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Options and Trade-offs: Reducing Greenhouse Gas Emissions from Food Production Systems

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Sanderine Nonhebel

INTRODUCTION

Agriculture is producing food for the worlds' population and is therefore a sector of vital importance. The amount of food required depends on the size of population and consumption per capita. The FAO (Bruinsma, 2003) estimates that a 50% increase in global food production in the next 30 years is needed to feed the global population. This increase in needs is caused by an increase in the global population (from 6 to 8.3 billion people) and by a change in consumption patterns. The change in consumption includes not only the consumption of more food per person, but also an increase in the consumption of more luxurious products like livestock products as milk and meat. Since it requires 4 kg of wheat (as feed) to produce one kg of pork (Nonhebel, 2004), the increased consumption of meat requires yet a larger increase in agricultural production.

The present agricultural practices, however, already put an enormous claim on the local and global environments. Agriculture is the main cause for pressures on the environment, including deforestation, loss of biodiversity, land degradation, salinization, over extraction of water, emission of some categories of greenhouse gasses and ammonia, leaching of nitrates etc. The 50% increase in food production without a large increase in environmental impacts will be a challenge for the coming decades.

Food production can occur in very different ways, varying from so called extensive systems, where hardly any external inputs are used to very intensive production systems which require large amounts of external inputs (chemical fertilizers, pesticides, machinery etc.). The extensive systems are characterized by low inputs and low yields per ha and the intensive systems by high inputs and high yields per ha. Different systems have different effects on the environment. Low input systems show low emissions but require vast amounts of land, while the high input systems show large emissions to the environment but require a smaller acreage to produce the same amount of food.

In principle, an increase in food production can be obtained via different routes: increase of the land used for food production or increase in the production per hectare (intensification). The FAO estimates that 80% of the required food

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production increase will be obtained from intensification, while the other 20% will be obtained through expansion of land use (Bruinsma, 2003). This implies that with respect to the environmental impacts of increased food production, the environmental effects associated with intensification will be the most important.

To obtain an impression of the possible environmental implications of this increase in global food production, the history of agriculture in Western Europe can serve as an example. In the last 30 years intensification in West European agriculture took place. As a result of the technical improvements in agriculture, the yields per ha nearly doubled (FAO, 2003). The technical improvements included a variety of activities like improvements of crops through breeding, expanded use of chemical fertilizers and pesticides, better water management, increased knowledge of the farmer etc. However, this yield increase per hectare came along with the increase of the emissions of nitrates and ammonia causing regional eutrophication and acidification.

In the 1980s environmental regulations were introduced in agriculture to reduce its effect on the environment. In The Netherlands, these regulations resulted in a 30% reduction in agricultural emissions of nitrates and ammonia (RIVM, 2001). This shows that changes in farming practices can lead to a large reduction in emissions.

Agriculture has recently been recognized to be an important source of the greenhouse gasses methane and nitrous oxide. Not much research has yet been done on options to reduce these emissions. The FAO estimates that a 50 percent increase in production will therefore come with a similar magnitude increase in methane and nitrous oxide emissions.

The purpose of this chapter is to inventory options to reduce greenhouse gas emissions related to the production of food. Experience obtained in the past decade with respect to reduction of the nitrate and ammonia emissions shows that such reductions require changes in production techniques and substitution of other resources. These other production techniques may lead to unwanted effects in other parts of the system. To prevent problems arising elsewhere attention must be paid to trade-offs with other environmental themes as well as trade-offs with food security. This chapter will present such an analysis with the situation in the Netherlands used as the starting point.

DESCRIPTION OF THE NETHERLANDS AGRICULTURAL SYSTEM

The Netherlands agricultural system can be characterized as a high input system (large inputs per ha resulting in high yields). The inputs per ha (fertilizers) are the highest in the world, and so are both crop yields per ha, and milk production per cow (LEI, 2003; FAO, 2004). Agriculture and food production put a large claim on available resources and cause large emissions to the environment. In the Netherlands, about 60% of the land is in use for agricultural production and agriculture is the largest fresh water user. Further, agriculture is the major cause of the eutrophication and acidification problems (RIVM, 2001). About 90% of the nitrogen and phosphorus emissions originate from agriculture due to fertilization of crops, both by applying manure and chemical fertilizer. With respect to acidification over 40% of the national NH_3 emissions are due to the application of manure.

