for NH_3 is evaluated to decrease from the 2,3% in 1997 to 1,7% in year 2003 (see chapter 6). The amount used at golf courses is exogenous and, in the base forecast, assumed to be constant (5,8 kt N).

Emissions from wastewater sludge used as fertilisers.
Sludge from wastewater treatment plants and some waste from industry contain nitrogen, and part of this is used as fertiliser. The amount of N in sewage and industrial waste used as fertiliser is calculated in relation to the annual monitoring programme for the aquatic environment. Wastewater sludge is evaluated as containing 43,8 kg N per ton dry weight and the industrial waste is evaluated as containing 20,3 kg N per ton. In 1997 91,8 kt wastewater sludge in dry weight and 199,8 kt industrial waste was used as fertiliser. The N content of this is given in Table 5.2.4. In addition the table shows that 1,9% of the N content is evaporated as NH_3 and 1,25% of the remaining N is evaporated as N_2O. The total amount of N_2O evaporated from the use of wastewater sludge and industrial waste is calculated to 156 ton N_2O.

Table 5.2.4 Wastewater sludge and industrial waste used as fertilisers in 1997

Source	kton sludge/waste	N content kg N/ton dw	ton N	NH_3 evap %	N_2O evap. %	ton N_2O
Wastewater sludge	91,8	43,8	4.021	1,9	1,25	77
Industrial waste	199,8	20,3	4.056	1,9	1,25	78
Total						156

Data for N in wastewater sludge and industrial waste used as fertilisers is from Grant, R. et al (1999) and unpublished data from Blicher-Mathiesen, G. NERI.

For forecasts, the amount of N from wastewater sludge and industrial waste used as fertilisers is exogenous, and the percentage evaporated as NH_3 is assumed to decrease to 1,5% in year 2003 (see chapter 6).

Emissions from crop residuals.

Emission of N_2O from crop residuals is based on the nitrogen content in vegetable production. Assuming that the N content in vegetable production is equally divided between crop residuals and the crop, the N content of crop residuals equals the N content of the harvested crop. The N content in crops is estimated to about 34 kg N per ton crop in dry weight for nitrogen fixing crops and about 19 kg N per ton dry weight for grain crops. (Andersen J.M, 1999). For the crop categories of ESMERALDA the N content and the N_2O emission coefficient are given in Table 5.2.5.

Total emission from crop residuals are calculated as:

$$N_2O^{res} = 44/28 \cdot \sum_i NH_i \cdot \left(kN_i^{res} \cdot sN_i^{res}\right) \qquad \textbf{(5.2.6)}$$

NH_i the harvest of crop i in tons

kN_i^{res} the amount of N in crop residuals from crop i

sN^{res} the share of the N-input emitted as N_2O (1,25%, see Table 5.2.1)

Table 5.2.5 Emission of N_2O from crop residuals in 1997

Crop	Harvest 1000 ton	N-factor (kN_i^{res}) kg N/ton	N_2O-emission factor kg N_2O/ton	N in resid. ton N	N_2O emission ton N_2O
Wheat	4965	19,68	0,3866	97711	1919
Other grain crop	4563	16,82	0,3304	76750	1508
Pulse	384	33,69	0,6618	12937	254
Rape	291	37,56	0,7378	10930	215
Potatoes	1545	3,53	0,0693	5454	107
Sugar beets	3365	2,08	0,0409	6999	137
Fodder beets	2503	2,13	0,0418	5331	105
Rot grass	9256	5,50	0,1080	50908	1000
Perm. grass	4425	5,50	0,1080	24338	478
Fallow in ha[1]	158	70,00	1,3750	11060	217
Other crop				58892	1157
Total				361310	7097

[1] For fallow, the column harvest gives the area in ha and the emission coefficient is kg N_2O/ha.
Source: Data from Andersen, J.M. (1999) and Grant, R. et al (1999)

Emissions from N-fixation.

Some crops, mainly pulses and clover, are able to fix nitrogen from the air. In addition, nitrogen is fixed by free-living micro-organisms. This adds to the N input of agriculture and the resulting emissions of N_2O. For the crop categories of ESMERALDA N-fixation and emission coefficients are given in Table 5.2.6.

For grass only, the share of clover in the yield is N-fixing. For grass in rotation it is assumed that 80% of the area contains clover and that 20% of the yield in these fields is clover. For permanent grass it is assumed that only 5% of the yield is clover. The N-factors in Table 5.2.6 account for this and are in kg N per ton harvested.

Other crops include pulse seeds in grass fields. It is estimated that the N-fixing is 180-200 kg N per ha and in 1997 the area with this crop was about 3100 ha.

The last row of Table 5.2.6 reflects the asymbiotic N-fixing of micro-organisms. It is estimated that this N-fixation is 2 kg N per ha and is applicable for all agricultural land.
Emissions are calculated as:

$$N_2O^{fix} = 44/28 \cdot \sum_i NH_i \cdot kN_i^{fix} \cdot sN^{fix} \qquad \textbf{(5.2.7)}$$

NH_i	the harvest of nitrogen fixing crop i/area of crop
kN_i^{fix}	the N-factor for crop i
sN^{fix}	the share of N emitted as N_2O (1,25%)

Table 5.2.6 Emission of N_2O from N-fixation in 1997

Crop	Harvest 1000 ton	N-factor (kN_i^{fix}) kg N/ton	N_2O-emis. factor kg N_2O/ton	N-fixation ton N	N_2O emission ton N_2O
Pulse	384	34,22	0,6722	13140	258
Silage cereals	3275	1,58	0,0310	5161	101
- Lucerne	461	6,75	0,1326	3112	61
- Wholecrop	2814	0,73	0,0143	2050	40
Grass in rotation	9256	1,20	0,0235	11092	218
Permanent grass	4425	0,37	0,0074	1657	33
Other crops in ha[1]	3,1	200	3,9286	620	12
Asymbiotic N-fixing[1]	2688	2,00	0,0393	5376	106
Total				37048	728

[1] For other crop and asymbiotic N-fixing the figures in the first column are areas in ha and the emission coefficients are kg N_2O/ha.
Source: Data from Andersen, J.M. (1999)

Emissions from deposition

Normally, deposition of N from the atmosphere comprises deposition of ammonia NH_3 and nitrogen oxides NO_X. However, the IPCC focuses on depositions from agriculture only, and the deposition of N from NO_X generated within agriculture is minor. That is, in relation to the calculation of N_2O emission, deposition of N is set equal to the emission of NH_3 from agricultural activities. The equation for emission from deposition is

$$N_2O^{dep} = 44/28 \cdot 14/17 \cdot \sum_k NH_3^k \cdot kN_2O^{dep} \qquad \textbf{(5.2.8)}$$

N_2O^{dep}	the emission of N_2O from deposition of NH_3
NH_3^k	the amount of NH_3 evaporated/emitted of category k (see Table 6.1.1)
kN_2O^{dep}	the share emitted as N_2O (1% see Table 5.2.1)
$44/18$ and $14/17$	conversion factors from N to N_2O and from NH_3 to N, respectively.

For 1997, total NH_3 deposition is estimated to about 113 kt NH_3 or 93 kt NH_3-N. Assuming that 1% of the deposited N is evaporated as N_2O and converting from weight in N to weight in N_2O, for 1997 emissions related to N deposition is estimated to about 1,5 kt N_2O.

Assuming unchanged animal production, but reduced NH_3 evaporation rates and use of synthetic fertilisers, projected emissions for the year 2003 are calculated at the bottom of Table 5.2.7.

Table 5.2.7 Emission of N_2O from atmospheric N deposition

Emissions for year 1997	
NH_3 emission from manure (ton NH_3)	86189
NH_3 emission from synthetic fertilisers (ton NH_3)	8032
NH_3 emission directly from crops (ton NH_3)	13948
NH_3 emission from straw leaching (ton NH_3)	5070
NH_3 from wastewater sludge (ton NH_3)	186
Total deposition of NH_3 (ton NH_3)	113425
Total emission (N_2O^{dep}) (1% of total NH_3 deposition) ton N_2O	1468
Emissions for year 2003 assuming unchanged number of animals	
NH_3 emission from manure (ton NH_3)	71943
NH_3 emission from synthetic fertilisers (ton NH_3)	3705
NH_3 emission directly from crops (ton NH_3)	13831
NH_3 emission from straw leaching (ton NH_3)	5070
NH_3 from wastewater sludge (ton NH_3)	186
Total deposition of NH_3 (ton NH_3)	94735
Total emission (N_2O^{dep}) (1% of total NH_3 deposition) ton N_2O	1226

Source: Data from Andersen, J.M. (1999)

Emissions from nitrogen leaching and run-off.

According to IPCC the N_2O emission from leaching and run-off of nitrogen from agriculture is calculated as a fraction of the N leached. Of the total N-input from fertilisers, a share (sN^{leach}) is leached. This share depends on the combination of synthetic fertilisers and animal manure used and the handling of animal manure. According to IPCC, the default share of N leached is estimated to 30%. For the use and handling of fertilisers in Denmark, leaching is estimated to 32% in 1997. It is estimated that 2,5% of the leached N from soil, lakes and rivers is emitted as N_2O. That is

$$N_2O^{leach} = 44/28 \cdot sN^{leach} \cdot \left(\sum_k N^k \right) \cdot kN_2O^{leach} \quad \textbf{(5.2.9)}$$

N_2O^{leach}	the emission of N_2O from leaching
sN^{leach}	the share of the N-input that is leached
N^k	the amount of N-input of category k
kN_2O^{leach}	the share emitted as N_2O (2,5% see Table 5.2.1)
k	index for animal fertilisers, animal grazing and synthetic fertilisers

The amount of N-input and the total N_2O emissions from leaching and run-off are given in Table 5.2.8. For the projection shown in Table 5.2.8, only the use of synthetic fertilisers is reduced. The N-input from animal manure, wastewater sludge and industrial waste is assumed to be constant. However, in the model the amount of animal manure is determined endogenously and will change according to the number of animals. In addition the share of the N leached is assumed to be constant; however, due to a larger share of animal manure, the share leached may be expected to increase.

Table 5.2.8 Emissions from leaching & run-off

N source	N-input 1997 ton N	N-input 2003 ton N
Synthetic fertilisers	287600	179500
Animal manure	270601	270601
Wastewater sludge and industrial waste	8086	8086
Total N-input	566287	458187
N - leaching (32%)	181212	146620
	ton N_2O	
N_2O-emission (2,5%)	7119	5760

Emissions from histosols.

Histosols are cultivated organic soils originating from old N-rich organic matter. The total area in Denmark covered with histosols is 237.700 ha. However, only 184.400 ha are used for agricultural purposes of which 90% is used for permanent grassland with no net N_2O emission. Only 10% or 18.400 ha of histosols are cultivated and as such contribute to N_2O emission. The emission coefficient is estimated to 3 kg N_2O-N/ha. In total the emission is 0,087 kt N_2O.

5.2.2 Emission of N_2O from road transport.

Emission of N_2O from road transport accounts for 3% of total emissions in 1997. However, this share is expected to increase considerably, mainly due to the introduction of catalytic converters on gasoline driven vehicles. By regulating oxidation, catalytic converters reduce emissions of VOC, CO and NO_X, but at the optimal oxidation for reduction of CO and NO_X emissions, emission of N_2O is increased. As the N_2O emission coefficients for vehicles with and without catalytic converters differ considerably, the model distinguishes between vehicles with and without catalytic converters. As all new gasoline driven vehicles are required to have catalytic converters, the share of vehicles with catalytic converters is (as an approximation) calculated as:

$$sh_{cat}^{t} = \frac{\sum_{h=97}^{t} k_0 \cdot fCb^h}{Kcb^t} + 0{,}44 \qquad \textbf{(5.2.10)}$$

sh_{cat}^{t}	the share of vehicles with catalytic converters
fCb^h	the consumption of private vehicles in constant prices (variable in ADAM)
Kcb^t	the number of vehicles ultimo year t (in 1000 units) (variable in ADAM)
k_0	a constant representing the average price of private vehicles in the baseyear 1990 (constant in ADAM from the equation for Kcb)
0,44	the share of vehicles with catalytic converters in year 1997

Equation 5.2.10 is valid until the share reaches 1,0 which is the limit.

