July 1999 ECN-C--99-048

MATTER 2.0

A module characterisation for the agriculture and food sector

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Framework of the study

This report is a product of the MATTER project (MATerials Technologies for greenhouse gas Emission Reduction), published under ECN project number 7.7018. The Dutch National Research Programme on Global Air Pollution and Climate Change (NOP-MLK) sponsors the MATTER project.

Abstract

This report discusses MATTER 2.0, a MARKAL system engineering model for Western Europe. The report discusses the material flows in the Western European agriculture and the model structure for agricultural products. Next it discusses the greenhouse gas emissions and reduction options within the agricultural part of the model. Finally attention is paid to land quality differences within Western Europe.

CONTENT

SUMMARY

In recent years, the Western European MARKAL-model has been extended with a materials system module covering the whole life cycle 'from cradle to grave'. This model including energy and materials is called MATTER 1.0 (Gielen, Gerlagh and Bos, 1998). This document describes a further extension with an agricultural module, called MATTER 2.0.

Ten agricultural crop types are considered which cover about 90% of the agricultural land use in Western Europe. The pastures alone cover about 40% of the agricultural land use. Land quality and land productivity has been considered through a split into three regions: North and Middle Europe, Southern Europe high yields and Southern Europe low yield. The split for Southern Europe is important because 50% of the land area in Southern Europe that is characterised as agricultural land has actually a very low productivity because of water availability constraints and mountainous topography. Generally speaking, yields in Middle Europe are higher than the yields in Southern Europe. Three quarters of the land use can be allocated to animal products: meat, dairy products, eggs and wool. Most important agriculture greenhouse gas (GHG) emissions considered within the model are methane (CH_4) and nitrous oxide (N_2O). Total emissions for these gases are around 350 Mton CO_2 equivalents. This equals to 9% of the Western European GHG emissions. The main sources are:

- Methane from enteric fermentation in domestic livestock (160 Mton CO_2 equivalents).
- Methane from manure management (65 Mton CO_2 equivalents).
- Nitrous Oxide emission from fertiliser use (60 Mton CO_2 equivalents).
- Nitrous Oxide emissions from manure use (125 Mton CO_2 equivalents).

Reduction options dealt with are:

- Increase of the conversion efficiency of enteric livestock fermentation or change of the fodder composition,
- Change of the manure storage system,
- Reduction of the nitrogen input into the agriculture,
- Substitution of current meat or fodder products by other protein sources.

1. INTRODUCTION

MARKAL is traditionally an energy system model. In recent years, the model has been extended with a materials system module covering the whole life cycle 'from the cradle to the grave'. This model including energy and materials is called MATTER 1.0. This document describes a further extension, which will be referred to as MATTER 2.0. In this model version the agricultural land use is endogenised. The reasons for this extension are:

- Land use for food production determines the availability of agricultural land for energy and materials production. This land availability may change significantly in the next decades.
- A significant part of the Western European methane (CH_4) and nitrous oxide (N_2O) emissions are related to agricultural activities (Gielen et al., 1998).
- Lifestyle changes, resulting in changing food consumption, can be analysed with this detailed module.

The complexity of the agricultural system and its importance from a greenhouse gas (GHG) emission point of view require an endogenised agricultural module for proper analysis.

Chapter 2 discusses several model design issues. Chapter 3 will analyse the resource availability, processes and flows within the agricultural sector. Chapter 4 will analyse the greenhouse gas emission related to the agriculture. Chapter 5 will analyse greenhouse gas (GHG) mitigation strategies and Chapter 6 will focus on the influence of land quality on the productivity. Finally, in Chapter 7 some conclusions are given.

2. MODEL DESIGN ISSUES

Given the limited resources available and given the fact that approximately 10% of GHG emissions are accounted for by the activities considered, the module should be simple. A number of detailed agricultural models exist, e.g. the agricultural module within the Image model (Alcamo et al., 1994) and the Basic Linked System of Agricultural Policy Models (BLS) operated by IIASA. These characterisations of these models serve as an important guideline in the model design. Given the reasons for the agricultural module mentioned in Chapter 1, the following issues are relevant.

From a land use point of view:
- Earlier analyses (e.g. Lehmann et al., 1996; Spangenberg et al., 1995) have indicated that animal production is a key variable for land use. Pastures and fodder crops account for more than 50% of agricultural land use.
- Increasing productivity (both for crops and for meat production) must be considered, because it will significantly affect the land requirements in the next 50 years. (Gerlagh, 1998)
- Imports of fodder crops are significant (especially soybeans and tapioca) and must be considered.

From a GHG emission point of view:
- CH_4 emissions and fodder conversion efficiencies differ per animal, hence different animal/meat types must be considered.
- Emission reduction strategies for CH_4 include higher fodder efficiencies (genetic improvement, growth hormones, and higher protein/fat gain ratio) and improved fodder composition. The latter one would require a separate modelling of different fodder types. This will not (yet) be considered. The former ones can be modelled through increased fodder conversion efficiencies.
- Approximately 20% of CH_4 emissions are related to manure storage, hence storage systems must be considered.
- N_2O emissions are related to fertiliser use, hence fertiliser use must be considered. This includes natural and synthetic fertilisers.
- The bulk of HFC emissions are related to the use of cooling equipment. This equipment is especially applied in order to store food products. As a consequence, the bulk of HFC emissions can be related to the food chain. This relation is not considered in the model, because the commercial sector and the residential sector are modelled as separate modules.

From a lifestyle point of view:
- Human food consumption can be split into a number of food categories. Meat and fish and pulses, dairy products, starch type products, vegetables and fruits, oil products.
- Bottom-up analyses for Dutch households suggest an annual energy use of 60 GJ/household for the activity ‘food’ (including the food production 40 GJ) and shopping, storage and preparation (17 GJ) (UitdenBogerd, 1995). The latter one third will not be linked to the agricultural module (it is already included in the residential module). If the figure of 40 GJ is extrapolated to Western Europe, this suggests an energy use of 5 EJ for food production (10% of all energy use). This equals a CO_2 emission of 300 Mton. Moreover a fraction of this energy is biomass, without GHG emissions. However the 5 EJ includes the energy use by supermarkets, food transportation etc. This relation will not be included in the analysis.

3. ANALYSIS OF RESOURCE AVAILABILITY, PROCESS CHARACTERISTICS AND PRODUCT FLOWS

The first step in model design is a consistent mass flow, with as limitation that most losses were not considered. In this section existing statistics from agricultural material flows, such as production figures and input/output-data for conventional processes such as different husbandry systems are combined into a total mass balance for agriculture ‘from crop to food’. The analysis from land use up to food consumption consists of in the following steps.

- agricultural land use and crop yields (Paragraph 3.1),
- current agricultural crop use split into food and fodder (Paragraphs 3.2 and 3.3),
- animal breeding products and fodder requirement (Paragraph 3.4),
- overall balance of animal breeding (Paragraph 3.5 and 3.6).

The final result of this analysis is a balance shown in Figure 3.1.

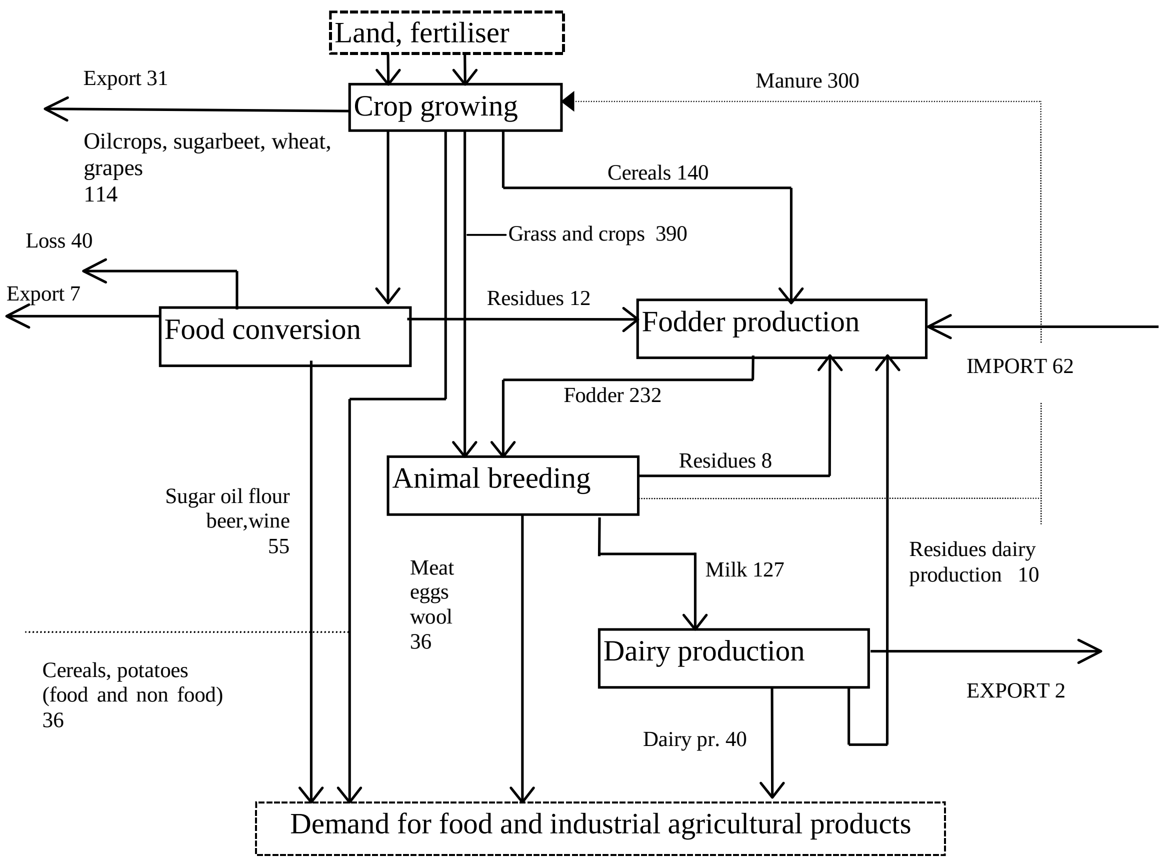

Figure 3.1 *The agricultural system ‘from crop to food’. All stream quantities are given in Mton (dry matter except milk and dairy products, uncertainty +/- 25%)*

3.1 Agricultural land use and production

Agricultural land use is detailed in Table 3.1. This table shows that 10 types of food and fodder crops together with the land use for pastures cover almost 90% of the agricultural land. Cereals, pastures and fodder crops dominate the land use. In Southern Europe the oil crops (mainly olives) are significant.