During the last decade several measures were taken to reduce the environmental impacts of agriculture. An example is the so called sod-injection technique. During the application of manure to soils large amounts of ammonia are emitted. To reduce these emissions the so-called sod injection technique was developed. With this system, manure was applied in the soil (at a depth of 5 cm) instead of on the soil surface. The adoption of this technique led to an enormous decline in the ammonia emissions (a 30% reduction). Another example is the mineral accounting system (MINAS) - a management system which gives farmers insight in the phosphorus and nitrogen surpluses on their farm that involves limits to emissions to the surroundings. The introduction of this system led to a 30% reduction of the phosphorus and nitrogen emissions (RIVM, 2001).

In addition to these adaptations in conventional production systems, an increased interest in other, more environmental friendly production systems can be observed. Subsidies are available to support farmers changing from intensive production systems to organic production systems. A policy goal states that by 2010 10% of the Netherlands agricultural production should be organic, rising from a level of 3% in 2004 (LNV, 2004).

The fact that agriculture is also a source for methane and nitrous oxide is only recently recognized. Inventories are currently being undertaken to the sources of these emissions (Novem, 2004). No overview exists with respect to the possible of the trade-offs of the potential greenhouse gas reduction options with other environmental emissions and food production.

ENVIRONMENTAL IMPACTS OF THE PRODUCTION AND CONSUMPTION OF FOOD

To gain insight in the trade-offs of GHG emission reduction options, methodologies developed in environmental sciences are applied. This section starts with a short description of the applied methods.

Environmental impacts of a production process can be studied from production and consumer side viewpoints. Approaching the problem from the production side implies that one determines the emissions related to a specific production process or a production sector. Approaching the problem from the consumer side implies the determination of the emissions related to consumption of certain products. Studying it from the production side implies that one is interested in the emissions occurring in a region (including the emissions required for the production of exports). Studying the problem from the consumption side implies that one is interested in all the emissions required to produce and transport items that are consumed/purchased in a region. This starting point includes the emissions abroad required for the imported goods.

Since production only occurs when there is consumption, on a global scale the total emissions calculated from the production side are equal to the total emissions calculated from the consumption side. At the level of a nation, imports and exports interfere with these results. A country that produces a lot for export will show large emissions in the production side analysis, but the emissions analyzed from the consumption side will be much lower. On the other hand, a country that imports all of its consumption will show no emissions in a production side analysis but large emissions from a consumer side analysis.

Greenhouse gas emissions from the production side

Examination of the Netherlands greenhouse gas (GHG) emissions from the production side results in the following observations. Total GHG emissions in the Netherlands are 220 10^9 kg CO_2 equivalent (RIVM, 2001) of which CO_2 is the most important. The CO_2 emissions arise mainly due to the use of fossil energy sources for needed production energy. Figure 12.1 shows CO_2 emissions by production sector. Energy production, transport and industry produce the largest amounts. The emissions by the agricultural sector are only 5% of the country total. Within this sector the heated glasshouses in horticulture are the largest emitters.

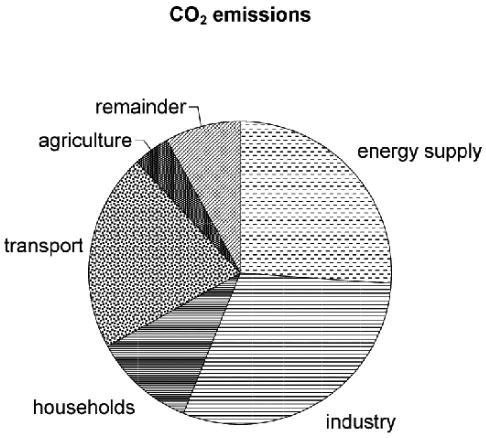


Figure 12.1 Contribution of the various production sectors to the total national CO_2 emissions in the Netherlands
Source: RIVM (2001).