An average N_2O emission coefficient is used for diesel vehicles and lorries; that is, the model does not distinguish between different sizes and types of lorries. Emission coefficients are defined in kg N_2O/TJ fuel used and total emissions from transport are calculated as:

$$N_2O^{transp} = \left(sh_{cat} \cdot kN_2O_{cat} + (1 - sh_{cat}) \cdot kN_2O_{non-cat}\right) \cdot qJtc1 + kN_2O_{diesel} \cdot \sum_i qJt_i + k_0 \quad \textbf{(5.2.11)}$$

$qJtc1, qJt_i$	the relevant energy consumption variables in EMMA
kN_2O_j	is the N_2O emission coefficient for category j (assumed to be constant)
k_0	is emission from other transport sources

The emission coefficients, energy consumption and total emissions related to road transport for 1997 are given in Table 5.2.9.

Table 5.2.9 N_2O emissions related to road transport in 1997.

	Share of vehicles	Emis. Coeff. (kN_2O^j) kgN_2O/GJ	Energy cons. (qJt(i)) TJ	N_2O emissions (ton N_2O)
Vehicles with catalytic converters	0,440	0,0139		
Vehicles with no catalytic converters	0,560	0,0021	83830	611
Diesel vehicles		0,0037	62200	232
Other sources				71
Total				**914**

Source: Data from CORINAIR and unpublished data from Winther, M. NERI

5.2.3 Emission of N_2O from energy

Emission from energy (excluding energy used for road transport) accounts for 6% of the total N_2O emissions in 1997. Due to the reduction of coal consumption at power plants, this share is expected to decrease. As N_2O emission from energy is minor, the emission is modelled at an aggregated level distinguishing only three types of fuels. That is, emissions are calculated as:

$$N_2O^{energy} = k_0 + \sum_j \left(qJ_jDK + qJ_jne\right) \cdot kN_2O_j \quad \textbf{(5.2.12)}$$

qJ_jDK	the consumption of fuel j by households and branches excl.energy conversion in TJ (variable in EMMA)
qJ_jne	the consumption of fuel j by energy conversion in TJ (variable in EMMA)
kN_2O_j	the N_2O emission coefficient for fuel j (assumed to be constant)
k_0	a constant representing other energy related emissions of N_2O

Emission coefficients, energy consumption and total emissions related to the energy consumption excl. road transport for 1997 are given in Table 5.2.10.

Table 5.2.10 N_2O emissions related to energy consumption in 1997.

	Energy consumption PJ	Emission coefficient kg N2O/GJ	N_2O emissions Ton
Solid (qJsDK+qJsne)	279	0,003	837
Fluid (qJfDK+qJfne)	183	0,002	366
Gas (qJgDK+qJgne)	189	0,001	189
Other sources			240
Total			1632

Source: Data from CORINAIR 1997.

Annex 5.2.1 N_2O emission coefficients for animal categories

The calculation of emission coefficients for the handling and use of manure and grazing animals for the years 1997 and 2003 is shown in Tables A5.2.1 and A5.2.2 respectively. The coefficients are calculated from the equations 5.2.4a-5.2.4c in section 5.2.1.

The data for the nitrogen ab animal (N^i) and fractions of the manure from grazing animals and the share of solid and liquid manure ($Frac^{i,man\,g}$ and s_k^i), are from Andersen et. al. (1999). The N_2O emission factors ($sN_k^{man\,j}$) are the IPCC default values, and the NH_3 evaporation ratios ($sNH_3^{i,man\,j}$) are calculated for Danish conditions. (Andersen et al. (1999))

Table A5.2.1 N_2O emission coefficients for animal categories in 1997.

Animal	man.type	N ab animal kg N/animal/year N^i	Share stable/graz share $Frac^{i,man j}$	NH3 evap share $sNH_3^{i,man j}$	Share solid/liquid share s_k	N_2O% emitted share $sN_k^{man j}$	Emission coefficient kg N_2O/animal/year $kN_2O^{i,man j}$
Dairy cows	handling solid	125,22	0,9	0,000	0,33	0,02	
	handling liquid	125,22	0,9	0,000	0,67	0,001	1,287
	fertilisers	125,22	0,9	0,206	1,00	0,0125	1,758
	grazing	125,22	0,1	0,070	1,00	0,02	0,366
	Total						**3,411**
Slaught calves	handling solid	33,66	1	0,000	0,78	0,02	
	handling liquid	33,66	1	0,000	0,22	0,001	0,837
	fertilisers	33,66	1	0,306	1	0,0125	0,459
	Total						**1,296**
Heifers	handling solid	35,12	0,55	0,000	0,73	0,02	
	handling liquid	35,12	0,55	0,000	0,27	0,001	0,451
	fertilisers	35,12	0,55	0,298	1	0,0125	0,266
	grazing	35,12	0,45	0,070	1	0,02	0,462
	Total						**1,180**
Nurse cows	handling solid	57,07	0,43	0,000	1	0,02	
	handling liquid	57,07	0,43	0,000	0	0,001	0,771
	fertilisers	57,07	0,43	0,339	1	0,0125	0,319
	grazing	57,07	0,57	0,070	1	0,02	0,951
	Total						**2,041**
Sows	handling solid	25,7	0,98	0,000	0,23	0,02	
	handling liquid	25,7	0,98	0,000	0,77	0,001	0,213
	fertilisers	25,7	0,98	0,307	1	0,0125	0,343
	grazing	25,7	0,02	0,070	1	0,02	0,015
	Total						**0,570**
Fattening pigs	handling solid	8,14	1	0,000	0,3	0,02	
	handling liquid	8,14	1	0,000	0,7	0,001	0,086
	fertilisers	8,14	1	0,309	1	0,0125	0,110
	Total						**0,196**
Poultry	handling solid	0,609	1	0,000	0,95	0,02	
	handling liquid	0,609	1	0,000	0,05	0,001	0,018
	fertilisers	0,609	1	0,442	1	0,0125	0,007
	Total						**0,025**
Fur animals	handling solid	4,59	1	0,000	0,5	0,02	
	handling liquid	4,59	1	0,000	0,5	0,001	0,076
	fertilisers	4,59	1	0,445	1	0,0125	0,050
	Total						**0,126**
Horses	handling solid	45,9	0,5	0,000	1	0,02	
	handling liquid	45,9	0,5	0,000	0	0,001	0,721
	fertilisers	45,9	0,5	0,360	1	0,0125	0,289
	grazing	45,9	0,5	0,070	1	0,02	0,671
	Total						**1,681**
Ovines	handling solid	21,9	0,31	0,000	1	0,02	
	handling liquid	21,9	0,31	0,000	0	0,001	0,213
	fertilisers	21,9	0,31	0,360	1	0,0125	0,085
	grazing	21,9	0,69	0,070	1	0,02	0,442
	Total						**0,740**

Source: Data from Andersen, J.M. (1999). For the calculation of NH_3 evaporation rates see Annex 6.1.1.

Table A5.2.2 N_2O emission coefficients for animal categories in year 2003.

Animal	man.type	N ab animal kg N/animal/year N^i	Share stable/graz share $Frac^{i,man\ j}$	NH3 evap share $sNH_3^{\ i,man\ j}$	Share solid/liquid share s_k	N_2O% emitted share $sN_k^{\ man\ j}$	Emission coefficient kg N_2O/animal/year $kN_2O^{i,man\ j}$
Dairy cows	handling solid	125,22	0,9	0,000	0,33	0,02	
	handling liquid	125,22	0,9	0,000	0,67	0,001	1,287
	fertilisers	125,22	0,9	0,165	1,00	0,0125	1,848
	grazing	125,22	0,1	0,070	1,00	0,02	0,366
	Total						**3,502**
Slaught calves	handling solid	33,66	1	0,000	0,78	0,02	
	handling liquid	33,66	1	0,000	0,22	0,001	0,837
	fertilisers	33,66	1	0,244	1	0,0125	0,500
	Total						**1,337**
Heifers	handling solid	35,12	0,55	0,000	0,73	0,02	
	handling liquid	35,12	0,55	0,000	0,27	0,001	0,451
	fertilisers	35,12	0,55	0,237	1	0,0125	0,289
	grazing	35,12	0,45	0,070	1	0,02	0,462
	Total						**1,203**
Nurse cows	handling solid	57,07	0,43	0,000	1	0,02	
	handling liquid	57,07	0,43	0,000	0	0,001	0,771
	fertilisers	57,07	0,43	0,272	1	0,0125	0,351
	grazing	57,07	0,57	0,070	1	0,02	0,951
	Total						**2,073**
Sows	handling solid	25,7	0,98	0,000	0,23	0,02	
	handling liquid	25,7	0,98	0,000	0,77	0,001	0,213
	fertilisers	25,7	0,98	0,250	1	0,0125	0,371
	grazing	25,7	0,02	0,070	1	0,02	0,015
	Total						**0,599**
Fattening pigs	handling solid	8,14	1	0,000	0,3	0,02	
	handling liquid	8,14	1	0,000	0,7	0,001	0,086
	fertilisers	8,14	1	0,255	1	0,0125	0,119
	Total						**0,205**
Poultry	handling solid	0,609	1	0,000	0,95	0,02	
	handling liquid	0,609	1	0,000	0,05	0,001	0,018
	fertilisers	0,609	1	0,401	1	0,0125	0,007
	Total						**0,025**
Fur animals	handling solid	4,59	1	0,000	0,5	0,02	
	handling liquid	4,59	1	0,000	0,5	0,001	0,076
	fertilisers	4,59	1	0,435	1	0,0125	0,051
	Total						**0,127**
Horses	handling solid	45,9	0,5	0,000	1	0,02	
	handling liquid	45,9	0,5	0,000	0	0,001	0,721
	fertilisers	45,9	0,5	0,290	1	0,0125	0,320
	grazing	45,9	0,5	0,070	1	0,02	0,671
	Total						**1,712**
Ovines	handling solid	21,9	0,31	0,000	1	0,02	
	handling liquid	21,9	0,31	0,000	0	0,001	0,213
	fertilisers	21,9	0,31	0,290	1	0,0125	0,095
	grazing	21,9	0,69	0,070	1	0,02	0,442
	Total						**0,750**

Source: Data from Andersen, J.M. (1999). For the calculation of NH_3 evaporation rates see Annex 6.1.1.

6. Acidification

Acid deposition of sulphur and nitrogen compounds mainly derives from emissions of SO_2, NO_x and NH_3. The effects of acidification show up in a number of ways, including defoliation and reduced vitality of trees, as well as declining fish stocks in acid-sensitive lakes and rivers (European Environmental Agency, 1998).

SO_2 and NO_x can be oxidised into sulphate (SO_4^{--}) and nitrate (NO_3^-) either in the atmosphere or after deposition, resulting in the formation of two and one H^+ respectively. NH_3 may react with H^+ to form ammonium (NH_4^+) and by nitrification in soil NH_4^+ is oxidised to NO_3^- and H^+ is formed (Wark and Warner, 1981).

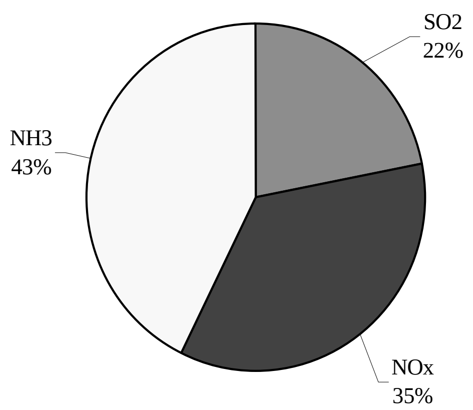
Weighting the individual substances according to their acidification effect, total emissions in terms of acid equivalents can be calculated as:

$$Acidification\ index = \frac{m_{SO_2}}{M_{SO_2}} \cdot 2 + \frac{m_{NO_x}}{M_{NO_x}} + \frac{m_{NH_3}}{M_{NH_3}} = \frac{m_{SO_2}}{64} + \frac{m_{NO_x}}{46} + \frac{m_{NH_3}}{17}$$

m_i	the emission of pollutant *i* in tons
M_i	the mole weight [ton/Mmole] of pollutant i

In terms of acid equivalents Figure 6.0.1 shows the relative contribution of emissions of SO_2, NO_x and NH_3 in 1998.

Figure 6.0.1 Contribution to acid index in 1997



Source: Illerup et al. (2000)

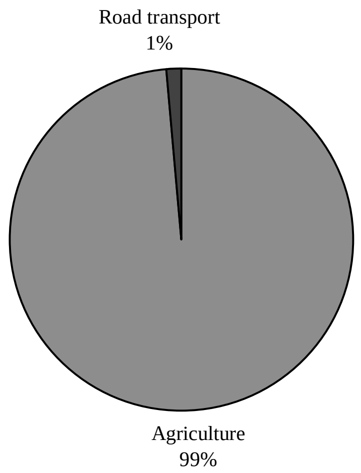
The actual effect of the acidifying substances depends on a combination of two factors: the amount of acid deposition, and the natural capacity of the terrestrial or aquatic ecosystem to counteract the acidification. In areas where the soil minerals easily weather or have a high chalk content, acid deposition will be relatively easily neutralised (Holte-Andersen, 1998).