Table 3.1 *Agricultural land use, Western Europe, 1997 (FAO, 1998) [Mha]*

Crop	South	Middle	North	Total
Wheat	5.56	10.67	1.20	17.43
Barley	4.24	5.93	1.98	12.15
Maize (total)	2.48	5.87	0.04	8.40
Pumpkins (fodder)	0.50	3.09	2.31	5.90
Other fodder	2.82	2.30	1.46	6.58
Oil crops	7.62	3.77	0.25	11.63
Grapes	2.39	1.05	0.00	3.44
Rapeseed	0.05	2.39	0.24	2.68
Sugar beet	0.49	1.48	0.17	2.14
Potatoes	0.22	0.99	0.12	1.33
Fruit & Vegetables	5.06	2.46	0.10	7.62
Pastures	21.39	34.97	1.13	57.50
Other crops	4.94	2.97	1.40	9.31
Total	*59.17*	*77.43*	*10.36*	*146.95*

Agricultural production

A survey of the productivity figures is given in Table 3.2. For food crops FAO statistics were used. For fodder FAO crop productivity data are very high and only available for 3 countries. Yield values about 40 ton/ha were found, which is not in line with the productivity of consumption crops or growth figure for these crops found in e.g. biomass production statistics (EC, 1999). Differences in productivity could be caused by differences in use of the crops (is the whole crop harvested or only part of the crop) and the water content.

Therefore for the productivity of fodder maize the data for consumption maize are used (8.2 ton/ha) and for the other fodder crops the production is estimated at 10 ton/ha based on (El Bassam, 1998; Kaltschmitt and Reinhardt, 1997). Note that maize also produces silage that is useful as fodder but is not included in this table. For potatoes and sugar beet FAO statistics show wet-weight figures. A water content percentage of 75% is assumed.

Table 3.2 *Productivity of several crops in the 3 European regions according to the FAO-statistics 1997 [tdm/ha] (FAO, 1998)*

Productivity	Food crops						Fodder crops	
	Cereal	Oilcrops	Grapes	Potatoes	Sugar beet	Rapeseed	Maize	Pumpkins
North	6.4	0.7	-	8.1	10.1	2.7	8.2	10
Middle	7.6	1.0	8.4	9.6	14.8	3.4	8.2	10
South	3.9	0.5	6.6	8.9	12.5	1.4	8.2	10
Total	*6.2*	*0.6*	*7.1*	*9.3*	*13.9*	*3.3*	*8.2*	*10*

The production of food and fodder crops can be calculated if data from Table 3.1 and Table 3.2 are combined. The only ‘crop’ which is not included in Table 3.2 is grass. This is caused by the direct use of pastures for grazing, which makes that part of the grass is not harvested. Data for the grazing quantity of animals were found for several countries, but not for the entire Western European agriculture. Dutch analyses of the dairy farming and environmental statistics show that the grass production is between 5-10 ton/ha in the Netherlands (CBS, 1997; CBS, 1998). A Swedish analysis of dairy farming assumes a grass production of 5 ton/ha. Because the relative high productivity of the Dutch cattle farming (LEI-DLO, 1996a) the low value, which is equal to the Swedish estimation is used as productivity of the average European pastures.

Vegetables and fruit are of minor importance when land use is taken into account. Table 3.3 gives an overview of the vegetable and fruit production in Western Europe and the highest and lowest productivity value found for each geographical region. These show differences in productivity are high between countries. Within this analysis the land use related to fruit and vegetable consumption is assumed to remain constant.

Table 3.3 *Production of fruits & vegetables in Western Europe (net weight) 1997 (FAO, 1998)*

	Vegetable productivity Average, lowest and highest		Fruit productivity Average, lowest and highest	
	[ton/ha]	Range [ton/ha]	[ton/ha]	Range [ton/ha]
North	18.8	10-51	7.8	3-15
Middle	13.1	4-105	21.0	2-54
South	7.8	4-13	31.9	20-37
Total	*9.5*		*26.8*	

The land use related to vegetable and fruit consumption is given in Table 3.1. The 'other land' in Table 3.1 is also assumed to remain constant and the production is not taken into account. Table 3.4 shows the production figures. The line indicates the distinction between food and fodder crops.

Table 3.4 *Production of food and fodder crops in tons dry matter (Mton DM) 1997 [Mton DM] (FAO, 1998; Kaltschmitt and Reinhardt, 1996)*

Crop type	South	Middle	North	Total
Cereal	45.3	144.8	20.6	210.6
Oil crops	3.5	3.8	0.2	7.5
Grapes	15.7	8.8	0.0	24.5
Potatoes	1.9	9.2	1.0	12.3
Sugar beet	6.1	21.9	1.8	29.8
Rape seed	0.1	8.2	0.6	8.9
Maize	14.6	27.8	0.4	32.8
Pumpkins	23.0	30.9	5.0	59.0
Other	28.2	23.0	14.6	65.8
Grasses	42.8	172.2	4.4	261.3
Total	*218.9*	*545.7*	*75.2*	*712.8*

EU data (EC, 1999) show that from the cereal production of 205 Mton, 31 Mton is net exported, 107 Mton is used for fodder, 42 Mton is used for human consumption, 15 Mton is used for industrial purposes, seeds 6 Mton and losses within the processes 3 Mton. The consumption after processing is 31 Mton. This indicates that 11 Mton is lost during the processing of cereals. The most common product is flour. (25 Mton, see Paragraph 3.2.1) If breweries are included in the industrial processing is unclear. Differences between use and production are due to stock changes.

3.2 Conversion of agricultural products

Food and fodder are the main uses of agricultural crops. The use as food is directly related to the demand for certain products such as oils and sugar. Most food is prepared, and many processes are used to convert the agricultural products into food.

Within this model the main processes are taken into account:
- flour production,
- oils and fats production,
- alcohol production (for example wine and beer),
- sugar production.

3.2.1 Flour

Flour is produced from cereals. The total EU-15 flour production amounts to 26.1 Mton, 8% (2 Mton) of which was net exported (Eurostat, 1998b). The remaining 24 Mton are used for production of bread, pasts, cakes, biscuits etc. (equivalent to approximately 70 kg per inhabitant per year). The feedstock for flour is common and durum wheat and -to a much lower extent- corn and rice. We estimate an input of 80% of wheat and 20% of corn.

3.2.2 Oils and fats

Table 3.5 gives a survey of the production, imports and export of the major types of oils and fats and the by-product protein meal. Within the EU industry statistics protein meal is included in the production figures of the oil and fat production. On mass base the protein meal represents about 70% of the industrial production. This protein meal is mostly used for the fodder industry. The demand for protein meal for fodder is much higher than the European production that leads to import of over 50% of the protein meal consumption.

Table 3.5 *Oil and fat, EU-15, 1994 [Mton] (Eurostat, 1998b)*

	Production	Total imports	Total exports
Vegetable oils			
Liquid[1]	6.8	0.4	1.5
Olive	1.4	p.m.	p.m.
Other	0.2	2.7	0.2
Total	*8.4*	*3.1*	*1.7*
Protein meal			
Soy	10.1	13.0	1.0
Rape	3.7	0.9	0.1
Sunflower	2.4	1.3	0.0
Maize	0.2	0.9	0.0
Others	0.1	0.8	0.0
Total	*17.2*	*20.1*	*1.2*
Marine oils and fats			
Fish meal	0.5	1.0	0.4
Marine oils	0.1	0.4	0.1
Total	*0.7*	*1.4*	*0.4*

3.2.3 Alcohol

Alcohol is used for consumption and some industrial purposes. The agricultural production is merely used for consumption alcohol. Most important alcoholic drinks are wine and beer. Therefore the input of grapes and cereals (mainly barley) will be taken into account within the model. The requirement of the processes is given in Table 3.6.

[1] Includes soy, rape, sunflower, cotton and maize.

Table 3.6 *Ethanol production, EU-12, 1994 [Mton] (Groenendaal, 1996, Eurostat 1998b)*

	Required	Million litre	Alcohol equivalent
Wine	20.5 grapes	16.4	2.0
Beer	7.6 barley	31.6	1.6
	0.05 sugar		
Spirits	1.5 molasses	1.1	0.9
(pure alcohol equivalent)			
Synthetic ethanol			0.6
Total			*5.1*

3.2.4 Sugar

Sugar production, consumption and net exports of the EU-sugar industry are shown in Table 3.7. Sugar is mainly used in the food industry for the production of canned food, fruit juice, confectionery and bakery, syrups and beverages. About 70% of the sugar consumption are taken by the food industry; households directly consume the other 30%. Sugar beets are the main feedstock.