When we focus on other greenhouse gasses, we find that the agricultural sector plays an important role with respect to the emissions of CH_4 and N_2O. Figures 12.2 and 12.3 show these emissions by sector. Nearly 50% of the national N_2O emissions occur in agriculture. This is mainly due to de-nitrification processes in soils resulting from application of manure and chemical fertilizers. Emissions from grasslands (dairy production) hold the largest share. A large part of the N_2O

emitted in industry is also associated with agriculture: the production of chemical fertilizer involves substantial emissions of N_2O (Kramer, 2000).

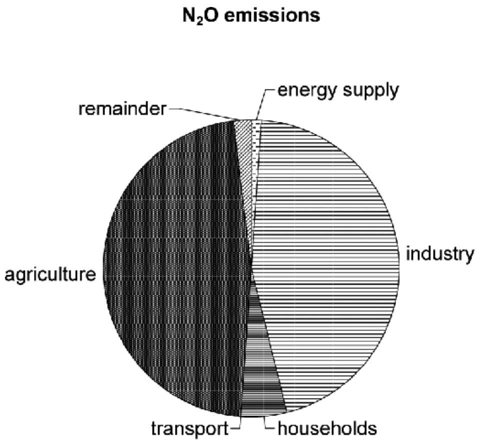


Figure 12.2 Contribution of the various production sectors to the total national N_2O emissions in the Netherlands
Source: RIVM (2001).

In terms of methane, 42% of the national CH_4 emissions originate from agriculture (figure 12.3). Enteric fermentation processes in ruminants (cows and sheep) are the largest suppliers, with again dairy farming being the largest contributor.

The above information is suggestive of several options to reduce national GHG emissions. The most extreme option is cessation of agricultural production in the Netherlands. The information in Figures 12.1, 12.2 and 12.3 indicates that this would result in a decline of 5% in CO_2 emissions, 50% in N_2O emissions and 40% in the CH_4 emissions. It is obvious that this is only a theoretical option, but in an analysis of possible trade-off's it is interesting to evaluate the consequences. It should be realized that options as 'decline production' in general or 'decline of the number livestock' are just milder forms of this option.

Another option involves greenhouse gas emission reducing improvements in the production system. Agricultural production can take place via various routes and up to now improvements were focused on the reduction of the acidification and eutrophication problems related to agriculture. The reduction of the GHG emissions from this sector has not received a lot of attention, and thus it is likely that there are opportunities that will lead to reduced emissions.

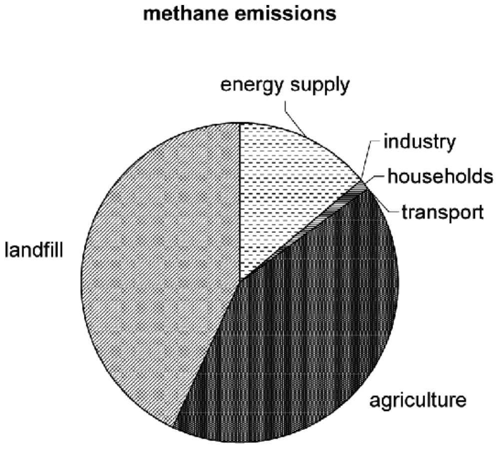


Figure 12.3 Contribution of the various production sectors to the total national CH_4 emissions in the Netherlands
Source: RIVM (2001).

Greenhouse gas emissions from the consumer side

The production side data were obtained from environmental statistics. Estimation of emissions related to consumption requires quite different methodologies. Life cycle analysis (LCA) methodologies (Rebitzer et al., 2004) are the most suitable tools. Initially LCA was developed to assess the environmental impacts of industrial processes; recently the method is also applied to agriculture (Audsley et al., 1997). It determines the environmental impacts of a product from cradle to grave, accounting for all the processes involved in manufacturing, transport and consumption of the product, this includes the extraction of the raw materials to possible waste treatments. Conducting an LCA involves a lot of information and a lot of work. To give an example: to calculate the environmental impacts associated with consumption of a litre of milk it is necessary to determine all the impacts required to get a litre of milk on the table of the consumer. This includes consideration of the impacts of farming practices; producing the fertilizers used on the farm; cooling, processing, packaging and transporting the milk from the farm via the dairy factory and the supermarket to the consumer; along with the waste treatments required to discard the packages.