The modelling of NH_3 emission is treated in this chapter. The modelling of SO_2 and NO_x emissions is included in ADAM/EMMA.

6.1 Emission of ammonia (NH_3)

The effect of NH_3 deposition is primarily as a contributor to acidification and eutrophication. Contrary to emissions of SO_2 and NO_x, emission of NH_3 is not transported over long distances, and about 80% of the total deposition in Denmark originates from Danish activities. However, Denmark is a net-exporter of NH_3 and about 60% of total emissions of NH_3 are transported across the border.
In 1997 the total emission of NH_3 from Danish sources was about 117 kt. Almost all the NH_3 emitted to the atmosphere originates from agricultural activities and only about 1% comes from road transport (see Figure 6.1.1).

Figure 6.1.1 Emissions of NH3 in 1997



Source: CORINAIR and Andersen, J.M. et al (1999)

6.1.1 Emission of NH_3 from agriculture.

Emission of NH_3 from agriculture originates from animal manure, synthetic fertilisers, wastewater sludge, agricultural crops and straw leaching. The contribution of the individual sources for 1997 is given in Table 6.1.1. The sources animal manure, agricultural crops and straw leaching account for 86 kt (76%), 22 kt (20%) and 5 kt (4%) respectively. The sources are independent of each other and are in the following treated separately.

Table 6.1.1 Emission of NH_3 by sources in 1997.

	N-input (kt N)	Share of N-input evaporated as NH_3	Emission in 1997 (kt NH_3)
Animal manure			**86,13**
Animals at stable	240,8	28,6%	83,63
Animals grazing	29,5	7,0%	2,51
Agricultural crops			**22,17**
Direct emission from crops			13,95
Synthetic fertilisers	287,6	2,3%	8,03
Wastewater sludge and industrial waste	8,1	1,9%	0,19
Straw leaching	7,8	65%	**5,07**
Total			**113,37**

Data from CORINAIR 1997 and Andersen, J.M. et al. (1999).

Emissions related to animal manure.
Emission of NH_3 from animal manure depends on the nitrogen content of the manure and the share of the N evaporated as NH_3. As is seen from Table 6.1.1 for animals at stable in 1997,

total N-input was about 241 kt N and the average share evaporated as NH_3 was 28,6%. However, both the N-input and the share evaporated depend on the size and composition of the animal livestock. In addition the share evaporated depends on the management of the manure, that is the type of stable, storage facilities and the time and technology used for spreading the manure.

In the model, emission from animal manure including emission from animal grazing is calculated as:

$$NH_3^{man} = k_0^{man} + \sum_i NH^i \cdot kNH_3^{i,man} \qquad \textbf{(6.1.1)}$$

NH_3^{man}	total emission of NH_3 from animal manure in kg NH_3
NH^i	number of heads in animal category *i*
$kNH_3^{i,man}$	aggregated NH_3 emission coefficient for animal category *i* in kg NH_3 per head
k_0^{man}	a constant for emissions from minor contributors not distinguished in the model

The aggregated emission coefficient for the individual animal categories is calculated from N ab animal, the fraction of the manure deposited under various conditions, and for each condition the share evaporated as NH_3, that is:

$$kNH_3^{i,man} = \left[N^i \cdot \sum_j Frac^{i,man\,j} \cdot sNH_3^{i,man\,j} \right] \cdot 17/14 \qquad \textbf{(6.1.2)}$$

N^i	the nitrogen ab animal in category *i* in kg N per head
$Frac^{i,man\,j}$	the fraction of the manure from animal category *i* deposited under condition *j*
$sNH_3^{i,man\,j}$	the share of the nitrogen from animal category *i* deposited under condition *j* that is evaporated as NH_3
17/14	a conversion factor from N to NH_3 (the molecular weight of NH_3 divided by the molecular weight of N)

For the individual animal categories, the emission coefficients are calculated in Annex 6.1.1 and for 1997 and 2003 emission coefficients and total emissions, assuming a constant number of animals, are shown in Table 6.1.2. Concerning emission coefficients for 2003 the calculation assumes full implementation of the Danish Action Plan on the Aquatic Environment (II). In relation to the situation in 1997, the coefficients for 2003 assume covering of slurry tanks, the definition of a maximum period of twelve hours between the addition of manure to un-vegetated soil and ploughing and changes in manure addition practice. In the model these changes are introduced via exogenous reductions of the share of N evaporated as NH_3. As is seen from Annex 6.1.1 evaporation rates are reduced for all animal and deposition categories except for animal grazing. The evaporation rate for animal grazing is a rough estimate; emission from this category is of minor importance and the effect of the action plan is uncertain.

Table 6.1.2 NH_3 emissions from animals in 1997 and 2003 assuming a constant number of animals.

Animal	Heads in 1997	Year 1997		Year 2003	
		Emission coefficient kg NH_3/animal/year	Emission ton NH_3	Emission coefficient kg NH_3/animal/year	Emission ton NH_3
Dairy cows	670354	29,31	19648	23,60	15820
Slaught. calves	369028	12,51	4615	9,99	3687
Heifers	839744	8,32	6988	6,90	5794
Nurce cows	125085	12,87	1609	10,87	1360
Sows	1068473	9,42	10062	7,69	8217
Fattening pigs	10074609	3,05	30770	2,52	25388
Poultry	18993560	0,33	6211	0,30	5622
Fur animals	2212811	2,48	5488	2,43	5377
Horses	38862	11,98	466	10,03	390
Ovines	64820	4,25	275	3,68	239
Total			86132		71893

See calculations in Annex 6.1.1

From Table 6.1.2 it can be seen that the major sources are the cattle and the pig sectors, accounting for 38% and 47% respectively of the NH_3 emission from animal manure in 1997. Poultry and fur animals each contribute with about 7%, while horses and ovines account for less than 1%. That is, the animal sectors in ESMERALDA account for about 92% of the NH_3 emissions related to animal manure. Concerning changes from 1997 to 2003, on average emission coefficients decrease by 18%. Emission coefficients for poultry decrease considerably less and for fur animals the coefficient is almost constant. The largest decrease is seen for sows, which is due to a large share of the manure being liquid, the required coverage of slurry tanks and changes in manure addition practice. Assuming a constant number of animals, total emission is reduced equal to the average for the coefficients. However, as the number of dairy cows and pigs in the Action Plan is expected to decrease (assuming unchanged milk quota and increased milk production per cow and increased productivity per sow) actual emissions of NH_3 from animal manure are expected to decrease further.

Emissions related to agricultural crops.

As is seen from Table 6.1.1 emissions from agricultural crops comprise direct emission from plants, emission from the addition of synthetic fertilisers and emissions from wastewater sludge and industrial waste used as fertilisers.

Direct emission from plants.

Plants may both emit to and fix NH_3 from the atmosphere, and the size and direction of the ammonia transport depends on the crop, the nitrogen in the plant, climatic factors, the concentration of ammonia in the air and the addition of fertilisers. Empirical estimates of NH_3 emissions from fields show considerable variations, both for fields with the same crop and for the various crops. It is therefore not possible to give specific estimates for various crops, and in the model only rough estimates per ha are used. For conventional arable land, crop emissions are set to 5 kg N per ha (6.07 kg NH_3 ha^{-1}) and for grass and organic farmed land emissions are set to 3 kg N per ha (3.64 kg NH_3 ha^{-1}). Emissions from fallow land are assumed to be zero. The difference between conventional arable crops and grassland or organic farming is ascribed to a difference in the addition of fertilisers. For organic farming the nitrogen supply is mainly based on mineralised nitrogen, which is supplied more in phase with the needs of the plants, and therefore gives a reduced emission of ammonia.

For 1997 and 1998 the direct emissions from crops are given in Table 6.1.3. As can be seen from the table, conventionally-farmed arable crops are by far the largest contributor and a substitution to increased grass, organic farming and fallow will reduce the direct emissions from crops.

Table 6.1.3 Direct emissions from crops in 1997, 1998 and estimate for 2003

Year	Emission coef.	1997		1998		2003	
Crop	kg NH3 ha-1	ha	ton NH3	ha	ton NH3	ha	ton NH3
Conventional arable crops	6,07	1949308	11832	1912621	11610	1840962	11175
Grass excl. fallow	3,64	544322	1981	566098	2061	544888,3	1983
Organic farming excl. fallow	3,64	36844	134	42237	154	185000	673
Fallow	0	157540	0	150894	0	47000	0
Total		2688014	13948	2671850	13824	2617850	13831

Data from Andersen, J.M. et al. (1999) p. 36-37 and Statistics Denmark (1999) Table 278.

For year 2003 the calculation in Table 6.1.3 assumes full implementation of the Action Plan for the Aquatic Environment II. According to this, the arable land is assumed reduced by 54.000 ha (20.000 ha is used for forest, 16.000 ha is used for establishment of wetlands and 18.000 ha SFL-area sensitive areas for the protection of groundwater contamination by nitrogen leaching) is taken out of rotation.) In addition the area of organic farming is assumed to increase to 170.000 ha and for 15.000 ha SFL-area the manure standard for nitrogen is reduced by 40%, which is evaluated as having the same NH_3 emission coefficient as organic farming (the 185.000 ha organic farming of Table 6.1.3) Furthermore, the area of fallow land is reduced to 47.000 ha, which counterweights the reduction of NH_3 emissions. Finally, assuming an unchanged distribution between conventional arable crops and grass, the net effect of the Action Plan is an almost unchanged direct emission of NH_3 from crops. (The effect for the direct emissions from crops of reducing the general nitrogen manure standard by 10% is evaluated to be minor and is therefore not included in the calculation in Table 6.1.3.).

Emission from addition of synthetic fertilisers

NH_3 emissions from the use of synthetic fertilisers are dependent on the composition of the fertilisers, the spreading practice and environmental conditions. Evaporation of NH_3 from different synthetic fertilisers varies from 0 to 30% of the nitrogen content of the fertiliser, however, for the fertilisers mainly used in Denmark the evaporation is fairly limited. For the present use of synthetic fertilisers, the average evaporation is estimated to be 2,3% of the nitrogen content. According to the Action Plan on the Aquatic Environment II the use of synthetic fertilisers is assumed to be reduced by approximately 40%. The use of synthetic fertilisers is, however, forecasted by ESMERALDA. Due to the reduced nitrogen manure standard, it is evaluated that fertilisers with large evaporation potentials are replaced by fertilisers with lower evaporation rates. On average the NH_3 evaporation rate is expected to decrease to 1,7%. As is seen from Table 6.1.4 the total effect of the Action Plan is that emissions from the use of synthetic fertilisers are reduced to approximately half the present level.

Table 6.1.4 Emission from the use of fertilisers.

Year	ton N	% evap.	ton NH3
1997	287.600	2,3	8032
2003	179.500	1,7	3705

Data from Andersen, J.M. et al (1999) p. 49-50

Emission from wastewater sludge and industrial waste used as fertilisers.

As mentioned in chapter 5, sludge from wastewater treatment plants and some waste from industry contain nitrogen and part of this is used as fertilisers. The amount of sludge/waste used as fertilisers and the content of N are given in table 5.2.4 and are rewritten in Table 6.1.5. The NH_3 evaporation for the wastewater sludge and industrial waste is evaluated to be 3% of the total N content; however, if the field is ploughed within 12 hours after the sludge/waste has been spread, evaporation is reduced to only 1,5%. For 1997 it is estimated that 3/4 of the fields were ploughed within 12 hours after spreading and for year 2003 all fields have to be ploughed within 12 hours. Emission related to the use of wastewater sludge and industrial waste is given in Table 6.1.5.

Table 6.1.5 Wastewater sludge and industrial waste used as fertilisers in 1997

Source	kton sludge/waste	N content kg N/ton TS	ton N	NH_3 evap %	ton NH_3
Wastewater sludge	91,8	43,8	4.021	1,9	93
Industrial waste	199,8	20,3	4.056	1,9	94
Total					186

Data N in wastewater sludge and industrial waste used as fertilisers is from Grant, R. et al (1999) and unpublished data from Blicher-Mathiesen, G. NERI.