One ton of sugar beets produces 115 kg sugar, 60 kg molasses and 400 kg wet pulp which is transferred to 22 kg dry matter (Brand and Melman, 1993). The by products of the industry, molasses and beet pulp, are used for the fodder industry and distillation of spirits. The chemical and zootechnic industry uses about 3-4% of the sugar.

Table 3.7 *Sugar production/consumption, EU-15, 1993/94 [ton DM] (Eurostat 1998b)*

	Sugar	Molasses	Beet pulp
Production	17.1	7.18	2.6
Consumption	12.6		
Direct	3.8		
Indirect	8.8		
Net Exports	4.5		

3.3 Fodder

Table 3.4 shows that a major part of the agricultural production is used as fodder. Therefore the fodder use will be analysed in more detail. First the fodder demand of the current West European livestock will be analysed and compared with the overall fodder production. Main effort is to get the 'bottom up' information (such as, the consumption pattern of an average cow) in line with the production and consumption balances from agriculture and industry.

The breeding of livestock in West Europe includes many very diverse breeding methods, from extensive pasture management in some South European regions to intensive rearing systems for pigs and chickens in the Netherlands and Portugal. Though differences between different breeding techniques are large for this analyses only one system for each animal group will be taken into account. Main effort is to get insight in the material flows of the agriculture (see Figure 3.1). In total five types of livestock are distinguished, these are dairy cattle, meat cattle, pigs, sheep and poultry. Within the poultry categories a distinction is made between eggs and meat producing poultry. The analysis for these categories will be analysed in three steps:

- First the demand for fodder will be analysed for each livestock type.
- Second the demand for meat will be analysed for each livestock type.
- Thud the conversion of fodder to meat will be analysed.

Table 3.8 *Cereals, grass, fodder and prepared feed consumption by animals (Cederberg, 1998; IPCC, 1997)*

[kg/animal/year]	Heifers	Dairy cows	Non-dairy cows	Pigs	Sheep	Chicken
Cereals/silage	2000	3100	1900			
Grass/hay	750	2100	1000		500	
Maize (crop and prepared food)	10	100	100	300		10
Soy/Tapioca	20	50	50	330		16
Dairy pulp	170					
Not defined		1200	350	170		7
Total	*2950*	*6550*	*3400*	*900*	*500*	*33*

Fodder demand livestock

The need for fodder for the different animal types per head of stock is distinguished in Table 3.8. This table shows that dairy cattle consume most fodder per head, over 6,0 ton annual, whereas pigs and sheep consume 900 and 500 kg respectively. No data on intensive sheep breeding where found. Because sheep are ruminants and their role within the analysis is limited, it is assumed that sheep solely eat grass.

A Dutch analysis of the requirement for livestock systems and an IPCC analysis of the greenhouse gas emission related to the agriculture are both very valuable sources of information on the fodder demand for livestock (Brand and Melman, 1993; Cederberg, 1998; IPCC 1997). When we compare these data with agricultural production figures (see Table 3.4), there appears to be a difference in the main contents of fodder. The major production is grass whereas the figures in Table 3.8 indicate that cereals and silage dominate the fodder pattern. Further the quantity is not in line with the agricultural production. In case the data of Table 3.8 were combined with the current stock, it appears that the consumption of fodder should be around 750 Mton, which is more than the complete food and fodder production in Western Europe. Because the production statistics are a better representation of the overall production for fodder purposes these are used to complete the overall balance.

Prepared feed

Beside direct fodder-crops most livestock in Western Europe also gets prepared feed. A survey of the mixtures used in the Netherlands is given in Table 3.9.

Table 3.9 *Contents of protein mixes used as fodder-supplement [%] (Brand and Melman, 1993; Cederberg, 1998; IPCC 1997)*

	Heifers	Dairy Cattle	Non Dairy Cattle	Pigs	Chicken
Soy	3	12	12	25	30
Tapioca				35	19
Maize	2	21	21	9	30
Slaughter residues				4	7
Wheat				8	
(Other) residues		50	50		
Dairy pulp	77				
Rest	18	17	17	19	14

This data should be integrated in the overall balance and in line with the fodder pattern already found in Table 3.8 and overall production and import and export statistics. For ruminants, as cattle and sheep it is only part of the total intake, but the non-ruminants depend solely on this fodder, sometimes mixed with some fodder crops. In Table 3.8 this fodder is counted for as maize, residues and soy/tapioca.

The prepared animal feed produced in the EU (see Table 3.10) consists of cereals, feeding cake and flours, by-products of the food industry and other constituents (Eurostat, 1998b). In the same time the EU-15 imported about 52 million tonnes of raw material for the fodder production. It is assumed that the 40 Mton cereals are part of the 107 Mton cereals for fodder purposes found in EU-agricultural statistics. Because no distinction is made between ‘prepared’ and non-prepared cereals a higher production of fodder is used in this analyses. These values are given between brackets in Table 3.10.

Table 3.10 *Production and import of prepared food for feedstock (Eurostat, 1998b; EC, 1999)*

[Mton/year]	Production food	Import
Cereals(incl. non prepared)	40 (107)	4
Feeding cake and flours	29	
Oil seeds and products (mainly soy)		38
Tapioca/manioc		17
By products food industry	19	
Other constituents	29	7
Total	*117 (184)*	*66*

There is a major input of food production residues (pulp). Table 3.9 shows an analysis of the protein mix for different livestock groups. For heifers and dairy cattle Dutch and Swedish data are used. Again it is assumed that the available residues will be used, and therefore the food production itself is the limiting factor. Non dairy cattle are assumed to get the same protein mix as dairy cattle. Because the data sources are focused on just a few countries, no difference is made between the regions in Western Europe.

The differences in feeding patterns between heifers, dairy and non-diary cattle make a specification necessary to get insight in the fodder demand structure. It is assumed that dairy and non-dairy heifers have the same feeding pattern[2].

Finally the feeding pattern should be in line with overall production of fodder as earlier calculated. A comparison with the total consumption data for non-diary cattle that are derived from IPCC analyses of Western European agricultural emissions is made (IPCC, 1997). This shows that the Swedish and Dutch analyses results in a 25% higher intake of fodder compared with the Western European estimate according to the IPCC. The IPCC data seem more in line with the West European agricultural production statistics.

Therefore the overall quantity is based on these data whereas the feed intake contents ratio of the Dutch and Swedish analyses is used to define the different feeding patterns of the animal groups. The ‘other constituents’ in Table 3.10 are divided over the categories in order to get the feeding pattern more in line with the feeding pattern found earlier this section. The analysis is summarised in Table 3.11. The total intake of Table 3.11 is not equal to the production and import summarised in Table 3.10 because of the use of some imported streams in the production processes. Especially feeding cakes are assumed to be made out of cereals, (imported) soy and food processing residues. Therefore only these categories where found in Table 3.11.

[2] Because two-third of the cattle is used for meat production it is assumed that also two third of the heifers is used for meat production.

Table 3.11 *Total intake of produced fodder and fodder crops, million tons dry matter (summary of other tables in Section 3.3)*

Total Input [Mton DM]	Cattle Milk	Meat	Pigs	Chicken Eggs and meat	Meat	*Total*
Cereals and products	48	31	44	7	10	*140*
Food processing residues/ Imported soy	4	5	44	10	14	*77*
Slaughter/dairy residues	3	10	5			*18*
Total (= output)	*55*	*46*	*93*	*17*	*24*	*235*

3.4 Animal products

This section will analyse the livestock and the number of animals slaughtered in relation to the overall meat production. Further the production of dairy products, eggs and wool will be taken into account. Main meat products in Western Europe are beef, veal, pork and chicken.

Table 3.12 and Table 3.13 shows the heads slaughtered and the meat produced for the three regions in Western Europe. Note that there is a difference between the number of heads slaughtered and the stock, for example, the average lifetime of a chicken when slaughtered is a bit more then 2 months. This explains why the number slaughtered is about 5 times higher than the stock.

Table 3.12 *Stock and number of heads slaughtered, EU 1995 [Mton] (FAO, 1998)*

		Bovine	Sheep	Goats	Pigs	Chicken
Stock	North	6	3	0	16	39
	Middle	66	63	1	76	629
	South	15	50	10	31	320
	Total	*87*	*117*	*12*	*121*	*987*
Slaughtered	North	2	2	0	27	269
	Middle	20	33	1	117	2,993
	South	8	38	7	49	1,442
	Total	*30*	*73*	*8*	*193*	*4,704*

The final meat production is found in the production statistics of the EU industry. These data are shown in Table 3.13.

Table 3.13 *Production and export of meat (carcass weight) EU 1994 [Mton] (FAO, 1998; Eurostat, 1998b)*

	Beef and Veal	Sheep	Pigs	Chickens	Other meat[1]
North	0.5	0.0	2.1	0.3	
Middle	5.8	0.6	10.2	4.1	
South	1.9	0.4	4.3	2.1	
Total	*8.2*	*1.1*	*16.6*	*6.5*	*0.9*
Total Exports	1.2	0.0	0.8	0.7	0.0

[1] Data from panorama of EU-industry.

3.4.1 Cattle products

Both dairy and meat production are directly related to cattle and other animal farming. Several statistics show a difference in meat production, fodder and grass demand and lifetime for diary and non dairy cattle. Therefore we will distinguish these two animal types within this analysis. A survey of the milk production of dairy cattle is given in Table 3.14. It shows the number of cattle, which is related to the milk production according to the statistics. Productivity figures and the ratio between dairy and non-dairy cattle were found in (LEI-DLO, 1996a) for EU-12. Figures for other countries are estimations.