In principle, when the environmental impact of all consumer goods is known the environmental impact of the total consumption can be determined by multiplying the environmental impact per unit of the product by the number of units of the product purchased.

The large amount of work involved in such an analysis makes it practical for only a limited number of products. This implies that there is no overview for the total environmental impact of the total consumption bundle. Only an energy based LCA exists with respect to the total consumption bundle. Namely, Kok et al. (2001) analyzed the energy requirements of over 350 products and services (including food, music lessons, bicycles, clothing etc.) starting with the energy required to extract the raw materials to the energy involved in the waste treatments. Figure 12.4 shows some of their results. Half of the energy attributed to households concerns heating, electricity, and transport (petrol for the car) and the other half has to do with product consumption and accounts for energy that was used elsewhere in society. In this 'consumption half' food is a major player.

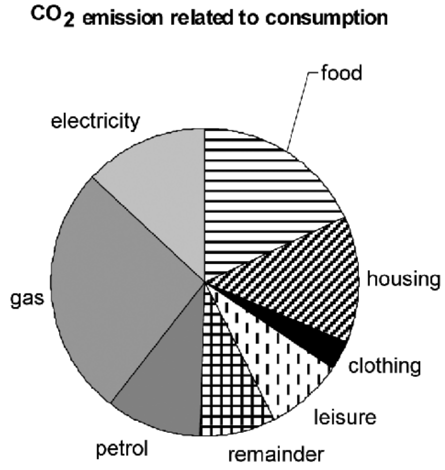


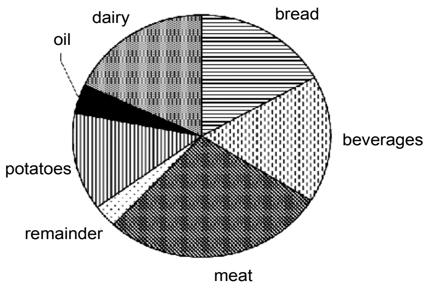
Figure 12.4 Distribution of the CO_2 emissions related to consumption over the different spending categories
Source: Vringer and Blok (2000).

This large contribution of food to total energy requirements is quite in contrast to what is found in the production perspective (where agriculture only accounted for 5% of the national energy use). This is because energy used in other sectors than agriculture is substantially used in association with consumed food. In a consumer oriented approach the energy used for transporting food is attributed to food, while in a production-oriented approach it is attributed to the transport sector. A comparable situation exists for the industrial sector. In a consumer oriented approach, the energy used in the food industry is attributed to food as is the energy used in the fertilizer industry.

With respect to food a detailed study exists in which CO_2, CH_4 and N_2O related to over 150 food items were examined (Kramer, 2000). In that study, greenhouse gas emissions along the complete production chain were analyzed and those results will be discussed in detail.

The 150 food commodities are grouped into categories. ‘Bread’ aggregates products where grains (wheat, rice, maize) are the major ingredients like breads, cakes and pastry, but also pastas. ‘Potatoes’ represents potatoes and vegetables and fruits, ‘Beverages’ aggregates beer, coffee, tea, fruit juices, but also confectioneries. The category ‘Meat’ concerns all meat and fish products, ‘Dairy’ includes milk, yogurt, butter and cheese, the ‘Oil’ category involves vegetable oils and fats to fry, ‘Remainder’ includes spices and ready to eat meals.

Figure 12.5 shows the emissions related to these different categories. One should realize that emissions related to consumption depend on both emissions per unit and the amount consumed. The emissions related to an exotic fruit can be very high, but when the volume consumed is small then the contribution to national emissions is low. This also holds the other way round: the emissions of for instance a unit of milk may be low, but since it is consumed in very large quantities the overall impact can be high.