For forecasts, the amount of N from wastewater sludge and industrial waste used as fertilisers is exogenous; however, as mentioned above, the % evaporated as NH_3 is assumed to decrease to 1,5% in year 2003.

In summary emissions of NH_3 from crops are calculated as:

$$NH_3^{crop} = k_0^{crop} + \sum_i NA^i \cdot kNH_3^{i,crop} + (N^{fert} \cdot sNH_3^{fert}) \cdot 17/14 + (N^{ww} \cdot sNH_3^{ww}) \cdot 17/14 \qquad \textbf{(6.1.3)}$$

NH_3^{crop}	the total emission of NH_3 from crops in kg NH_3
NA^i	the area with crop *i* in ha.
$kNH_3^{i,crop}$	the coefficient for direct emissions from crop *i* in kg NH_3 per ha (see Table 6.1.3)
N^{fert}	the amount of N-input from synthetic fertilisers in kg N
sNH_3^{fert}	the share of synthetic fertilisers evaporated as NH_3 (see Table 6.1.4)
N^{ww}	the amount of N-input from wastewater sludge and industrial waste in kg N
sNH_3^{ww}	the share of wastewater sludge and industrial waste N evaporated as NH_3 (see Table 6.1.5)
k_0^{crop}	a constant for emissions from minor contributors not specified in the model
17/14	a conversion factor from N to NH_3

Emissions related to straw leaching

Emission of ammonia from straw leaching is considerable and depends on the method used for leaching. Traditionally, 3% ammonia is added to the straw, and after ventilation 1%-point of the ammonia is absorbed in the straw, that is, a major part of the ammonia is emitted. A number of empirical estimates of the emission of ammonia for different techniques and conditions for straw leaching are available; however, statistical data for the conditions and actual methods used are not available. Therefore, in the model emissions are roughly estimated to 65% of the ammonia used. The amount of ammonia used for straw leaching is estimated to be 7.800 ton (Andersen, J.M. et al. (1999) p. 48) and assuming that 65% of this is emitted, emissions amount to 5.070 ton NH_3. In the model this amount is exogenous and in a base forecast assumed to be constant.

6.1.2 Emission of NH_3 from road transport

Emission of NH_3 from road transport accounts for 1% of total emissions in 1997; however, due to the introduction of catalytic converters on gasoline driven vehicles this share is expected to increase. The introduction of catalytic converters reduces emissions of VOC, CO and NO_X, but at the optimal conditions for the reduction of CO and NO_X emissions, emission of NH_3 is increased. As for N_2O emissions, in the model we distinguish between vehicles with and without catalytic converters, and the share of vehicles with catalytic converters is calculated by equation 5.2.11 in chapter 5.

For diesel vehicles and lorries an average NH_3 emission coefficient for all categories is used. That is, the model does not distinguish different sizes and types of lorries. Emission coefficients are defined in kg NH_3/GJ fuel used and total emissions from transport are calculated as:

$$NH_3^{transp} = \left(sh_{cat} \cdot kNH_{3cat} + (1 - sh_{cat}) \cdot kNH_{3non-cat}\right) \cdot qJtc1 + kNH_{3diesel} \cdot \sum_i qJt_i + k_0 \qquad \textbf{(6.1.4)}$$

sh_{cat}^t	the share of vehicles with catalytic converters
kNH_{3_j}	the NH_3 emission coefficient for category j (assumed to be constant)
$qJtc1, qJt_i$	the relevant energy consumption variables in EMMA
k_0	emission from other transport sources

The emission coefficients, energy consumption and total emissions related to road transport for 1997 are given in Table 6.1.6.

Table 6.1.6 NH_3 emissions related to road transport in 1997.

	Share of vehicles	Emis. coef. (kNH_3^j) kg NH_3/GJ	Energy cons. (qJt(i)) TJ	NH_3 emissions (ton NH_3)
Vehicles with catalytic converters	0,440	0,0380		
Vehicles with no catalytic converters	0,560	0,0008	83830	1439
Diesel vehicles		0,0005	62200	31
Total				**1470**

Source: Data from CORINAIR and unpublished data from Winther, M. NERI

Annex 6.1.1 Calculation of NH_3 emission coefficients for animal categories.

Animal	Type of manure	N ab animal kg N/ animal/year N^i	Share of manure % $Frac^{i,man\ j}$	NH_3 evap % $sNH_3^{i,man\ j}$	Emission coefficient kg NH_3/ animal/year $kNH_3^{i,man\ j}$	NH_3 evap % $sNH_3^{i,man\ j}$	Emission coefficient kg NH_3/ animal/year $kNH_3^{i,man\ j}$
				Year 1997		Year 2003	
Dairy cows	Solid	125,22	0,27	0,240	8,868	0,200	7,390
	Liquid	125,22	0,67	0,180	16,504	0,140	12,836
	Deep litter	125,22	0,06	0,350	2,874	0,280	2,299
	Total in stable	125,22	1	0,206	28,245	0,165	22,525
	grazing[1]	125,22	0,1	0,070	1,064	0,070	1,064
	Total				**29,310**		**23,589**
Slaught calves	Solid	33,66	0,06	0,24	0,589	0,200	0,490
	Liquid	33,66	0,22	0,18	1,619	0,140	1,259
	Deep litter	33,66	0,72	0,35	10,300	0,280	8,240
	Total		1	0,306	**12,507**	0,244	**9,989**
Heifers	Solid	35,12	0,06	0,240	0,338	0,200	0,281
	Liquid	35,12	0,27	0,180	1,140	0,140	0,887
	Deep litter	35,12	0,67	0,350	5,500	0,280	4,400
	Total in stable	35,12	1	0,298	6,978	0,237	**5,568**
	grazing	35,12	0,45	0,070	1,343	0,070	1,343
	Total				**8,321**		**6,912**
Nurse cows	Solid	57,07	0,1	0,240	0,715	0,200	0,596
	Deep litter	57,07	0,9	0,350	9,387	0,280	7,509
	Total in stable	57,07	1	0,339	10,102	0,272	**8,105**
	grazing	57,07	0,57	0,070	2,765	0,070	2,765
	Total				**12,867**		**10,870**
Sows	Solid	25,7	0,12	0,400	1,468	0,360	1,321
	Liquid	25,7	0,77	0,270	6,358	0,210	4,945
	Deep litter	25,7	0,11	0,460	1,547	0,410	1,379
	Total in stable	25,7	1	0,307	9,374	0,250	**7,646**
	grazing	25,7	0,02	0,070	0,044	0,070	0,044
	Total				**9,417**		**7,689**
Fattening pigs	Solid	8,14	0,3	0,400	1,186	0,360	1,068
	Liquid	8,14	0,7	0,270	1,868	0,210	1,453
	Total			0,309	**3,054**	0,255	**2,520**
Poultry	Solid	0,609	0,2	0,390	0,058	0,340	0,050
	Liquid	0,609	0,05	0,230	0,009	0,200	0,007
	Deep litter	0,609	0,75	0,470	0,261	0,430	0,238
	Total		1	0,442	**0,327**	0,401	**0,296**
Fur animals	Solid	4,59	0,5	0,200	0,557	0,190	0,529
	Liquid	4,59	0,5	0,690	1,923	0,680	1,895
	Total			0,445	**2,480**	0,435	**2,425**
Horses	Deep litter	45,9	1	0,360	10,032	0,290	8,082
	Total in stable	45,9	1	0,360	10,032	0,290	
	grazing	45,9	0,5	0,070	1,951	0,070	1,951
	Total				**11,983**		**10,032**
Ovines	Deep litter	21,9	1	0,360	2,968	0,290	2,391
	Total in stable	21,9	1	0,360	2,968	0,290	
	grazing	21,9	0,69	0,070	1,284	0,070	1,284
	Total				**4,252**		**3,675**

Data for N ab animal is from Andersen, J.M. (1999) Table 4.2. The share evaporated and the share deposited as solid, liquid, deep litter and from animal grazing are from Andersen, J.M. et al (1999) Annexes 5 and 2 and unpublished data from J.M. Andersen.

7. Eutrophication of the aquatic environment

Eutrophication of the aquatic environment is caused by discharge of nutrients leading to increased production of phytoplankton, algae and higher aquatic plants, which in turn leads to deterioration of water quality, oxygen deficit and a reduction in the utility of the aquatic area. In Denmark the negative effects of eutrophication are generally greatest in lakes and fjords, as well as in coastal and open marine areas (see Christensen et al (1994) chapter 2.4). In watercouses eutrophication is of minor importance. The nutrients causing eutrophication of the aquatic environment are nitrogen (N) and phosphorus (P). For lakes the limiting factor for the growth of phytoplankton is phosphorus, and for open marine areas the growth is limited by the nitrogen available (see Holten-Andersen et al (1998) chapter 2.4.4 and 2.4.5). The main sources of nutrients discharged to the aquatic environment are leaching from agricultural land and point source discharges i.e. wastewater from municipal and industrial sewage treatment plants. Another source is atmospheric deposition; however, the contribution from this source is minor and relatively constant.

In the mid 1980s serious episodes of oxygen deficit in marine waters led to the adoption of the Action Plan on the Aquatic Environment in 1987. The aim of this plan was to reduce the nitrogen and phosphorus discharges to the aquatic environment by 50% and 80% respectively, among other things by improving sewage treatment and reducing total agricultural consumption of fertilisers (see Christensen, N. et al (1994) p. 70).

The specific eutrophication of a given aquatic environment depends on the amount of nutrients discharged by the catchment area of the aquatic environment in question, and this varies considerably between different parts of Denmark. In addition, for agriculture, alongside the amount of fertilisers used and the nutrients in the harvest, leaching from agricultural land depends on the type of soil and the cultivation method.

In this chapter we look at the development in aggregated indicators for the load with nutrients at a national level. It is not the intention to look at discharges from specific catchment areas to specific lakes or marine waters, and the link from the aggregated indicators to actual eutrophication is not included. To relate the aggregated indicators to actual eutrophication in specific aquatic environments, complex biological models are needed, and this is beyond the present modelling. However, at the aggregated level the development of the indicators suggests whether the need for actions becomes increasingly urgent or not.

7.1 Discharges of nitrogen (N) and phosphorus (P)

The main sources of nitrogen and phosphorus discharged to the aquatic environment are leaching from agricultural land and point source discharges. In this chapter emission from agricultural areas is described only by nitrogen and phosphorus balances, which gives the loss-potential from agricultural land and not the actual leaching causing eutrophication. Discharges from point sources are discharged directly into the aquatic environment and contribute more directly to the eutrophication of the aquatic environment. That is, figures for the two sources may not be added and are treated separately.

7.1.1 N and P from agriculture (N- and P-balances for agriculture)

The N- and P-balances for agricultural land calculated in this chapter are field balances aggregated to national figures. The balance is the difference between the amount added to fields and the amount removed via the harvest, and for N the amount evaporated. This difference gives the potential loss to the aquatic environment and contains leaching from the root-zone, changes in the stock in the soil and for N, denitrification. To move from the balance to the loading and eutrophication of various aquatic environments, part of the N and P is converted/used before it reaches the lakes and marine environment where eutrophication is a problem. In addition, the time lag from a change in the balance to an observable change in the loading of the aquatic environment is considerable, and annual variations in the loading of a given aquatic environment are more dependent on weather conditions than on changes in the balance. In wet years nitrogen and phosphorus run-off, and hence the loading, are relatively high and in dry years the run-off and loading are relatively small.

The N- and P-balances for 1997 are given in Table 7.1.1. As can be seen from the table, input to the land consists of animal manure, synthetic fertilisers, and wastewater sludge and industrial waste used as fertilisers. For N, N-fixation and atmospheric deposition also add to the input. Removals comprise N and P in the harvest and for N, evaporation of NH_3 and N_2O. For nitrogen the majority of these sources and removals are either directly or implicitly modelled in the chapters 5 and 6.

Table 7.1.1 N and P-balances for agricultural land in 1997

Source	kt N	ktP
Input, total	696,7	83,2
Animal manure	270,3	54,4
Synthetic fertilisers*	287,6	23,3
Wastewater sludge and industrial waste	8,1	5,5
N-fixation	37,0	
N-deposition	93,7	
Removed, total	*473,9*	*53,6*
Harvest	361,3	53,6
Total NH_3 evaporation	93,7	
N_2O evaporation	18,9	
Balance	222,8	29,6

*Includes 5.8 kt N and 1 kt P used at golf courses.