Table 3.14 *Dairy cattle and milk production 1994 (LEI-DLO, 1996a; FAO, 1998; Eurostat, 1998a)*

	Milk cattle [million]	Production [ton milk /cow year]	Milk production [Mton]
North	2.1	5.7	12
Middle	17.5	5.4	95
South	4.1	4.7	19
Total	*23.8*	*5.3*	*127*

The milk production is related to the consumption of dairy products. A survey of the European production of the most important dairy products combined with conversion factor from milk to these products show that cheese is a very important dairy product. The different total milk production values in Table 3.14 and Table 3.15 are mainly related to the difference between EU-12 and EU+EFTA.

Table 3.15 *Dairy products, EU-12, 1993 [Mton] (Eurostat, 1998b; Over and Vrenken, 1994)*

	Production	Domestic use	Total exports	Milk required for production
Drinking milk	29.9	29.6	0.3	29.9
Cream	1.2	1.2	0.0	1.2
Concentrated milk	1.2	0.8	0.3	2.7
Whole milk powder	0.9	0.4	0.5	7.8
Skimmed milk powder	1.3	1.0	0.1	11.3
Butter	1.7	1.7	0.3	1.7
Cheese	5.7	5.3	0.5	52.6
Total	*41.9*	*40.0*	*2.0*	*107.1*

Milk cows are pregnant 50% of the time and the calves are not all useful for milk production. After a lactation of several years cows are slaughtered, and meat is produced. About 1 calf is produced with each 16 ton of milk. This leads to 4 million calves with the milk and dairy production (Cederberg, 1998). The average life of a dairy cow is 6 years. This ends up in 1 Mton meat production as a result of dairy production.

3.4.2 Poultry and Sheep products

Wool production in Western Europe amounted to 0.189 Mton in 1997. Lamb and mutton meat production amounted in the same year to 1.1 Mton (FAO, 1998). Based on a total of 117 million sheep, the average production is 9 kg meat and 1.6 kg greasy wool per sheep. On average, each tonne of greasy wool contains 640 kg wool fibre and 360 kg residues (fat, dirt etc.) (EA, 1999).

The main product of poultry husbandry is meat. The EU chicken meat production is 6.4 Mton chicken meat. Egg production was 4.1 Mton in EU 12 in 1991. Detailed data were found for the Dutch situation. About 40% of the Dutch chickens in 1991 were held for the egg-production. These chickens produce about 10% of the total Dutch meat production (LEI-DLO, 1996b). Because the ratio between egg production and poultry meat production is the same for the Netherlands and Western Europe, these ratios will also be used for the West European situation. There is no difference modelled in fodder input between the two poultry groups.

3.5 Fodder to meat efficiency

Several other authors have investigated the fodder to meat conversion. All analyses focus on one country with specific circumstances (e.g. Moller et al., 1996; Wams, 1993). One source of European data were found to be IPCC statistics for the West European Agriculture that describes weigh gain compared to fodder intake (see Table 3.16).

Table 3.16 *Fodder conversion efficiencies (Brown, Kane and Roodman, 1994)*

Type	Quantity [kg/kg weight gain]
Cattle	7.0
Pigs	4.0
Poultry	2.2

Besides weight gain energy is also required for maintenance (so called metabolise energy), feed gathering (high in case of grazing) and growth (not necessarily weight gain). Further the fodder use efficiency is, certainly in case of ruminants lower than 100%. A balance will be made in the next section.

Further there is a relation between the live weight (result of weight gain) and the final meat production. Cattle are usually sold as live weight. The hot carcass weight constitutes usually about 60% of the live weight (so-called dressing percentage). Another important ratio is the cut yield. This is the relationship between the hot carcass weight and the final weight of boneless retail cuts. There are (in the US) 5 yield grades. Grade 1 is an estimated retail cut yield of 52.6% or greater, grade 5 is a yield of 45% or less. This is assessed by the amount of fat over the rib eye, heart and kidney fat, area of the rib eye and hot carcass weight (University of Vermont,1999). Multiplication of both factors suggests a factor four-weight difference between the live weight and the boneless meat. Overall meat production in Western Europe is shown in Table 3.13. These data represent the boneless meat production and are in line with the EU average annual meat consumption of 90 kg per inhabitant.

3.6 Balance Western European livestock production

Finalising the system we now can define the agricultural processes with are used to satisfy the demand for meat in Europe. For this purposes we compare the fodder intake and the meat production as allocated in this chapter per livestock group. For this reason we defined several animal-groups distinguished by animal type and product. The groups (or in MARKAL-terms processes) we want to take into account are:
- Cattle producing milk and meat
- Cattle producing meat
- Pigs producing meat
- Poultry producing eggs and meat
- Poultry producing meat
- Sheep producing meat and wool.

For all groups with exception of the sheep a prepared fodder intake is assumed. This fodder production is no representation of the specific mixtures currently used in the agriculture but a gathering of all fodder streams found in literature excluding grass and fodder crops shows the in and output of the fodder production and the meat production of the animal groups defined. We consider each fodder process a mixing process without losses. The silage is mostly corn silage that is not taken into account in the production statistics of corn.

Table 3.17 *Input and output in the livestock production 1997 [Mton]*

Animals production Input	Cattle dairy	Cattle Meat	Pigs	Poultry Eggs	Poultry Meat	Sheep	*Total*
Prepared Fodder	73	53	93	17	24		260
Crops	40	80	6				126
Grass	110	100				58	268
Silage[1]	100						100
Total	*266*	216	99	17	24	58	754
Output							
Meat	1.1	7.1	16.6	0.6	5.8	1.2	*31.3*
Milk	127						127
Eggs				4.1			
Wool						0.2	

[1] Silage is a by-product of maize production that is not included in the production tables in this chapter.

The use of silage and most residues is limited to the availability of these by-products. This means that no maize or food is produced because of the demand of these streams but only the residuals are used in the most effective way. This means no crops or food processing is modelled because of the demand for residues.

Comparing the last two tables it seems that meat conversion is relatively low. This is mainly caused by the difference between weight gain and consumption meat mentioned earlier. There is also a difference between ruminants (sheep and cattle) and non-ruminants. Because of the low digestive efficiency of cellulose digestion the conversion is lower for ruminants. Parts of the ruminant graze (most sheep for example) which leads to a high-energy requirement for costume maintenance. Further the very low meat consumption from sheep compared to the present stock shows that most sheep are not held for meat production.

4. EMISSION OF NON-CO_2 GREENHOUSE GASES FROM AGRICULTURE

Greenhouse gas emission in agriculture is related to many sources. The agricultural percentage of non-CO_2 greenhouse gas emissions is significant. About 50% of the EU methane emission of around 23 Mton (Watson et al.,1996; Adger, Petternella and Whitby, 1997; De Jager and Blok, 1998) is related to agricultural processes: 8 Mton from enteric fermentation of ruminants and 3 Mton related to manure. For N_2O the EU emission is about 400-800 kton, 50-70% caused by agriculture. Main sources for both gases within the agriculture are:

- Methane from enteric fermentation in domestic livestock.
- Methane from manure management.
- Nitrous Oxide emission from nitrogen use.
- Nitrous Oxide emissions from manure (storage).

4.1 Methane emission

Methane emissions are mainly caused by digestion processes from ruminant livestock and anaerobic digestion as part of wet treatment of manure. These two sources will be investigated. The methane emission related to digestion processes is estimated at 8 million tons in Western Europe. For manure storage this is about 3.1 Mton (Gerbens, 1999a).

4.1.1 Enteric Fermentation

The normal digestive process of certain animals produces methane. This is a result of the digestion of cellulose, and therefore mainly caused by ruminants such as cows, sheep and goats. Table 4.1 shows that over 70% of the livestock methane emission are related to cattle. This methane represents a significant part of the energy available in the fodder. The methane 'loss' for cattle ranges from 3 to 8% of the food energy content. Western European average loss is around 6%.

Table 4.1 *Enteric fermentation emission factors 1995 (Leng, 1998; IPCC, 1997)*

Animal type	Emission [kg CH_4/head/year]	Number of EU animals [million heads]	Emission [× 1000 ton CH_4/year]
Dairy cattle	100	30	3.0
Non-dairy cattle	65	57	3.7
Sheep	8	117	0.9
Goat	5	12	0.1
Pigs	1.5	121	0.2
Poultry	0.078	986	0.1
Total			*8.0*

4.1.2 Emission related to manure

Manure production

Before we will focus on the methane production related to manure storage, first the quantity of manure produced is calculated. The manure production is equivalent to the fodder intake minus methane losses, minus maintenance losses and minus animal weight gains. The methane loss for cows due to conversion to methane is approximately 6% of the food intake (energy based).

The losses for maintenance is another 20% and for weight gain about 25%. Consequently, the amount of manure is approximately 50% of the fodder intake, approximately 350 Mton/year. Note that percentages weight gain and maintenance energy requirement are different for the livestock groups mentioned.

Overall manure production in European Union is about 1124 Mton (Orenblad, 1998). This includes dry manure, wet manure and in some cases cleaning water from stables. Very specific data were only found for the Dutch agriculture. These sources include data on the specific manure production for all types of livestock (CBS, 1998; CBS, 1999). Because of the high productivity standard in the Dutch agricultural the absolute manure production figures are not representative for Western Europe. Therefore only the ratio between manure and fodder intake are used in Table 4.2. This shows a crude indication of the manure produced by the different livestock categories. Most manure flows have a high water content. This is in line with several other publications which show dry matter contents of 5-10% for e.g. pig manure (Behmel, 1998; CBS, 1999).