CO_2 emissions related to food consumption

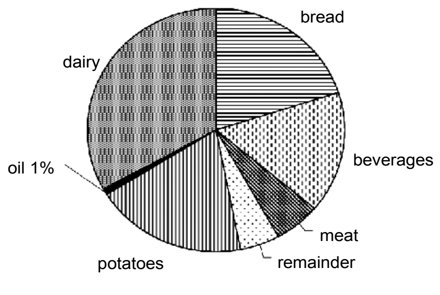
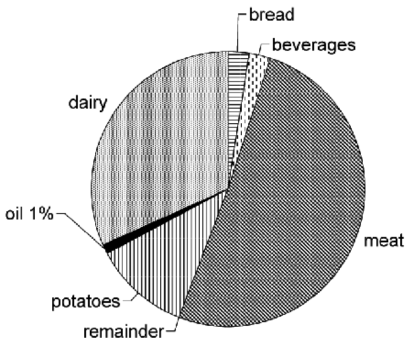

N2_O emissions related to food consumption

Figure 12.5 Distribution CO_2, CH_4 and N_2O emissions and CO_2-equivalents over various food product categories in the Dutch food consumption package

Source: Kramer (2000).


methane emissions related to food consumption

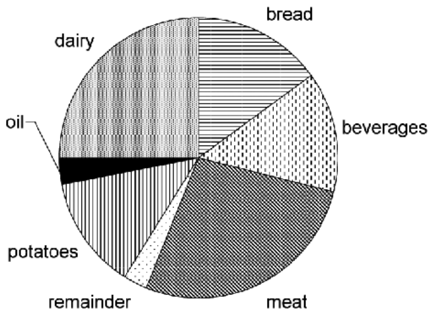

CO_2 equi related to food consumption

Figure 12.5 Continued

The emissions are not distributed evenly over the categories and gasses. With respect to CO_2, bread, beverages, meat and dairy provide the largest contribution (80%). With respect to CH_4, meat and dairy are responsible for 80% of the emissions. For N_2O the largest share arises from dairy, bread, beverages, and potatoes. For all greenhouse gasses, dairy consumption plays the largest role. More detailed analysis of the emissions attributed to dairy shows that the CO_2 emissions arise from chemical fertilizer production (this fertilizer is used to fertilize grasslands), production of livestock feed (a large part is from imported soybeans, which are transported over large distances) and in milking, cooling, transporting and packaging. The CH_4 emissions attributed to milk are mainly due to the CH_4 emitted by the cows in enteric fermentation. The N_2O emissions occur during the production of chemical fertilizer and as a result of de-nitrification processes in grasslands. So different parts of the production chain are responsible for the emissions.

This also accounts for the other commodities including food packaging. With respect to CO_2 20% of the emissions occur as part of primary production, and the remaining 80% arise outside the agricultural production system, either through delivery of inputs, processing and transport of food, retailing or in the households (cooling and cooking). The emissions of N_2O and CH_4 show a different picture with 80% of these emissions occurring in association with primary production.

The differences in environmental impact of the various consumption items imply that there are options to change emissions under alterations in consumption patterns. From Figure 12.5 it is apparent that for CH_4 the consumption of milk, cheese and meat is of importance. For N_2O the emissions are spread more evenly over the consumption items (all agricultural production requires chemical fertilizer), but dairy holds the largest share. Refraining from milk and meat, for instance, would result in a 75% reduction of CH_4 emissions, related to food consumption, for N_2O refraining from milk and meat results in a reduction of about 40%.

Another option to reduce the environmental impact from consumption is the purchase of products which are produced using processes with lower environmental impacts much like those discussed in the production side analysis. However, a change in production techniques from the consumer point of view may involve other changes. To give an example: the use of vegetables grown in heated greenhouses involves large amounts of energy. Improvement of the production techniques from the producer side would include the use of better-insulated greenhouses. From a consumer perspective a switch to vegetables grown in the open air is also an option. A comparable situation exists for transport: from a producer perspective reduction in energy use in transport can be obtained from more efficient trucks. From a consumer perspective less transport is also an option (increasing consumption of locally grown products).

Potential greenhouse gas reduction options

The previous analysis shows three different routes to reduce greenhouse gases emitted during the food production. The first is a national production reduction with the complete close down of the agricultural sector as its most extreme alternative. The analysis presented in this chapter shows that this leads to a 50% reduction of the national N_2O and CH_4 emissions. The second originates from the consumption side and involves changes in consumption patterns (a switch away from products creating large greenhouse gas emissions). Refraining from meat and dairy would lead to significant greenhouse gas reductions. The third route involves improvement of production techniques, this route emerges both in the consumer and production side analyses.