Input from animal manure

Input from animal manure is calculated from norm figures for the annual N and P content per animal and as such depends on the size and composition of the livestock, i.e. total N and P from animal manure is calculated as:

$$N^{man} = \sum_i NH^i \cdot kN^{i,man} \qquad \textbf{(7.1.1)}$$

$$P^{man} = \sum_i NH^i \cdot kP^{i,man}$$

N^{man}, P^{man}	the total animal manure N and P ab animal in kg
NH^i	the number of heads in animal category i
$kN^{i,man}$, $kP^{i,man}$	N and P ab animal for animal category i in kg per head

N and P coefficients per animal and total emission for 1997 are given in Table 7.1.2. Concerning forecasts, the N and P coefficients are assumed to be constant.

Table 7.1.2 N ab animal in 1997

Animal	Heads in 1997 NH^{i}	Emission coefficient kg N/animal/year $kN^{i,man}$	Emission ton N $N^{i,man}$	Emission coefficient kg P/animal/year $kP^{i,man}$	Emission ton P $P^{i,man}$
Dairy cows	670354	125,22	83942	22,47	15063
Slaught. calves	369028	33,66	12421	6,80	2509
Heifers	839744	35,12	29492	4,59	3854
Nurse cows	125085	57,07	7139	7,46	933
Sows	1068473	25,70	27460	7,10	7586
Fattening pigs	10074609	8,14	82007	1,82	18336
Poultry	18993561	0,61	11567	0,14	2564
Fur animals	2212811	4,59	10157	0,90	1992
Horses	38862	45,90	1784	7,30	284
Ovines	64820	21,90	1420	3,65	237
Other animals			2916		993
Total			270304		54351

Data for N ab animal is from Andersen, J.M. (1999) Table 4.2. Data for P ab animal is based on unpublished data from Andersen, J.M. NERI.

Input from synthetic fertilisers

The use of fertilisers is forecasted by ESMERALDA; however, according to the Action Plan on the Aquatic Environment II, the use of N in synthetic fertilisers is assumed to be reduced by approximately 40%, from 287.6 kt N in 1997 to 179,5 kt N in the year 2003.

Input from wastewater sewage and industrial waste used as fertilisers

As mentioned in chapter 5, sludge from wastewater treatment plants and some waste from industry contain nitrogen and phosphorus, and part of this is used as fertilisers. The amount of N and P in sewage and industrial waste used as fertilisers is calculated in relation to the annual monitoring programme for the aquatic environment. (Grant, R. et al 1999) For wastewater sewage the N content is estimated to 43,8 kg N per ton dry-weight, and industrial waste is evaluated to have an N content of 20,3 kg N per dry-weight. The P content per ton dry weight is estimated to 30,2 kg for wastewater sewage and 13,4 kg for industrial waste. For 1997, wastewater sewage of 91.8 kt dry weight and industrial waste of 199.8 kt were used as fertilisers. The N and P content is given in Table 7.1.3.

Table 7.1.3 Wastewater sludge and industrial waste used as fertilisers in 1997

Source	Sewage/waste ton	N content kg N/ton TS	ton N	P content kg P/ton TS	ton P
Wastewater sewage	91.845	43,8	4.023	30,2	2.774
Industrial waste	199.777	20,3	4.063	13,4	2.681
Total			8.086		5.455

Data: N and P in wastewater sludge and industrial waste used as fertilisers is from Grant, R. et al (1999) and unpublished data from Blicher-Mathiesen, G. NERI.

Concerning forecasts, the amount of N and P from wastewater sludge and industrial waste used as fertilisers is exogenous.

N-fixation

As mentioned in chapter 5, nitrogen fixing crops, mainly pulses and clover fix nitrogen from the air. In addition N is fixed by free-living micro-organisms. This adds to the N input of agriculture. For the crop categories of ESMERALDA, N-fixation is treated in section 5.2.1, and figures for the amount of N fixed are given in Table 5.2.6.

The amount of N added to agricultural land by N-fixation is calculated as:

$$N^{fix} = \sum_i NH^i \cdot kN^{i,fix} \qquad \textbf{(7.1.2)}$$

N^{fix}	the amount of N fixed by crops in ton N
NH^i	the harvest of nitrogen fixing crop i/area of corp in kt or 1000 ha
$kN^{i,fix}$	the N-fixation factor for crop i in kg N per ton harvest

N-deposition
According to the IPCC Guidelines used for the calculation of N_2O emissions (chapter 5.2), it is assumed that the deposition of N equals the emission of NH_3 measured in kg N. As is seen from Table 7.1.1, this implies that the deposition of N is counterbalanced by the evaporation of NH_3.[14]

N and P removed by harvest
The N and P contained in the harvest and thereby removed from the soil are calculated from the amount harvested of the different crops, and norm figures for the content of the various crops. The norm figures are based on chemical analysis and measurements of nutrients in the various crops. That is, the total N and P removed via harvest is calculated as:

$$N^{harv} = k_0^{harv} + \sum_i NH^i \cdot kN^{i,harv} \qquad \textbf{(7.1.3)}$$

$$P^{harv} = k_0^{harv} + \sum_i NH^i \cdot kP^{i,harv}$$

N^{harv} and P^{harv}	the total N and P in the harvest
NH^i	the harvest of crop i in tons
$kN^{i,harv}$ and $kP^{i,harv}$	the N and P content of crop i measured in % of the harvest
$k_0^{harv,N}$ and $k_0^{harv,P}$	the constant terms representing ton N and P in crops not specified in the model

For 1997 the harvest, the N and P content and the total N and P in the harvest is given in Table 7.1.5. Looking at the table, it can be seen that both the N and the P content vary considerably between crops, and that for both substances the major contributors are grain crops and grass.

[14] In standard calculations of field balances, deposition of N is normally assumed to be an amount per ha. In Grant, R. et al (1999), for Denmark the deposition is assumed to be 21 kg N/ha.

Table 7.1.5 N and P in the harvest in 1997

Crop	Harvest kton	N-factor (kN_i) N %	N in harvest kton N	P-factor (kP_i) P %	P in harvest kton P
Wheat	4965	1,968	97,71	0,323	16,04
Other grain crop	4563	1,682	76,76	0,344	15,70
Pulse	384	3,369	12,95	0,068	0,26
Rape	291	3,756	10,94	0,828	2,41
Maize for silage	1649	0,486	8,01	0,069	1,14
Other silage cereals (N-fixing)	3275	0,613	20,08	0,062	2,03
Potatoes	1545	0,353	5,45	0,053	0,82
Sugar beets	3367	0,208	7,00	0,031	1,04
Fodder beets	2503	0,213	5,33	0,031	0,78
Rot grass	9256	0,550	50,91	0,066	6,11
Perm. Grass	4425	0,550	24,34	0,061	2,70
Straw	3763	0,536	20,17	0,068	2,56
Other crop			21,66		2,03
Total			361,31		53,61

Data: Grant, R. et al (1999) and unpublished data from Grant, R.,NERI

N evaporated as NH_3 and N_2O

Part of the N input is evaporated as NH_3 or N_2O, and therefore does not contribute to the potential leaching of N to the aquatic environment. However, atmospheric deposition of N is included. As is seen from Table 7.1.1, in this model (according to IPCC guidelines) atmospheric deposition is assumed to be equal to agricultural emission/evaporation of NH_3.

Evaporation of NH_3 and N_2O is given in chapter 5.2 and 6.1, Table 5.2.1 and 6.1.1, and is in Table 7.1.1 converted from tons NH_3 and N_2O to tons N.

7.2.1 Point source discharges of N and P

Point sources discharge nutrients directly into aquatic environments and thereby contribute to the eutrophication of the aquatic environment. Since the mid 1980s, discharge of N from point sources has reduced by about 66%, and discharge of P has reduced by 91%. Today point sources contribute to the N loading of the fresh waters with 6% and of the marine waters with 4% of the total loading. For the loading with P, point sources contribute with 30% for the fresh water and 21% for the marine waters. (Punktkilder 1998, chapter 9) The considerable reductions are due to Action Plans on the Aquatic Environment that among other things have occasioned massive investments in both municipal and industrial sewage treatment plants.

For the years 1997 and 1998, N and P discharges from individual point sources are given in Table 7.2.1. The major point source is sewage treatment plants; however, rural housing, industrial point sources and fish farming are also important sources.

Table 7.2.1 N and P discharges from point sources in 1997 and 1998

Source	N-input (ton N) 1997	P-input (ton P) 1997	N-input (ton N) 1998	P-input (ton P) 1998
Sewage treatment plants	4.853	666	5.166	601
Rain water overflow*	801	204	968	254
Rural housing	1.119	255	999	228
Industrial point sources	1.801	145	1.428	124
Fishfarming	1.494	122	1.531	125
Total	10.068	1.392	10.092	1.332

*In normal years 847 ton N and 217 ton P.

Source: Data from Punktkilder (Point Sources) 1997 and 1998.

Sewage treatment plants

In 1998 the number of sewage treatment plants was 1475, of which 1190 were municipal plants. The rest were private plants. However, the amount of sewage treated by private plants was less than 1% of the total sewage treated. Over time the number of treatment plants has decreased, as small and older plants have been replaced by larger plants with improved treatment facilities. In 1998 about half of all sewage was treated by the 25 largest plants.

Inflow to sewage treatment plants comes from both private households and various industries, and the inflow from these categories is quite different with respect to organic content and load of other contaminents. In order to aggregate sewage from different categories, sewage is weighted according to the oxygen required for decomposing the organic matter in the water. The standard measure used is person equivalents (PE), defined as 1 PE = 60g BI_5 (BI_5 is the five-day biochemical oxygen demand for decomposing organic matter in a water sample.)

In 1998 the total load on sewage treatment plants was 8.8 mill PE, and over the period 1989 to 1998 the load has varied between 8.2 and 9.4 mill PE. About 52% of the load comes from households and 48% is from industrial sources. In 1998 the amount of water treated was 243 l/PE per day or about 802 mill. m^3. In addition to household and industrial wastewater, the amount of water includes rainwater and water seeping into the sewage system. In normal years rainwater discharged via sewage treatment plants is estimated to 92 mill. m^3.

The treatment of sewage for N and P differs for various types of treatment plants. However, about 85% of sewage is treated in plants that remove about 90% of both N and P. Table 7.2.2 gives the loading, cleaning and discharge from sewage treatment plants in 1997 and 1998. As is seen from the table, the number of PE has increased from 1997 to 1998 and this has implied a corresponding increase in the amount of N discharged from the sewage treatment plants. However, for P the amount has decreased, which is ascribed to an increase in the treatment efficiency of the treatment plants. In Table 7.2.2, treatment efficiencies are calculated from reported discharges and calculated amounts in the inflow. In "Punktkilder 1998" efficiencies for the different types of treatment plants and the amount of water treated by the individual types of plants are given. Using this information, average cleaning efficiencies are slightly lower than the efficiencies given in Table 7.2.2 (about 2%). However, the data on inflow, treatment efficiencies and actual discharges are fairly uncertain.

Table 7.2.2. Loading, cleaning and discharge from sewage plants in 1997 and 1998

	Person equivalents (PE)	N in inflow gN/PE/dag	P in inflow gP/PE/dag	Inflow ton N	Inflow ton P	Cleaning efficiency % N	Cleaning efficiency % P	Discharge ton N	Discharge ton P
1997	8238526	9,5	2,3	28567	6916	0,83	0,9037	4853	666
1998	8769012	9,5	2,3	30407	7362	0,83	0,9184	5166	601

Source: Data from Punktkilder 1997 and 1998.

Discharges of N and P from sewage treatment plants are calculated as:

$$N^{sew} = PE \cdot kN^{PE} \cdot 365 \cdot (1 - kN^{clean}) \quad \textbf{(7.2.1)}$$

$$P^{sew} = PE \cdot kP^{PE} \cdot 365 \cdot (1 - kP^{clean}) \quad \textbf{(7.2.2)}$$

N^{sew} and P^{sew} discharges of N and P from sewage treatment plants in ton
PE the numbed of person equivalents
kN^{PE} and kP^{PE} the inflow of N and P per person equivalents per day in ton
kN^{clean} and kP^{clean} cleaning efficiencies in %

Inflow coefficients and cleaning efficiencies are exogenous variables. The number of PE is forecasted as

$$PE = PE^{housholds} + PE^{industry} \qquad \textbf{(7.2.3)}$$
$$PE^{households} = k^{h} \cdot U$$
$$PE^{industry} = k^{i} \cdot fXn$$

U	the population in persons
fXn	production in manufacturing in mill. DKK 1990 prices

Table 7.2.2b Forecast coefficients for person equivalents

	1997	1998
PE	8.238.526	8.769.012
$PE^{households}$	4284033,5	4559886,2
$PE^{industry}$	3954492,5	4209125,8
U	5.284.000	5.301.000
fXn	465.992	474.875
k^{h}	0,811	0,860
k^{i}	8,486	8,864

Source: Data for U and fXn ADAM databank

The forecast of discharges from sewage treatment plants is interpreted as a long term trend and is not intended to reflect annual changes that are heavily dependent on the amount of rain water running through the system.