Table 4.2 *Manure production in the Western European Agriculture(uncertainty +/- 25%)*

Manure production	[Ton manure/head/year]		[Mton manure/year]	
	Wet	Dry	Wet	Dry
Cattle	13.3	2.5	1,161	300
Sheep + Goats	1	0.2	129	26
Pigs	1.1	0.13	250	32
Chicken	0.02	0.01	20	10
Total			*1444*	*360*

CH_4 emissions related to manure storage

The world wide methane emission related to manure storage is estimated at 10-18 Mton, of which 3,1 Mton is emitted in Western Europe. The manure storage of swine and cattle account for about 80% of the emission. This emission is a result of anaerobic processes that takes places in case of wet storage of manure. The previous section shows that most swine manure has water content over 90%, which is usually wet stored. The same goes for the liquid stored cattle manure. Table 4.3 shows the Western European methane emission distinguished for animal type and management system.

Table 4.3 *Western European methane emission related to manure by animal type and management system for 1990 (Gerbens, 1999b)*

Animal type		Management System	
Dairy cattle	1.1	Pasture/Range	0.1
Other cattle	0.9	Liquid slurry	2.7
Swine	0.9	Solid storage	0.1
Poultry	0.1	Lagoon/Daily spread	0.0
Other animals	0.1	Other	0.1
Total	*3.1*	*Total*	*3.1*

4.2 Nitrous Oxide emissions from agriculture

Most analyses of agricultural N_2O emission take only fertiliser-related emissions into account. It is recommended by the IPCC expert group to add the emission related to animal excreta, plant residues, biological nitrogen fixation and atmospheric deposition. So far world-wide information for fertiliser and manure is available. The nitrogen input in agriculture by animal excreta is almost equal to the fertiliser-related nitrogen, both around 80 Mton world wide in 1990. More insight in both input streams is necessary to analyse the related N_2O emissions. Unfortunately a detailed balance including other sources of the nitrogen and losses is only available at a more local level. A survey of the nitrogen balance of the Dutch agriculture is given in Table 4.4. This shows that fertiliser and manure are the dominant nitrogen sources[3]. Therefore we will focus this section on fertiliser and manure and their contribution to N_2O emissions.

Table 4.4 *Balance of nitrogen in the Dutch agricultural land 1997 (CBS, 1997) [average kg N/ha]*

Supply	N	Use and losses	N
Fertiliser	200	Crops	226
Manure	261		
Deposition	34		
Crops	10		
Other	10	Soil/Ground water	290

It might be useful to analyse the N_2O emission related to manure storage. But figures related to this item are scares and are too limited for analyses (IPCC, 1997). Therefore these emissions are not taken into account.

4.2.1 Emissions related to fertilisers use

Fertilisers are the main source of nitrogen within the West European agriculture (Cederberg, 1998; LEI-DLO, 1996; CBS, 1999). Distinction can be made between countries and crops related figures, where the country figures show the macro level fertiliser use. Applying regular fertiliser use figures for different crops, to the entire Western European agriculture leads to an overestimation of N_2O emissions. This can be illustrated by comparing several local oriented LCA sources with overall fertiliser use statistics. Table 4.5 shows that use of LCA data, based on North and Middle European production methods, leads to fertiliser use data around 17 Mton nitrogen whereas the current use of N-based fertiliser is around 10 Mton. This overestimation is mainly due to the wide range of fertiliser use standards through Western Europe, from about 190 kg/ha in the Netherlands to about 40 kg/ha in Greece. Realistic modelling of south European crops requires therefore more insight in the relative extensive methods used in this region.

Table 4.5 *Use of Nitrogen LCA-statistics vs. fertiliser statistics (Lysen et al., 1992; Eurostat, 1997)*

Crop	N/ha use	Total N [Mton]	Country/Region	N/ha use	Total N [Mton]
Wheat/Barley	100	3.0	Netherlands	186	0.4
Maize	150	1.3	Belgium/Lux.	110	0.2
Pumpkins	75	0.4	Germany	100	1.8
Other Fodder	70	0.5	France	80	2.4
Rapeseed	200	0.5	UK	88	1.5
Sugar beet	75	0.2	Scandinavia	82	0.8
Potatoes	100	0.1	Greece	66	0.6
Other	100	2.8	Italy	55	0.9
Pastures	150	7.9	Portugal	34	0.1
			Spain	30	0.9
			Rest		1.0
Total		*17.4*	*Total*		*10.5*

[3] Fertiliser and manure use standards in the Netherlands are very high, but even with 50% lower fertiliser and manure use rates, the conclusion remains the same.

The current method for the calculation of the N_2O -emission out of fertiliser use statistics is to assume that about 1.25% (+/- 50%) of the nitrogen added is converted into N_2O. In conclusion, total fertiliser use represents an emission of 60 Mton CO_2 equivalents (uncertainty ± 50%).

4.2.2 Emissions related to manure use

The nitrogen that is available in manure is about 12 million tons, subdivided into about 7 Mton related to cattle farming, and 2.5 Mton related to both sheep and pigs. The nitrogen chemistry of the available streams is complex. Most important sources of nitrogen emission in agriculture are the leaching of nitrate to water and the emission of ammonia (NH_3) to the air. Limited data sources suggest that organic nitrogen sources such as animal manure induce higher N_2O emissions per unit of N added to the soil than mineral nitrogen (N) (Watson et al., 1996). Some of this nitrogen is converted into ammonia and subsequently converted into N_2O. Another fraction is converted into nitrates and subsequently converted into N_2O. Conversion values range from 0.1-0.7% for nitrogen in dung to 0.1-3.8% for nitrogen in the urine fraction (Oenema et al., 1997). In conclusion the emission factors for N_2O from manure are uncertain. Applying a default emission factor of 2% (Smith, Taggart and Tsuruta, 1997) suggests an emission of 125 Mton CO_2 (+/- 50%) equivalents.

5. GHG EMISSION REDUCTION OPTIONS

The following analysis will start with a brief overview of emission reduction options that are related to the current agricultural practice, focusing on CH_4 and N_2O. This chapter will focus on options, which reduce:

- the enteric fermentation related methane emission,
- the nitrogen use and related N_2O emissions,
- methane emission related to manure storage.

The analysis of emissions and reduction options is mainly based on research by Gerbens. (Gerbens, 1999a; Gerbens 1999b) Another important data source is the monitoring of emission because of the Kyoto protocol for reduction of greenhouse gas emissions and several related (IPCC, 1997; EPA, 1998; De Jager and Blok, 1993). Identification of the most important sources will lead to the most important options to reduce the emissions.

5.1 Methane emission reduction

Methane emission reduction is focussed on enteric fermentation processes and improvements in manure storage facilities. Both will be analysed in this section.

5.1.1 Enteric fermentation

A number of strategies exist to reduce these emissions (Gerbens, 1999a):

- increase the conversion efficiency (e.g. optimisation of the level of feed intake),
- substitute roughage by fodder,
- change the fodder composition by addition of concentrates.

Increase efficiency

Because the methane emission is a result of the difficult digestion of ligno-cellulose crops such as grass, a change in fodder pattern towards easier to digest fodder could change the emission related to fermentation. Another way round is increasing the milk or meat productivity of the cattle. This has several advantages. Besides the lower emission of methane it also leads to a lower fodder input requirement for a certain output of milk or meat. This effect is large because a major part of the fodder requirement (and proportional emission) is related to maintenance and a higher production per animal will lead to a decrease of the emission per unit milk or meat. For the Netherlands it is estimated that with the breeding and selection of high productive cows the feed requirement decreases with 10% over a 10-year period.

Substitute roughage by fodder

The increase of the digestibility of the fodder by replacing roughage by (high protein) fodder will lead to a decrease of digestive methane emissions. The use of maize silage seems an important opportunity to increase the digestibility of the fodder and decreases the emissions. Most uncertain is the availability of good quality feed on the local market. The use of residues is cost effective in most cases, but it seems questionable if the roughage/fodder use structure will change drastic.

Concentrates

More reduction can be achieved by adding the right concentrates to the fodder used. Some additives can prevent the methane production by the digestion processes as part of the ruminant digestion. For this purpose several lipids are mentioned. Some additives are fewer fibres containing alternatives as starch and sugars that require less intense digestion and therewith influence the fermentation process. Mean result of this change in feeding pattern is an increase of the meat production per livestock unit. This option is only realistic in case the available grassland can be used for other purposes and the extra meat production can be sold. An overview of the feed conversion improvement methods is given in Table 5.1.

Table 5.1 *Option for the increase of fodder conversion efficiency in Western Europe (Gerbens, 1999a)*

Option	Reduction [Mton CH_4]	Equal milk [% CH_4]	Equal meat [% CH_4]
Improving level of feed intake	0.5	8	6
Replacing roughage by concentrates	0.4	6	8
Changing composition of concentrates	1.1	19	11

Cost estimates for almost all options are negative because the increase in conversion efficiency leads to a higher production with only limited amount of additives. The same livestock produces more meat that automatically leads to a decrease in methane production per kg meat produced.

It is difficult to estimate the reduction potential of these options. The availability of additives and specialised concentrates is limited and a very high control level is necessary. Few analyses pay attention to side effects and changes of the complete agricultural system. The feeding pattern is mostly coupled with available by products and the use of additives as hormones is not publicly accepted. Further requires the use of improved fodder a closer attention to the breeding because the animals are more susceptible to metabolistic disorders (Schiere and Tamminga, 1998).