The routes suggested involve changes in production processes and/or in consumption patterns. These changes require other inputs and result in other emissions. The next section pays attention to the consequences of implementing the suggested changes for food security and the other environmental themes.

DETERMINING THE CONSEQUENCES OF THE REDUCTION OPTIONS

Effects and trade-offs when reducing agricultural production

Since the agricultural sector has large effects on the environment a reduction in production or even a complete close down of the production sector is expected to have large effects on the environment. Agriculture is the main cause for eutrophication, acidification and a large emitter of N_2O and CH_4, a decline of this sector will reduce these problems. So it seems that there are no local trade offs to the other environmental themes (they even benefit from it).

However, the trade-offs with respect to global environmental conditions are large. In the coming decades, agricultural production has to increase to fulfill the needs of the global population. A local decline in production is only possible when production is increased somewhere else. A local reduction of the production will lead to local reduction of the acidification and eutrophication problems, however since production has to increase somewhere else, these ‘increased production regions’ will encounter increases in their acidification and eutrophication problems. On a global scale this implies that the environmental effects (such as acidification) are simply moved to other regions. Global greenhouse gasses emissions will not be affected only emissions on a national level.

Focusing on local food to requirements in more detail shows an extra trade-off. When a nation decides reduce its agricultural production to reduce the environmental effects, this will imply that the displaced food has to be imported from somewhere else. Such imports require transport and transport requires energy and the use of energy results in the emissions of greenhouse gasses. To obtain an impression of the magnitude of these emissions it is calculated what happens when the Netherlands agricultural production is moved to Eastern Europe and the products are transported back.

If we assume that the production process remains the same across countries, this would imply that emissions in the agricultural part of the production chain remain the same, but arise somewhere else. The remainder of the production chain changes since the transport distances from the producer (farm) to the consumer increases. If we assume that food is transported by truck over 1,000 km, the emissions related to this transport have to be added to the present emissions.

Table 12.1 shows the results for milk and potatoes (using data from Kramer, 2000). In the present situation, when milk is produced in the Netherlands, it requires 1.5 kg CO_2 equivalent to produce and deliver 1 litre of milk to the consumers table. To produce and deliver a kg of potatoes 1.23 kg is required. Emissions involved to transport 1 kg food over 1,000 km include 0.24 kg CO_2 equivalent. So when the food for the Dutch population is imported from Eastern Europe this would imply a 15-20% increase in the greenhouse gas emissions related to food.

Here an interesting trade-off can be observed. Based on the analysis from the production perspective the complete removal of the Dutch agricultural system would mean a reduction of the national greenhouse gas emissions with about 5-10% (in CO_2 equivalents, based on Figures 12.1-12.3). From a national perspective closing down agriculture might be an option and it is seems that a lot of the other national environmental problems will be simultaneously solved. However, from a global environmental point of view another picture arises. The close down of the agricultural sector implies that all the food has to be imported. When Dutch consumers stick to the same food consumption pattern this would mean an increase in the GHG emissions attributed to the Dutch food consumption patterns by 15-20%. Thus while national GHG emissions decline, increasing production in other countries increase their emissions (since they replace lost Dutch production) and the resultant transport to meet Dutch consumer needs makes the overall GHG emission effect negative (on a global scale the greenhouse gas emissions will even increase).

Table 12.1 The greenhouse gas emissions attributed to 1 litre milk and 1 kg potatoes purchased by the Dutch consumer (produced in the Netherlands) and the emissions that come together with the transport by truck over 1,000 km

	CO_2 (kg)	CH_4 (g)	N_2O (g)	CO_2 equivalent (kg)
1 litre milk	0.8	26	0.46	1.49
1 kg potatoes	0.9	1.	1.	1.23
1,000 km transport	0.22	0.34	0.05	0.24

Note: Data obtained from Kramer (2000).