Rainwater overflow

Concerning rainwater overflow, two types of sources are distinguished: overflow from sewage treatment plants that contains some sewage, and separate discharges of rainwater that contain plain rainwater. As is seen from Table 7.2.3, the concentration of nutrients in the overflow from treatment plants is considerably higher than in plain rainwater from separate discharges. In wet years such as 1998, rainwater overflow and therefore also discharge of nutrients are relatively large, while in dry years like 1997 discharges are relatively small. However, as the capacity on sewage treatment plants increases, discharge of nutrients from rainwater overflow decreases.

Table 7.2.3 Discharges related to rain water

Year		Overflow sewage plants	Separate rain water discharges	Total
Normal assuming the capacity in 1998	Water 1000 m^3	43.067	150.611	193.678
	mg N/l	12,0	2,0	
	mg P/l	3,24	0,49	
	ton N	516	308	824
	ton P	140	74	213
1997	Water 1000 m^3	43.526	144.861	188.387
	mg N/l	11,8	2,0	
	mg P/l	3,1	0,5	
	ton N	513	288	801
	ton P	133	72	206
1998	Water 1000 m^3	52.996	190.701	243.697
	mg N/l	11,3	1,9	
	mg P/l	3,0	0,5	
	ton N	597	371	968
	ton P	160	94	254

Source: Data from Punktkilder 1997 and 1998. Annex 3.2 and 3.3.

Concerning the forecast, discharges from rainwater overflow are exogenous and calculated assuming a normal year. Overflow from sewage treatment plants is expected to decrease slightly as treatment capacity increases, while discharges from separate rain water discharges are fairly constant.

Rural housing

Rural housing consists of houses with separate drainage systems not connected to collective sewage treatment plants. Included in this category are houses in rural areas and summer houses. For these houses a number of sewage treatment systems with different discharge/N and P cleaning characteristics are available. Collection tanks and seep drainage give a 100% cleaning of N and P and are used at most summer houses and about 40% of rural houses. For the remainder of the rural and summer houses a large number of sewage treatment systems are available. Typical treatment systems are:

- mechanical cleaning (cleaning only 10% of the N and P)
- mechanical cleaning with field drainage (cleaning 55% of the N and P), and
- collection tanks for toilet sewage and mechanical cleaning of other sewage (cleaning 90% of the N and 80% of the P)

The calculation of discharges of N and P for 1997 and 1998 is given in Table 7.2.4.

Table 7.2.4 Discharge of N and P from rural housing in 1997 and 1998.

	1997 Rural housing	1997 Summer houses	1997 Total	1998 Rural housing	1998 Summer houses	1998 Total
No. of houses	232.100	116.500	348.600	230.800	115.600	346.400
No. of houses with coll. or seep drain	89.100	103.300	192.400	86.339	102.291	188.630
No. of houses with discharge	143.000	13.200	156.200	144.461	13.309	157.770
Person equivalents per house (PE)*	2,8	0,625		2,8	0,625	
N loading (4,4 kg PE^{-1})	2859472	320375	3.179.847	2843456	317900	3.161.356
P loading (1,0 kg PE^{-1})	649880	72813	722.693	646240	72250	718.490
N cleaning for houses with discharge %	0,375	0,500		0,448	0,555	
P cleaning for houses with discharge %	0,375	0,380		0,447	0,450	
N discharge in kg N	1101100	18150	1.119.250	982605	16287	998.892
P discharge in kg P	250250	5115	255.365	223683	4575	228.258

Source: Data from Point Sources 1997 and 1998.

As is seen from the table, the number of rural houses and summer houses has decreased slightly; however, the increase in houses with discharges is mainly due to better information on rural houses. The number of person equivalents is assumed to be 2,8 for rural houses and 2,5 for summer houses; however, summer houses are used for only 3 months per year, which gives an annual loading of 0,625 PE. Annual loading per PE is assumed to be 4,4 kg N and 1,0 kg N. The degree of cleaning is a weighted average of the cleaning % for the used sewage treatment systems. As can be seen, the cleaning % is increasing, and due to sewage treatment plans for rural areas, the cleaning % is expected to increase further. According to plans, about 40% of the rural housings with discharges are expected to change their sewage treatment systems in order to reduce discharges of N and P.

The equations for discharges of N and P from rural houses are given in eq. 7.2.4 and 7.2.5.

$$N^{rural} = \sum_i NH^{i,rural} \cdot PE^{i,rural} \cdot kN^{rural} \cdot \frac{NH^{i,disc}}{NH^{i,rural}} \cdot \left(1 - cN^{i,rural}\right) \qquad \textbf{(7.2.4)}$$

$$P^{rural} = \sum_i NH^{i,rural} \cdot PE^{i,rural} \cdot kP^{rural} \cdot \frac{NH^{i,disc}}{NH^{i,rural}} \cdot \left(1 - cP^{i,rural}\right) \qquad \textbf{(7.2.5)}$$

N^{rural} and P^{rural}	are discharge of N and P from rural housings
$NH^{i,rural}$	the number of rural houses (i = rural housing or summer houses)
$PE^{i,rural}$	the person equivalents per house (2,8 for rural houses and 0,625 for summer houses)
kN^{rural} and kP^{rural}	the N and P loading per PE (4,4 kg N PE^{-1} and 1,0 kg P PE^{-1})
$\frac{NH^{i,disc}}{NH^{i,rural}}$	the share of houses with discharge
$cN^{i,rural}$ and $cP^{i,rural}$	the N and P cleaning %

Concerning forecasts, projections of the number of rural - and summer houses, the share of houses with collection tanks and seeping and the cleaning % for houses with discharges are exogenous.

Industrial point sources

Industrial point sources include firms with specific permission for discharge of water to the aquatic environment. About 100 firms have such permission, and in 1998 they discharged in total 63,5 mill m^3 water, 1428 ton N and 124 ton P, most of which were discharged to the marine environment. Discharges from aggregated branches for 1997 and 1998 are given in Table 7.2.5. As is seen from the table, the largest contributor is the fish industry; however, contributions from production of paper and cellulose as well as sugar are also considerable. Looking at the development from 1997 to 1998, considerable reductions are observed for "paper and cellulose" and "fish meal manufacturing". In the case of "paper and cellulose", reductions are due to the closure of pulp production mid-1998, improved cleaning and reduced loading at sources. For fishmeal manufacturing, reductions are due to improved cleaning. In general, future discharges from industrial point sources are expected to decrease, due to improved cleaning and firms/point sources being connected to municipal sewage treatment systems.

Table 7.2.5 Discharges of water, N and P from industrial point sources in 1997 and 1998.

				1997			1998			1998	
Branches	ADAM var.	Prod. in 1998	No. of firms	Water m^3	N ton	P ton	Water m3	N ton	P ton	N coef. kg/mill kr	P coef. kg/mill kr
Chemical industry	fXnk	61230	6	953	20	3	1091	20	3	0,327	0,049
Pesticide industry	fXnk	61230	1	1274	20	10	1253	25	16	0,408	0,261
Paper and cellu.	fXnq	70460	4	3456	236	27	3906	102	7	1,448	0,099
Sugar	fXnf	111465	6	5354	131	14	4889	133	18	1,193	0,161
Fishmeal manuf.	fXnf	111465	4	23972	422	6	24826	276	5	2,476	0,045
Processing of fish	fXnf	111465	21	11167	346	67	11913	386	59	3,463	0,529
Airports	fXqt	98954	10	1800	135	1	2689	98	2	0,990	0,020
Other	fXn	474875	49	15744	491	17	12920	388	14	0,817	0,029
Total			101	63720	1801	145	63487	1428	124		

Source: Data from Point Sources 1997 and 1998.

Discharges from industrial point sources are forecasted according to

$$N^{ps} = \sum_i fX_i \cdot kN^{i,ps} \tag{7.2.6}$$

$$P^{ps} = \sum_i fX_i \cdot kP^{i,ps} \tag{7.2.7}$$

fX_i — the production in 1990 prices for branch i (given in column 2 and 3 of Table 7.2.5)

$kN^{i,ps}$ and $kP^{i,ps}$ — N and P discharge coefficients in kg/mill.kr (given in the last two columns of Table 7.2.5)

The discharge coefficients are exogenous, and are expected to decrease as cleaning is improved and point sources are closed and instead connected to municipal sewage treatment plants. A major uncertainty in the forecast is that production of firms with point source discharges is minor, seen in relation to the production in the ADAM branches used for forecast. This implies that firms with point source discharges may develop quite differently from the aggregated ADAM branch.

Fish farming

Fish farming includes fresh water and salt water fish farming. Discharges of N and P from fish farming are related to the surplus/waste of feed and fish excrements. In total there are about 425 fresh water and 40 salt water fish farms, mainly concentrated in Jutland. Fish farms are regulated by specific allowances for the amount of feed they may use. Measured by employment and production value, fish farms are relatively small and less than 10% of the farms are allowed to use more than 200 tons of feed per year. For 1997 and 1998 the amount of fish produced, the feed used and the discharges of N and P are given in Table 7.2.6. As is seen from the table, the major part of the total production, the use of feed and the discharges of N and P are ascribed to fresh water fish farming. Over time the amount of feed per ton fish produced has declined as fish farms have become more efficient. On average the feed used per ton fish produced has decreased from 1,25 in 1989 to about 1,0 in 1998, and this has reduced discharges from fish farming considerably.

Table 7.2.6 Discharge of N and P from fish farming in 1997 and 1998.

	1997			1998		
	Fresh water	Salt water	Total	Fresh water	Salt water	Total
Production of fish in ton	31.957	5.800	37.757	31.607	7.030	38.637
Use of feed in ton	31.131	7.200	38.331	32.586	8.643	41.229
Discharge of N in ton	1227	268	1.495	1241	290	1.531
Discharge of P in ton	92	30	122	92	33	125

Data from Point Sources 1997 and 1998.

Concerning forecasts, discharges from fish farming are exogenous. Although fish farming is part of the ADAM branch "agriculture etc." the production at fish farms is minor and strictly regulated.

8. Applications of the model complex

Individual blocks of the model are presented in the preceding chapters. In this chapter a few applications of the complete system of satellite models to ADAM are presented. Calculations are based on the complete system of ADAM/EMMA/LADA/ESMERALDA and environmental satellite models. However, the presentation focuses on the satellite models presented in the previous chapters. The applications presented are meant to illustrate types of analyses with the model complex and are not in-depth analyses of specific topics.

The model complex may be used for:

- baseline scenarios/projections where environmental themes/indicators are projected in line with and consistent with economic variables
- sensitivity and multiplier analyses introducing changes at various levels, ranging from general economic changes to specific changes of individual emission factors, the difference being that changes are introduced in different parts of the model complex.

8.1 A baseline projection

Given an economic projection by ADAM/EMMA/LADA/ESMERALDA and specification of a number of additional environmental and technical assumptions, the model complex may be used to calculate the development of environmental indicators. In the present chapter, the economic baseline projection is the projection used by the Ministry of Finance in "En holdbar fremtid Danmark 2010" (A Sustainable Future Denmark 2010). This is supplemented with a new agricultural ESMERALDA scenario and environmental and technical assumptions from specific legislation and sector plans for e.g. the energy, agricultural and waste sectors.[15]

Aggregated economic development is summarised in Table 8.1.1. The overall economic growth is about 1.7% p.a., with the service sectors growing faster than industry. Gross energy consumption of fossil fuels is decreasing considerably and the share of wind power is doubled in the period up till 2010. Still, wind power accounts for only 2% of the gross energy consumption in year 2010.