Other possibilities to increase animal productivity are:
- Alkali/ammonia/urea treatment of low quality roughage.
- Chopping of low quality fodder to improve digestion.
- Adding growth hormones or anabolic steroids. The social acceptance of these methods is very questionable. Most hormonal additives are banned by legislation, many based on the unknown risks when they accumulate in meat or milk for human consumption.

The first two possibilities seems of limited interest in Western Europe were the quality of fodder is controlled and most fodder is already prepared. The estimated methane emission reduction by these methods is <10 kton CH_4.

5.1.2 Manure storage facilities

Storage of manure at outdoor temperatures in the Northwest European climate will decrease the methane emissions by 60-100% compared to storage within the stable at 20°C. Complete emptying and cleaning of manure storage silos will prevent inoculation of new manure. This will slow down the methane production process and reduce emissions by 30-100%, depending on the regular storage period (6 or 2 months, respectively) (Gerbens, 1999b). Direct application of manure can reduce the emissions by 100%. However the costs for long range transportation pose a major obstacle. In conclusion, a reduction of CH_4 emissions by 25-40% seems feasible.

Controlled digestion of manure

The production of methane for energy purposes out of manure by anaerobic digestion has many advantages. The methane can be used and the emissions from the storage or direct use of the manure are avoided. The best method for the digestion depends on several site-specific aspects as the quantity of manure available, the surrounding temperature, the fodder used and the livestock involved. Anaerobic digestion and several other manure-to-energy conversion processes will be analysed within another part of the MATTER-model.

5.2 Increase fertiliser use efficiency

An important part of the European agricultural policy focuses these days on opportunities to decrease the environmental burden caused by the surplus use of nitrogen in the agriculture (LEI-DLO,1996a; Stroney and McKenzie-Hedger, 1997). In most cases an integrated approach with both livestock and crops is used to reach a higher efficiency. Comparisons are mostly based on whole farm analyses.

Table 5.2 *Impact of intensity of farming on greenhouse gas emissions (Loethe, Fuchs and Zeddies,1991)*

		High	Intermediate	Low
Grassland	[ha]	34	34	34
Fertiliser	[kg N per ha]	85	42	0
Net yield of grass	[ton]	94	83	75
Concentrate bought	[ton dry matter]	66	70	77
N_2O emission	[kg]	190	112	65
CH_4 emission	[ton]	9.9	8.8	8.0
CO_2 emission related to fossil energy use and concentrate and fertiliser production	[ton]	65	55	57
GHG emissions	[ton CO_2 eq.]	331	269	235
Milk production	[ton milk]	453	433	428
GHG emissions	[kg CO_2 eq./kg milk]	0.73	0.62	0.59

Table 5.2 shows three dairy farm types with different intensity of fertiliser use. A lower use of fertiliser leads to a lower yield of grass. The nutrient deficiency is compensated with concentrate bought. The indirect energy requirement of the concentrate production leads to an increase of the indirect CO_2 emission for the low farm related to the intermediate farm. The high indirect energy requirement of the high intensity farm is related to fertiliser production. Concerning the emission of greenhouse gases this example shows that the N_2O emission is decreased by $^2/_3$ in the low intensity farm. This is caused by both lower fertiliser use standards and lower amounts of nitrogen in the manure produced. The decrease in methane production is related to the increase in concentrate used as fodder. This is not in line with ‘traditional’ low intensity farming systems. Research on extensive agriculture with lower concentrate use and high levels of grass use show that in this case the methane emission would increase by 12-15% because of the lower digestibility of the fodder (Cederberg, 1998).

Large scale uses of ecological and integrated farming methods within the EU were already found in Finland and Austria (OECD, 1998). The intermediate system seems to integrate the best of both systems. The milk production remains high, with a 20% reduction of greenhouse gas emissions.

When overall GHG emissions mitigation is analysed this is questionable. The reduction of GHG emissions is small in comparison to the emission reductions that can be achieved through increased biomass use (e.g. (Kaltschmitt and Reinhardt, 1996)). For this reason, it is not considered a sensible strategy from a GHG policy point of view. Off course other environmental considerations such as eutrophication can pose important incentives for an extensification strategy. Because of the GHG focus of this analysis, it has not been considered in more detail.

Slow release fertilisers

A more technical solution to improve the efficiency is the use of slow-release fertilisers. Until now these fertilisers are relatively expensive and their use is limited because of the low prices of conventional fertilisers. With the expected EC and USA legislation concerning the run off of nutrients it is necessary for the industry to continue developing this kind of fertilisers (Shelley, 1994).

Based on several sources Gerbens (1999b) assumes that an increase of 20% of the fertiliser nitrogen use efficiency is possible within the Western European agriculture. These figures seem rather optimistic because practical applications still seem far away (Vance, 1997).

In conclusion an emission reduction of 20-40% seems feasible for synthetic fertilisers. For natural fertilisers, an emission reduction of 10-20% seems feasible. Total agricultural N_2O emissions can be reduced by 15-25% based on technological changes in the current production structure.

5.2.1 Alternative artificial nitrogen sources

Decrease of fertiliser use is already a major item within the environmental policy of many European countries. Many different regulations were introduced during the last decade in order to decrease the fertiliser use standard (Storey and McKenzie-Hedger, 1997). In some case the decrease is already reported. A more environmental practice may lead to a major decrease in fertiliser use next decades.

Fertiliser use standard can be decrease by the use of biological sources for nitrogen or by the use of slow release fertilisers. Within an analysis of options to improve the energy efficiency of N-fixation De Beer (1998) distinguishes several options for biological fixation. The three main sources are:

1. *Symbiotic systems.* This is a natural source of nitrogen but in some cases micro-organisms can be added to the soil to increase the fixation.
2. *Genetic Engineering of crops to enable symbioses*. In this case plants are genetically manipulated to make symbiotic nitrogen fixation possible.
3. *Genetic engineering of crops to enable nitrogen fixation.* In this case crops are genetic changed in such a way that they can fix nitrogen themselves.

The use of biological fertilisation is interesting but requires a high research effort and drastic change within the agricultural practice. Therefore it is very unlikely that biological fertilisation will become common practice within the next decades. The research is developing fast and promising but prospects cannot yet been given. It is still focused on the fundamental methodological issues (Vance, 1997).

5.3 Meat and fodder substitution

The agricultural production satisfies a certain demand, which means that changes in demand pattern also influence production and the related processes and emissions. The analysis of the agricultural production in Chapter 3 shows that meat consumption is by far the most important final use of agricultural products, both for land use and production. Decrease of meat consumption would for that reason have a significant impact on both land availability and agricultural related emissions.

Three developments can be distinguished which might influence the meat consumption or the meat consumption related structure. These are:

- Structural change of consumption pattern.
- Replacement of meat by other protein sources.
- Use other protein sources as fodder.

Consumption pattern

Higher fish consumption is a main option to reduce the meat consumption and the related fodder use. Total fish supply in Europe (including Eastern Europe, Finnish, shellfish and aquatic plants) amounted to 18.1-kg protein intake per citizen in 1995. This suggests a total fish landing of 6.3 Mton (based on (FAO, 1999)). Fish products represent approximately 9% of the total protein intake. An increase of fish consumption could decrease the meat demand. Another option is a shift to pulses and other protein sources. An analysis of the West European food pattern shows that an 80% decrease in meat consumption is possible within a healthy pattern (Lehmann, 1996). The importance of meat production within the agriculture as shown in this analysis, shows that this option could help with the creation of more land for biomass production and the decrease of agriculture related GHG emissions.

Replacement by other proteins
Technology to replace meat by other protein sources is already available. These are high protein products, mostly produced by micro-organisms. This so-called novel protein food should be able to replace 40% for the Dutch meat production (DTO, 1997). This is mostly the meat used for prepared food such as sausages and soups. The social acceptance of these products is very uncertain. The preliminary state of the technology makes that potentials and cost estimation are not found in literature.

Substitution of fodder
An example is the conversion of natural gas into proteins by micro-organisms. This process normally takes place by deep-sea circumstances. A Norwegian company, Norfern, now introduces the production of protein for the fish industry by controlled micro-organisms in a plant in Norway. They use 20 million m^3 natural gas to produce 10 thousand ton protein. The reaction requires also ammonia, oxygen and some minerals. For the next decades it is supposed to be a serious competitor to Soy for fodder use, but foresights are very unclear and so far not considered (Didde, 1999; DTO, 1997).

6. LAND QUALITY ANALYSIS

The range of different soils, climates, vegetation, and topography has a significant impact on the possibilities for different uses within the EU. Some Northwest European regions have high precipitation and very fertile soils with on the other site Mediterranean regions were precipitation and poor soils are the limiting factors for agricultural use (Lee, 1991). This is of major importance when land use changes are taken into account. For example South Europe has a significant land use for oil crops which are relative poor ground. This land can not be used for high productivity energy crops. The suitability is related to soil type, precipitation and slope. The last one mainly influences erosion risks and the suitability for mechanisation. In most South European countries almost 50% of the land has a slope over 15% which makes it less useful for plantations. This and more aspects of land suitability are defined within an agricultural soil map for both pastures and arable land. This map distinguishes 4 arable and 5 grassland classes, which are not complementary. Figure 6.1 shows that for middle European countries useful agriculture land is more than land in current use. This means that land quality is no necessarily limitation for the productivity within the scenarios. For Southern Europe it shows that only 22% of the land is suitable for either pastures or crops. This means that more than half of the current agricultural land is poor soils with limited potentials. Therefore we should not define this land as available for all crops.