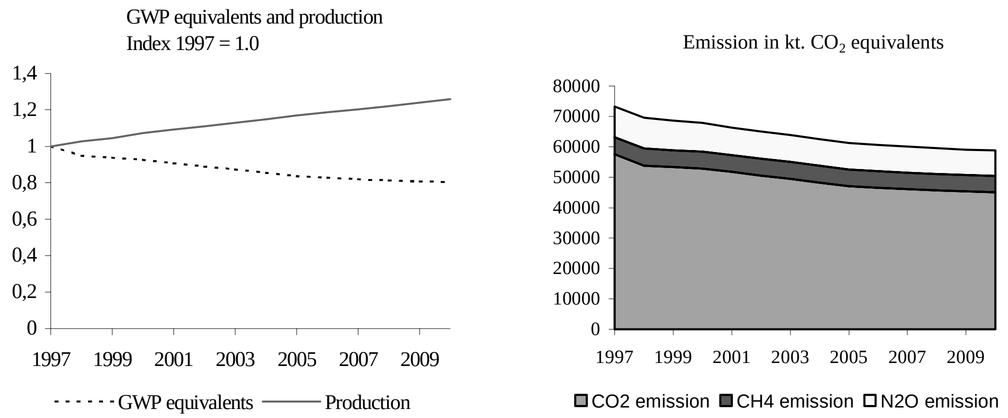
Table 8.1.1 Aggregated economic development.

Index 1997 = 1.0	1997	2000	2005	2010
Population	1,000	1,010	1,022	1,030
Private consumption in constant prices	1,000	1,041	1,150	1,268
Gross domestic product in constant prices	1,000	1,065	1,157	1,238
Gross output in constant prices	1,000	1,073	1,170	1,259
Production in constant prices in:				
Agriculture	1,000	1,038	1,048	1,067
Manufacturing	1,000	1,029	1,129	1,204
Services	1,000	1,120	1,263	1,410
Public service	1,000	1,056	1,125	1,156
Export in constant prices	1,000	1,158	1,416	1,660
Gross energy consumption of fossil fuels in TJ	1,000	0,910	0,862	0,852
Total gross energy consumption in TJ	1,000	0,946	0,917	0,909
Wind energy in TJ	1,000	1,596	1,995	2,234
Share of wind energy	0,0080	0,0136	0,0175	0,0198

[15] Energy 21, the Actionplan on the Aquatic Environment, the Danish Action Plan for a Sustainable Agriculture, Waste 21.

For the environmental themes climate change, acidification and eutrophication, the development in emissions is shown in the Figures 8.1.1 - 8.1.4. The GWP equivalents are expected to decrease, mainly due to the reduced consumption of fossil fuels. This implies a considerable reduction in CO_2 emissions, which in 1997 account for 78% of total GWP equivalents. This share is decreasing as emission of CH_4 and N_2O decrease less. The sources of anthropogenic emission of CH_4 and N_2O are mainly agricultural. Given the increase in agricultural production, emission of CH_4 from agriculture is projected to increase. Emission from enteric fermentation decreases slightly, while emissions from manure management more than counterbalance the decrease. The difference in development is due to a change in the weights of the individual animal groups. The production of pigs increases and the number of cows decreases. The slight decrease in total emission of CH_4 is caused by a considerable decrease in emission from landfills. Due to legislation, deposition rates - especially for organic matter that emits CH_4 during decomposition - are reduced significantly. Emission of N_2O decreases mainly due to a decrease in the use of synthetic nitrogen fertilisers and reduced leaching and run-off of nitrogen. N_2O emission from the animal sector is almost constant, which may be surprising as production and individual emission coefficients increase (due to reduced evaporation of NH_3). However, changes in the composition of animals reduce the total emission from the animal sector.

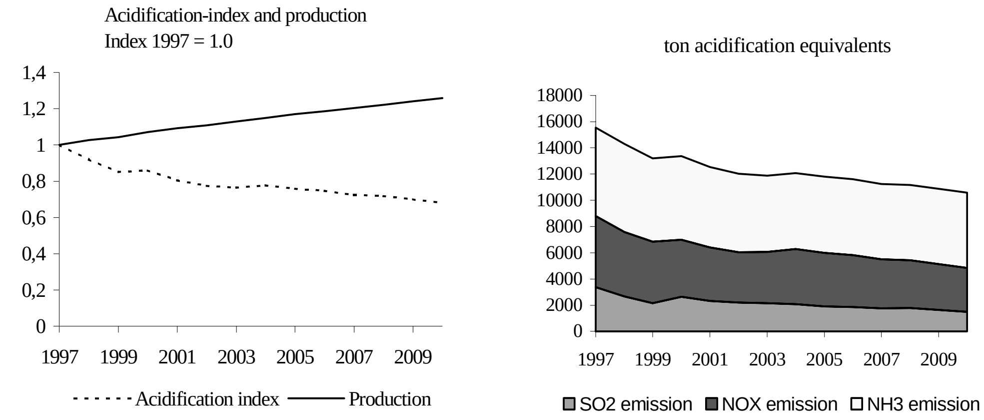
Figure 8.1.1 Emission of greenhouse gases



Emission of acid gases is reduced quite substantially to about 65% of the emission in 1997. Emissions of SO_2 and NO_x are reduced by 55% and 45% respectively, the major reason being that SO_2 and NO_x cleaning at power plants is increased. Concerning emission of NO_x the introduction of catalytic converters on gasoline-powered vehicles, and improved standards for diesel-powered vehicles also contribute considerably to the reduction of emission.

Emission of NH_3 is reduced by about 15% due to improved handling of animal manure and reduced use of synthetic nitrogen fertilisers in the agricultural sector. Emission of NH_3 from transport is more than doubled. The introduction of catalytic converters increases emission of NH_3 while reducing other emissions from vehicles. However, transport only contributes with 2% of total NH_3 emissions in 1997 and this increases to 4% in 2010.

Figure 8.1.2 Emission of acid gases.

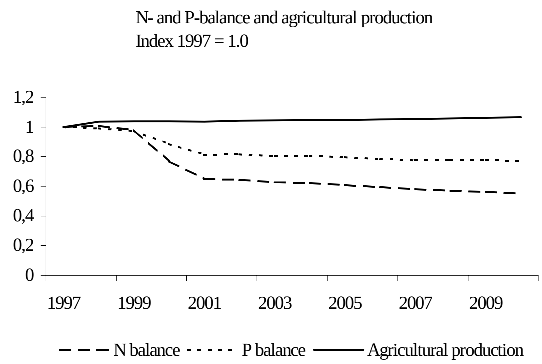


In the case of eutrophication of the aquatic environment, both the N- and P-balances of the agricultural production are reduced. The two balances express the difference between the amount added to fields and the amount removed.

The N-balance is reduced by about 65 kt N or about 10% of the total N-input to the agricultural land. The reduction is made up of a 50 kt N reduction in the use of synthetic N fertilisers and an increase in the N content of the harvest of about 20 kt N. Both the deposition of N and the evaporation of NH_3 and N_2O decrease, implying that the net result is unchanged. The total N content in the animal manure is almost constant.

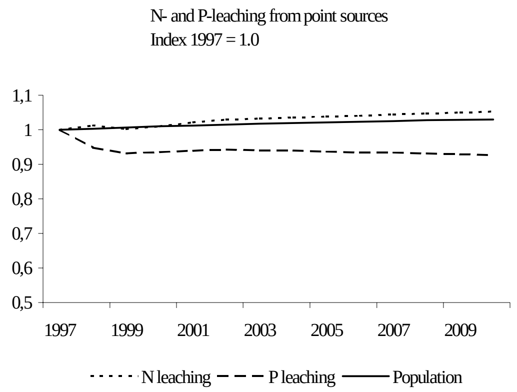
The P-balance is reduced by about 5 kt P or about 6% of the total P-input to agricultural land. This reduction is composed of a decrease in the use of synthetic fertilisers of 2 kt P and an increase in the P content of the harvest of about 4 kt P. The P content of the animal manure increases by about 1 kt P.

Figure 8.1.3 N- and P-balances for agriculture



Leaching of N and P from point sources is shown in Figure 8.1.4. About half of the discharge from point sources comes from sewage treatment plants. Inflow to sewage treatment plants is forecasted to follow population growth, and cleaning efficiencies are exogenous and here assumed to be constant. N and P from rural areas are assumed to decrease due to changed treatment in rural areas. Discharges from other sources change only marginally (minor increases or constant). The difference in the development of leaching of N and P respectively is caused by differences in the relative contribution of the different sources.

Figure 8.1.4 N and P leaching from point sources



8.2 Sensitivity and multiplier analyses

8.2.1 Change in general economic activity

In this section, the effects of a permanent increase in the public purchase of goods of 1 bill. DKK (measured in constant 2000 DKK) in the years 2000 to 2010 are analysed. This is analysed by changing the ADAM variable public purchase of goods, simulating ADAM/EMMA/LADA, using an ESMERALDA baseline scenario for disaggregation and conversion to physical variables and calculating emissions using the emission satellite models. Increased public purchase implies an increase in public consumption of about 0.4% and an initial increase in GDP of 0.09%, but the effect is reduced over time as wages increase and exports decrease. After 10 years the effect on GDP of a permanent increase in public purchase of goods is only 0.03%. Looking at production, total output increases, but while output in the service sectors increases permanently, output in agriculture and (over time) output in manufacturing decreases. Production in the agricultural sector decreases as the production is supply-determined and wages/unit costs increase, while export prices are exogenous and unchanged. Concerning manufacturing, the decrease in agricultural production implies that less input is supplied from agriculture to the food manufacturing industry, which decreases the production of this industry. For the other manufacturing branches, the increased wages/costs mainly imply a decreased export and over time, reduced production. For the service sector the initial production increase is larger and the less competitive nature of the sector implies a slower adjustment to the increased wages.

Table 8.2.1 Economic effects of a 1 bill. increase in the public purchase of goods.

Changes in %	2000	2005	2010
Population	0,000	0,000	0,000
Private consumption in constant prices	0,029	0,021	0,043
Gross domestic product in constant prices	0,086	0,040	0,026
Gross output in constant prices	0,126	0,078	0,051
Production in constant prices in:			
Agriculture	-0,012	-0,108	-0,154
Manufaturing	0,043	-0,077	-0,147
Services	0,128	0,104	0,084
Public service	0,351	0,377	0,391
Export in constant prices	-0,015	-0,096	-0,153
Gross energy consumption of fossil fuels in TJ	0,032	0,036	0,024
Total gross energy consumption in TJ	0,030	0,034	0,023
Wind energy in TJ	0,000	0,000	0,000

Due to increased production and private consumption, energy consumption increases slightly. As the amount of wind power is unchanged, the increase is within the consumption of fossil fuels.

The environmental effects of the economic changes are shown in the Figures 8.2.1 - 8.2.3. Emission of greenhouse gases initially increases, but after 10 years the number of GWP-equivalents is almost unaffected by the increased purchase of public goods. CO_2 emissions increase due to increased energy consumption, but this is counterbalanced by decreased emissions of nitrous oxides (N_2O) and methane (CH_4) related to the reduced agricultural production.

Aggregated emissions of acid gases decrease, due to reduced agricultural production and emission of ammonia (NH_3). Energy-related emissions of SO_2 and NO_X increase slightly, but are almost unchanged after 10 years. Emissions of SO_2 actually decrease slightly due to a change in the composition of the fossil fuel consumption.

Figure 8.2.1 Effects on emission of greenhouse gases

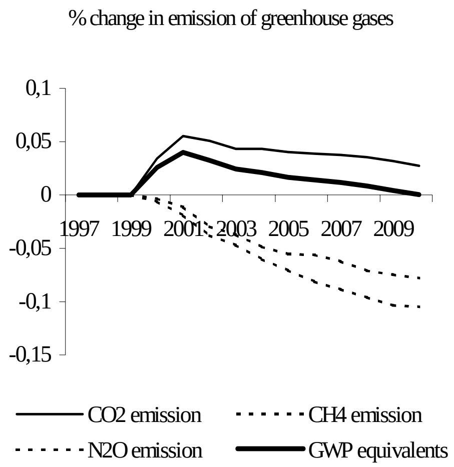
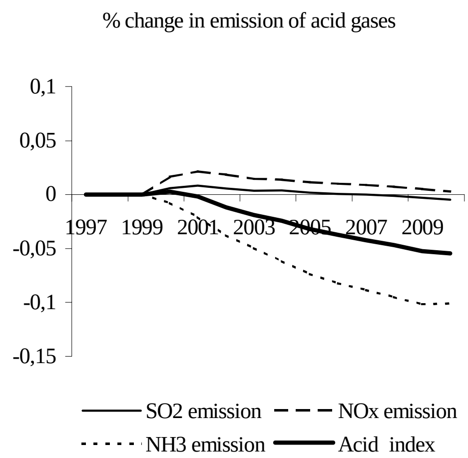
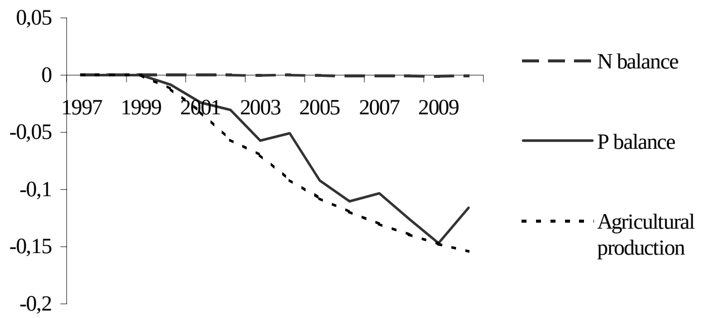


Figure 8.2.2 Effects on emission of acid gases



Finally, in the case of eutrophication, the N and P surplus of the agricultural sector decrease following the reduction of agricultural production. Assuming an unchanged use of synthetic fertilisers, the effect on the N and P balance of agriculture is shown in Figure 8.2.3. The relative effect on the P balance is larger than on the N balance. This is mainly due to the relative contribution of synthetic fertilisers in the two balances.