For this reason we will split the south European area in two soil types, 50% with high productivity levels and about 50% of the South European land as low valuable land only useful for oil-crops and some wheat and grass. Productivity figures will be lower in this region. The observation is in line with the data found in Table 3.2 that shows that average productivity figures in Southern Europe are significant lower compared to Middle and North European figures.

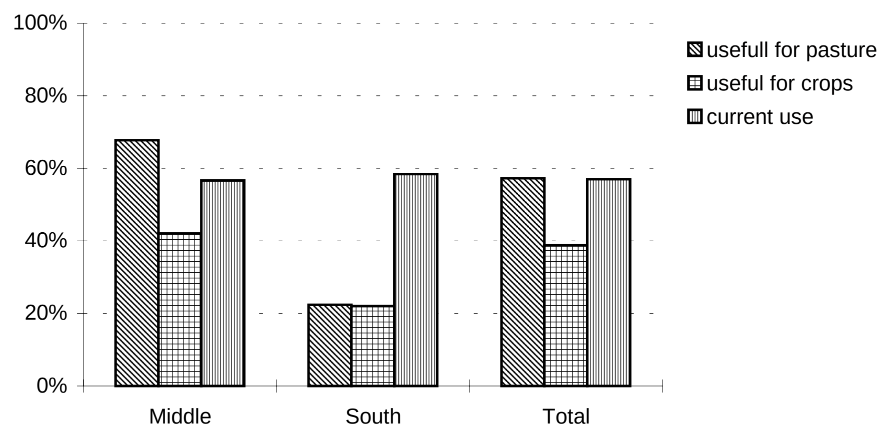

Figure 6.1 *Percentage of the land area suitable for grassland and arable land compared with the percentage current used for pastures and crops according to FAO-statistics*

7. CONCLUSIONS

Agriculture constitutes an important source of CH_4 and N_2O emissions. Together these emissions constitute about 7% of the total western European GHG emissions. On the other hand, biomass from agricultural crops can contribute to GHG emission reduction through substitution of fossil fuels and substitution of materials. Both aspects must be considered in the MATTER model that focuses on GHG emission reduction in Western Europe. Western European agriculture is diverse because of regional climatological conditions, soil quality and cultural differences. This complexity is simplified in a MATTER module that characterises the main elements. Ten agricultural crop types cover about 90% of the agricultural land in Western Europe. The pastures alone cover about 40% of the agricultural land use. Three quarters of the land use can be allocated to animal products: meat, dairy products, eggs and wool. For this reason, meat production and meat consumption deserves most attention. Land quality and land productivity has been considered through a split into three regions: North and Middle Europe, Southern Europe high yields and Southern Europe low yield. The split for Southern Europe is important because 50% of the land area in Southern Europe that is characterised as agricultural land has actually a very low productivity because of water availability constraints and mountainous topography. Generally speaking, yields in middle Europe are higher than the yields in southern Europe.

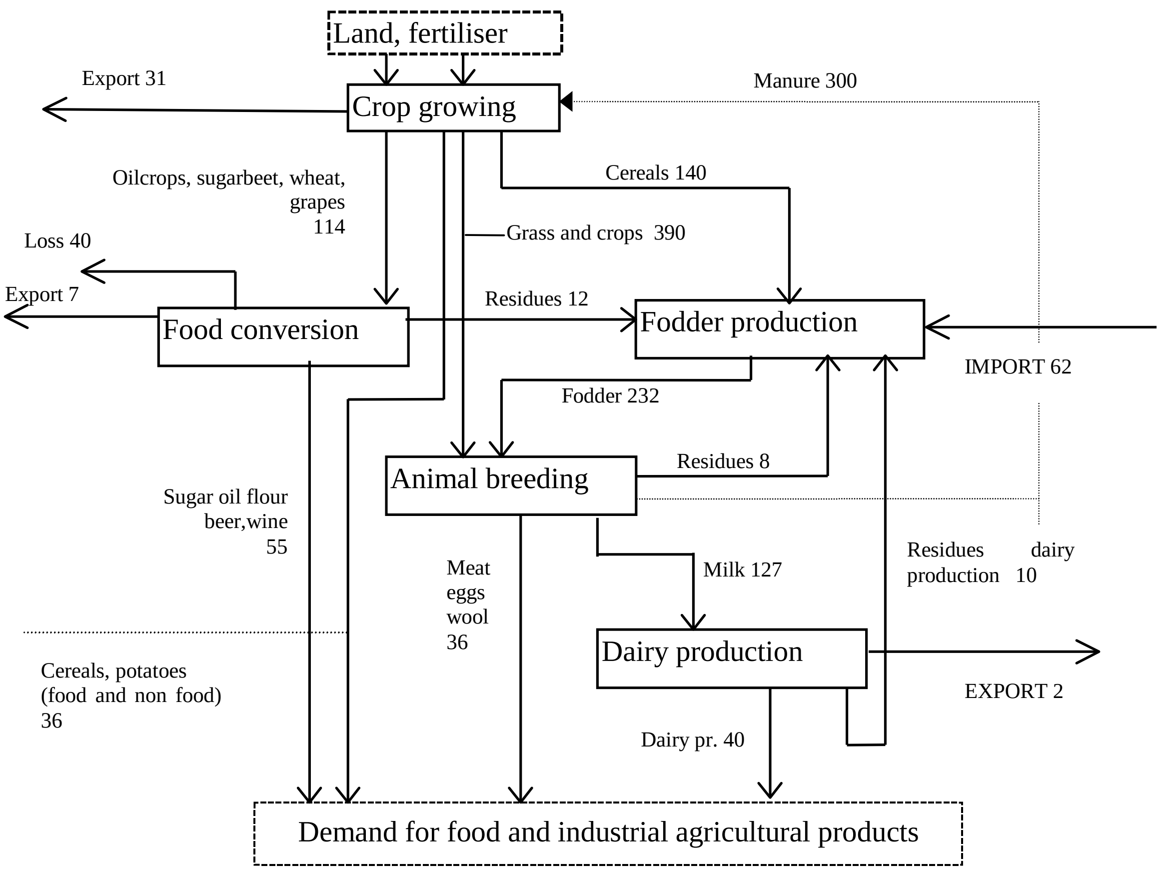

Figure 7.1 *The agricultural system 'from crop to food'. All stream quantities are given in Mton (dry matter except milk and dairy products, uncertainty +/- 25%)*

A material flow analysis for western European agriculture is shown in Figure 7.1. Total agricultural crop production amounts to 710 Mton dry matter. Cereals and grasses constitute together more than 50% of the biomass yield. Considerable uncertainty exists with regard to the grass yield. About 500 Mton plant biomass is used as fodder for the production of 35 Mton meat and 12 Mton dairy products (expressed in weight units dry matter). The weight efficiency is about 10%. The energy content of animal products is approximately twice as high as the plant biomass energy content. Comparison of fodder input and animal product yield suggests an average energy efficiency of 20%. Part of the efficiency loss can be attributed to the animal metabolism (heat and movement losses). Methane emissions constitute another important efficiency loss factor for ruminants, representing 6% of the weight input (10-15% of the energy input). 300 Mton manure represents another important loss factor (50-60% of the energy input). Finally a factor 2 difference exists between the living animal weight and the carcass weight (bones, skin etc.).

Western European livestock husbandry causes a methane emission of 8 kton per year due to digestion processes. Cattle account for 80% of this emission. The methane emission related to manure storage is about 3 kton per year. Few viable options exist for reduction of emissions related to ruminant digestion. Main strategies are based on increased efficiency of fodder conversion (the same production with less fodder input) and a shift from grass and straw to prepared fodder. These options can reduce the methane emissions by 25%. The costs for these emission reduction options are small or even negative. However, the trend towards extensification and more natural production methods may pose constraints.

Agricultural N_2O emissions are related to the use of nitrogen fertilisers. Many research projects give insight in emissions sources but most information is very site specific and less relevant for an overall analysis. Total emissions are in the range of 300-400 kton N_2O. Reduction of these emissions can be achieved through improved efficiency of fertiliser use. Slow release fertilisers and new fertiliser composition can result in a 20% reduction of fertiliser use. Further changes in consumption pattern are a major source of uncertainty especially in case of replacing animal proteins by proteins made by micro-organisms. This is a typical case for further sensitivity analyses.

REFERENCES

Adger W.N, D. Pettenella and M. Whitby: *Climate-change Mitigation and European Land-use Policies, CAB International*, Wallingford, Oxon, UK. 1997.

Alcamo ed. IMAGE 2.0: *Integrated Modelling of Global Climate Change*, Kluwer Academic Publishers, Dordrecht, 1994.

Beer J.G. de: *Potential for industrial Energy Efficiency Improvement in the Long Term.* Thesis; Faculty of Chemistry, Utrecht University, Utrecht; November 1998.

Behmel U: *Energy Related Processing of Organic Wastes in Agricultural Biogas Plants in Combination with the Effictive Use of Fertilisers,* Proceedings of the 10th European Biomass Conference, Würzburg, June 1998 pp. 156-159.

Brand R.A. and A.G. Melman: *Energie-inhoudnormen voor de veehouderij, deel 2, proceskaart Melasse* (In Dutch), TNO -IMET, Apeldoorn, 1993.

Brown L., H. Kane, D.M. Roodman: *Vital signs - The trends that are shaping our future 1994/1995,* Worldwatch Institute 1994, pp. 30.

CBS: *Kwartaalbericht Milieustatistieken* (In Dutch) 1998-4. pp. 41-53, CBS Voorburg, Netherlands, 1999.

CBS: *Kwartaalbericht Milieustatistieken* (In Dutch) 1997-4, CBS, Voorburg, Netherlands, 1998.

CBS: *Kwartaalbericht Milieustatistieken* (In Dutch) 1997-3, Voorburg/Heerlen, 1997.

Cederberg C.: *Life Cycle Assessment of Milk Production*, Swedish Institute for Food and Biotechnology, Rapport 1998-643, Goteborg, Sweden, 1998.

Didde R.: *Aardgas om op te eten,* (In Dutch) De Volkskrant 2-1-1999

DTO-Voeding: *Spectrum voor een duurzame voedselvoorziening*, (In Dutch) onderzoeks-programma Duurzame technologische Ontwikkeling, Uitgeverij ten Hagen & Stam b.v. 1997.

EA, Australian departement of environment, http://www.environmnet.gov.au/portfolio /epg/Environet/ncpd/auscase_studies/woolscour.html, 1999.

EC, European Commission DG 6: Agricultural statistics on the internet. http://europa.eu.int/comm/dg06/agristat/table.en/4144.pdf (01-06-1999).

El Bassam N.: *Energy Plant Species, Their use and impact on environment and development,* James and James, London 1998.

EPA, Inventory of U.S.: *Greenhouse Gas Emissions and Sinks 1990-1996*, EPA report 236-R-98-006, March 1998.

Eurostat: *EU statistic yearbook 1997*, Luxembourg, 1997.

Eurostat, European Commision: *Panorama of EU industry*, Luxembourg, 1998b.

Eurostat, Jaarboek ’97: *Een statistische blik op Europa 1986-1998* (In Dutch), 1998a.

FAO, information on internet: http://www.fao.org/waicent/faoinfo/fishery/publ/circular/ c886.1/europe2.htm, 1999.

FAO, statistical database on internet http://www.fao.org/lim500/ several databases, 1998.

Geodes: *Onderzoek naar toegevoegde Waarde Activiteiten voor Agribulk in Rotterdam, in opdracht van Gemeentelijk Havenbedrijf Rotterdam*, Giessen, December 1996.

Gerbens S.: *Cost-effectiveness of methane emission reduction from enteric fermentation of cattle and buffalo*, Department of Agricultural, Environmental and System Technology (AEST), Agricultural University Wageningen. Draft Report, Januari 1999a.

Gerbens S.: *Cost-effective Methane and Nitrous Oxide emission reduction technologies for animal waste*, Department of Agricultural, Environmental and System Technology (AEST), Agricultural University Wageningen. Draft Report, Januari 1999b.

Gerlagh T.: *Biomass for Greenhouse Gas Emission Reduction, Western European land availability 2000-2050*, ECN-report C--98-109 Petten, 1998.

Gielen, D.J.: *(et al.)* P.R. Koutstaal, T. Kram and S.M.N. van Rooijen, *Post-Kyoto, Effects on the Climate Policy of the European Union*, ECN-report C--98-040, Petten, June 1998.

Gielen, D.J., T. Gerlagh and A.J.M. Bos: *Biomass for Energy or Materials, A Western European MARKAL MATTER 1.0 model characterisation*. ECN-report C--98-099, November 1998.

Groenendaal B.: *Autarkisch Nederland: een onderzoek naar verschillende voedselpakketten en het bijbehorende energieverbruik*. (In Dutch) IVEM docteraalverslag 47, Groningen, 1996.

IPCC, Guidelines for National Greenhouse Gas Inventories: *Part 3: Greenhouse Gas Inventory Reference Manual*. 1997.

Jager D. de and K. Blok: *Cost-effectiveness of emission-reducing measures for methane in the Netherlands,* Ecofys report M702, Utrecht, Netherlands May 1993.

Jager D. de and K. Blok: *Emission reduction potential and costs for non-*CO_2 *greenhouse gases in the EU-15,* Fourth International Conference on Greenhouse Gas Control Technologies, Interlaken, August 30-September 2, 1998.

Kaltschmitt M. and G.A. Reinhardt: *Nachwachsende Energietraeger; Grundlagen, Verfahren, oekologische Bilanzierung*, (In German) Vieweg Verlag; Braunschweig/Wiesbaden, 1997.

Kaltschmitt M., G.A. Reinhardt (eds.): *Ganzheitliche Bilanzierung von nachwachsenden Energieträgern unter verschiedenen ökologischen Aspekten,* (In German) Vieweg, Braunschweig, 1996.

Lee J.: *Land Resources, Land use and Projected Land Availability for Alterative uses in the EC. In Land Use Changes in Europe*, Processes and Change, Environmental Transformations and Future Patterns, ed. by F.M. Brouwer, A.J. Thomas and M.J. Chadwick, The Geojournal Library, Kluwer Academic Publishers, Dordrecht, Netherlands. pp. 1-20, 1991.

Lehmann H., R. Paryke, A. Pfluger, T. Reeze: *Sustainable land use in the European Union.* Proceedings of the 9th European Bioenergy Conference; Copenhagen, Denmark 24-27 June 1996, pp. 1727-1731, Pergamon Press, Oxford 1996.

LEI-DLO: *Landbouw Milieu en Economie; editie 1996*, (In Dutch), Den Haag, 1996a.

LEI-DLO: *Landbouwcijfers 1994*, (In Dutch) pp. 98, pp. 115 en pp. 216, Den Haag, 1996b.

Leng R.A.: *Quantitative Ruminant Nutrition- A Green Sience, Department of Biochemistry, Microbiology and Nutrition*, University of New England, Anmidale, N.S.W. 2351. (http:/ciesin.org/docs/004-180/004-180.html, 9-11-1998).

Loethe K, C. Fuchs and J. Zeddies: *Reduction of Emissions in Farming Systems in Germany, in Land Use Changes in Europe, Processes and Change, Environmental Transformations and Future Patterns*. ed. by F.M.Brouwer, A.J. Thomas and M.J. Chadwick, The Geojournal Library, Kluwer Academic Publishers, Dordrecht, Netherlands, pp. 159-169, 1991.

Lysen E. et al.: *De haalbaarheid van de produktie van biomassa voor de Nederlandse energiehuishouding*. (In Dutch) Novem rep nr. 9208, Utrecht, 1992.

Moller H, M. Vold, K. Toresen, I. Ormstad: *Life Cycle Assessment of Pork and Lamb Meat*. In: D. Ceuterick (ed.): International Conference on Application of Life Cycle Assessment in Agriculture, Food and non-Food Agro-Industry and Forestry: Achievements and Prospects. VITO, March 1996.

Moller H., M. Vold, K. Toresen, I. Ormstad: *Life Cycle Assessment of Pork and Lamb Meat*. In: D. Ceuterick (ed.): International Conference on Application of Life Cycle Assessment in Agriculture, Food and non-Food Agro-Industry and Forestry: Achievements and Prospects. VITO, March 1996.

OECD: *The Environmental Effects of Reforming Agricultural Policies*, Paris, France 1998

Oenema O., G.J. Velthof, S. Yamulki and S.C.Jarvis: *Nitrous Oxide Emissions from Grazed Grassland* Soil Use and Management 13 pp. 288-295 (1997).

Orenblad, H.: *Biogasproduction and potential in Europe*, Proceedings Seminar, Boosting the market for bioenergy in Europe, 19-21 October 1998, Denmark, Part of EU-ALTENER-program.

Schiere H., S. Tamminga: *Assessment of Biotechnology in Animal Nutriotion*, Biotechnology and Development Monitor Journal, No. 27, pp. 9-11, no dated, Wageningen Agricultural University, http://www.zod.wau.nl/dps/diskette.htm (24-11-1998).

Smith K.A., I.P. Mc Taggart, H. Tsuruta: *Emissions of N_2O and NO associated with nitrogen fertilization in intensive agriculture, and the potential for mitigation*, Soil use and management 13, 1997, pp. 297-304.

Spangenberg J.H. et al.: *Towards Sustainable Europe: A summary: A Friends of the Earth International Discussion Document*, Wuppertal Institute for Climate, Environment and Energy, Friends of the Earth Europe, Brussels, January 1995.

Storey M, and M. McKenzie-Hedger: *Agricultural Policy Reform and Climate-Change Mitigation in Organization for Economic Coorperation and Development Countries*. In Climate-change Mitigation and European Land-use Policies, ed. W.N.Adger, D.Pettenella and M.Whitby pp. 23-34. CAB International, London, UK 1997.

Uitdenbogerd D.E.: *Energiebeslag van de huishoudelijke voedselverzorging. Een empirische analyse van activiteiten en voedselpatronen*. (In Dutch) ECN-I--95-010. Petten, May 1995.

University of Vermont Animal Science Department, Internet information: http://asci.uvm.edu/bramley/beef.html (1999).

Vance, C.P.: *Enhanced Agricultural sustainability through biological nitrogen fixation*; Proceedings of the NATO Advanced Research Workshop ‘Biological Fixation of Nitrogen for Ecology and Sustainable Agriculture’, Poznan Poland September 10-14, 1996; ed. by A. Legocki; Springer Verlag, Berlin, Heidelberg, New York 1997.

Wams T. (ed.): *Investeren in duurzame ontwikkeling, Twee sectorstudies: huishoudens en varkensvlees productie* (in Dutch), Milieudefensie, Amsterdam, February 1993.

Watson B. et.al.: *Climate change 1995. Impacts, Adaptions and Mitigfation of Climate Change: Scientific -Technical Analyses*, Contribution of WG II to the Second Assessment Report of the IPCC, Oxford University Press, 1996, pp. 762.

Watson R.T, M.C., Zinyowera and R.H. Moss: *Technologies, Policies and Measures for Mitigation Climate Change*, Technical Paper of the IPCC, IPCC working group II, November 1996.