Figure 8.2.3 Effect on the N and P balances for agriculture (% change)

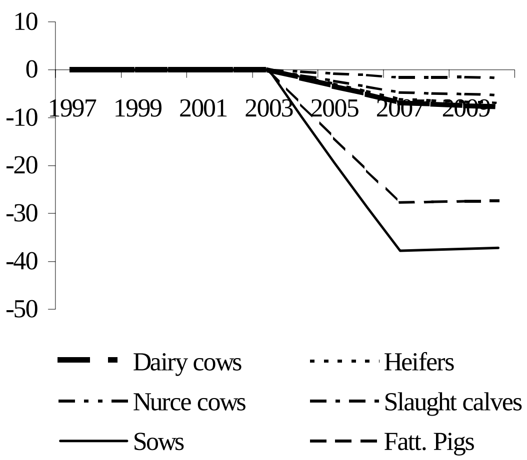


8.2.2 Change in agricultural production

One of the ways agricultural production is regulated is by rules of harmony, defining a maximum number of animal units allowed per hectare. An argument for this regulation is the securing of sufficient land for the spreading of animal manure. In this section we analyse the effect of tightening up the rules of harmony. Over the period 2004 to 2007 the number of animal units per hectare is effectively reduced by about 1/3 or 0.6 animal units per hectare. The effect on agricultural production is analysed by comparing an alternative scenario in ESMERALDA to the baseline scenario described in section 8.1. The agricultural effects in ESMERALDA are introduced into LADA and the aggregated economic effects are analysed in ADAM. Finally, the effects on emissions are calculated by use of the emission satellite models.

The effect on the animal production is shown Figure 8.2.4. Pig production is reduced by about 30% and production in the cattle sector is reduced by 7%. Introducing these changes in LADA-ADAM the aggregated economic effects are shown in Table 8.2.2.

Figure 8.2.4 Effect on number of animals when harmonisation rules are tightened (% change)



Total agricultural production is reduced by 10%, and as animal production is input to the food manufacturing industry, production in this industry is reduced. In general, industrial production is reduced by 4%, production in service sectors is reduced by 1.6% and total GDP is reduced by 1.4%. As a consequence, the consumption of fossil fuels is reduced by about 2%.

Table 8.2.2 Economic effects of change in agricultural production.

Changes in %	2000	2005	2010
Population	0,000	0,000	0,000
Private consumption in constant prices	0,000	-0,316	-0,514
Gross domestic product in constant prices	0,000	-0,799	-1,406
Gross output in constant prices	0,000	-1,194	-2,351
Production in constant prices in:			
Agriculture	0,000	-4,898	-9,968
Industry	0,000	-2,204	-4,279
Services	0,000	-0,819	-1,602
Sublic service	0,000	0,000	0,000
Export in constant prices	0,000	-1,655	-2,976
Gross energy consumption of fossil fuels in TJ	0,000	-0,700	-2,358
Total gross energy consumption in TJ	0,000	-0,636	-2,140
Wind energy in TJ	0,000	0,000	0,000

The environmental effects of the changes are shown in the Figures 8.2.5 - 8.2.7. Total emission of greenhouse gases is reduced by 4%. About half of this reduction is ascribed to reduced energy consumption and emission of CO_2 that is reduced by about 2.5%. Due to the reduced number of animals, emissions of methane (CH_4) and nitrous oxide (N_2O) are reduced considerably, by 10% and 6% respectively. Emission of CH_4 from agriculture is reduced by 14%, but as emission from landfills is unchanged, total emission is reduced by only 10%. Concerning N_2O, emission from manure managemant is reduced by 17%; however, as vegetable production is assumed unchanged, total emission from agricultural production is reduced only 7%. As CH_4 and N_2O only account for 22% of the GWP equivalents, these reductions add only about 2% to the reduction of total GWP-equivalents.

Emission of acid gases is reduced by 8%, the major part of which is ascribed to a 15% reduction in emission of ammonia (NH_3). Energy related emissions of SO_2 and NO_X are reduced by less than 2% and only contribute to a minor reduction of acid gas emission.

Figure 8.2.5 Effects on emission of greenhouse gases

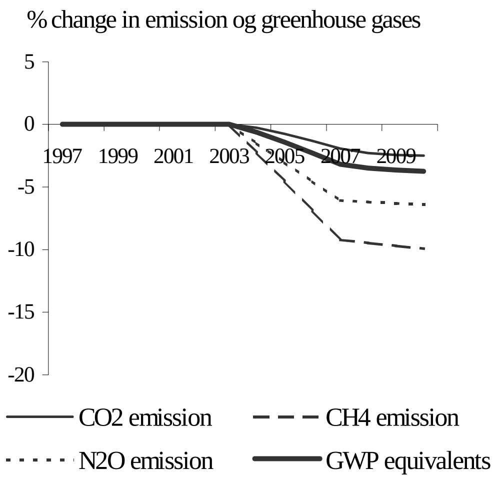
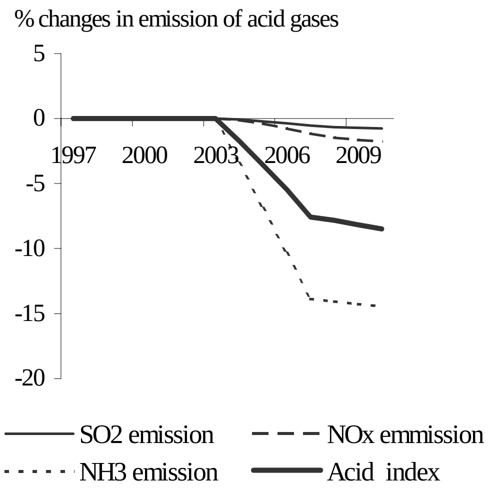
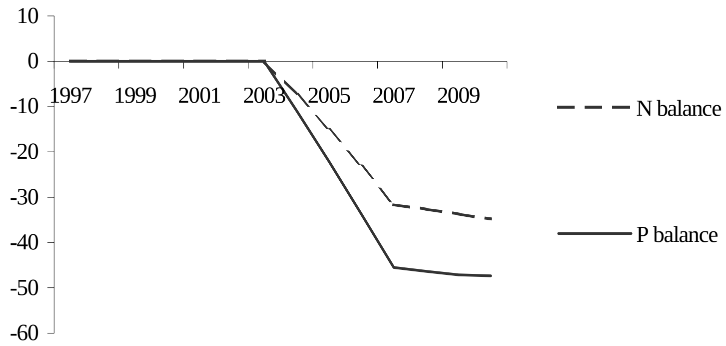


Figure 8.2.6 Effects on emission of acid gases



The reduced number of animals also implies a reduced production of animal manure, and assuming an unchanged use of synthetic fertilisers, the N and P balances for agriculture are reduced considerably.

Figure 8.2.7 Effect on the N and P balances for agriculture (% change)



8.2.3 Change in emission coefficients

In this section, an example of changes in emission coefficients is analysed. This is done by changing emission coefficients exogenously, and by using only the emission models for the calculation of emissions.

Assuming that the share of animals grazing (except for poultry and fur animals) increases by 10 percent points, emission coefficients per animal change, mainly due to differences in the handling of manure. Emission coefficients before and after the change are shown in Table 8.2.3. In order to show the effect on total emissions, agricultural production, prices etc. are kept unchanged in this section. That is, the change in agricultural practice is assumed to affect emission coefficients only, and not the level and composition of agricultural production.

CH_4 emission coefficients are reduced, as the evaporation of CH_4 from grazing animals is less than from animals at stable. For individual categories of animals, the change in the emission coefficient depends on the share of liquid manure. Evaporation from liquid manure is ten times the evaporation from solid manure, and from manure deposited at fields by grazing animals. Table 8.2.3 shows that the relative change of emission coefficients differs among animal categories. Total CH_4 emissions from manure management decrease approximately 10%, implying a decrease in CH_4 emission from agriculture of 2.4%. For total Danish emissions of CH_4, this is equivalent to a decrease of 1.7%.

N_2O emission coefficients increase or decrease, dependent on the share of solid contra fluid manure and the NH_3 evaporation rate at stable. If the share of liquid manure is large, emission coefficients increase, whereas if the share of solid manure and the evaporation of NH_3 is large, emission coefficients decrease. Total N_2O emission decrease slightly with the same order of magnitude as the total GWP equivalents.

NH_3 emission decreases considerably. In general, evaporation at stable is significantly larger than that from grazing animals; however, the decrease is not uniform for all animal categories (see Table 8.2.3). Figure 8.2.9 shows that total emission of NH_3 decreases about 5%, and that the decrease is larger in year 2000 than in 2010. The reason is that over time the baseline projection assumes a fall in NH_3 evaporation rate at stables. An increase in the share of animal grazing therefore saves less evaporation at stables. As total emissions of acid gases are assumed to decrease in the baseline projection, the effect on the total acid equivalents increases slightly.

Table 8.2.3 Emission coefficients for manure management before and after a 10% point increase in the share of animal grazing.

Animal	CH_4 manure management		N_2O manure management		NH_3 manure management	
	base	alt	base	alt	base	alt
Dairy cows	21,86	19,81	3,501	3,520	23,60	22,15
Slaught. calves	1,63	1,52	1,337	1,301	9,99	9,28
Heifers	1,57	1,41	1,202	1,171	6,90	6,20
Nurse cows	1,32	1,32	2,073	1,979	10,87	9,47
Sows	6,04	5,50	0,599	0,614	7,69	7,13
Fattening pigs	2,07	1,90	0,205	0,208	2,52	2,34
Poultry	0,05	0,05	0,025	0,025	0,30	0,30
Fur animals	0,00	0,00	0,127	0,127	2,43	2,43
Horses	1,10	1,10	1,712	1,638	10,03	8,81
Ovines	0,46	0,46	0,750	0,714	3,68	3,09

Figure 8.2.8 Effects on emission of greenhouse gases

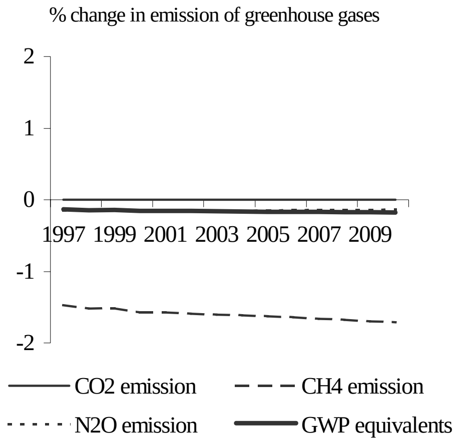
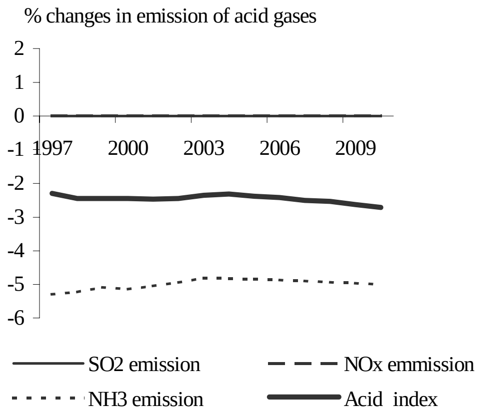


Figure 8.2.9 Effects on emission of acid gases



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