Possible adaptations in consumption patterns and associated trade-offs

The consumption of meat and dairy comes together with large emissions of greenhouse gasses (Figure 12.5). Altering diets to reduce consumption of these products would theoretically reduce GHG emissions. (Refraining from eating meat and dairy would lead to a 50% decline of the CO_2 equivalents related to food.) However, dairy and meat play important dietary roles with meat being important for protein supply and milk for its calcium. So just refraining from dairy and meat is not possible, replacements have to be found to fulfill the nutritional requirements of the human body. The design of these replacements is complicated as food also has emotional and cultural values. In the Kramer study mentioned earlier, options to reduce greenhouse gas emissions through changes in the consumption patterns are examined, taking the nutritional and social/emotional values into account.

Kramer (2000) designed 7 sets of changes in the menu (without changing the nutritional value of the menu) and calculated the reduction greenhouse gasses obtained with these changes. Table 12.2 shows a summary of the results.

Table 12.2 Possible changes in food consumption patterns and related reduction of the greenhouse gasses (in CO2 equivalent)

Set	*Description of the changes with respect to the present menu*	*Reduction (%)*
1	20% less meat, replaced by vegetables	3.3
2	As set 1, and twice a week vegetarian meal	5.4
3	As set 2, and no glasshouse vegetables, replaced by import	7.9
4	As set 3, but replaced by locally grown	8.8
5	As set 4, and 20% less rice and pasta, replaced by potatoes	8.9
6	As set 5 and 20% less milk, replaced by coffee and tea	10.5
7	As set 6 and 20% less cheese, replaced by jams	11.9

Note: Data obtained from Kramer (2000).

Set 1 involves a 20% reduction in meat consumption. Since we eat more meat than is necessary, a 20% reduction is possible without introducing a protein shortage. In set 1 only the caloric value is replaced with vegetables. In set 2 the meat is replaced by a vegetarian alternative (cheese or a vegetarian burger). Since consumer research has shown that a change to complete vegetarian lifestyle is not feasible (Nonhebel and Moll, 2001) the analysis involves a vegetarian meal twice a week. This twice a week a vegetarian meal involves a larger reduction of the meat consumption than the 20% in set 1. However the production of the vegetarian replacements also leads to emissions of greenhouse gasses, so that the net gain is smaller (2.1%).

Set 3 focuses on glasshouse vegetables. Heated glasshouses require large amounts of energy to produce tomatoes, peppers etc. In warmer climates (Spain), these vegetables can grow in open air systems, hardly requiring energy. A change from glasshouse vegetables to imported open air vegetables is therefore an option. However, in that case the vegetables have to be transported from the production area to the consumer. When this extra transportation is included the change from glasshouse to import will involve a GHG emission reduction of 2.5%. Replacing glasshouse vegetables with locally grown open air vegetables leads to a far larger decline in emissions: 3.4%. This option seems promising (just replace the vegetables in the meal), however one should realize that such a change involves the use of other vegetables since not all vegetables can be grown in the open air. A change to locally grown 'open air' vegetables also implies large changes in seasonal menus. In the summer season not many changes are expected, but in the winter season the consumption of locally grown vegetables involves a menu with only cabbages, unions and carrots.

The change from rice and pasta to potatoes (set 4) had hardly any effect on emissions. With respect to milk and cheese some gain is expected. In the sets studied (6 and 7) the nutritional value is not replaced (the present consumption allows a reduction of 20%; see the discussion in set 1 for meat). Milk is replaced by coffee or tea and cheese is replaced by jam.

Table 12.2 shows that a substantial change has to be made to obtain a 10 percent emission reduction. To obtain this reduction meat consumption is nearly halved and in winter season vegetables in the menu include only onions, carrots and cabbage. This is in contrast with the analysis at the start of this paragraph that indicated that refraining from eating meat and drinking milk would result in a 50% decline of the emissions. The difference can be explained by the fact that just refraining is not possible, replacements are needed to fulfill the needs for food and these replacements also require emissions.

Cleaner production techniques and their trade-offs

The option of reducing emissions through applying cleaner production techniques emerged both from the production and consumer points of view. We will first analyze the improvement options from the production side analysis and focus on the options to reduce the CH_4 and N_2O emissions by changing production techniques in the agricultural sector, followed by an analysis from the consumer perspective.

Options to reduce CH_4 emissions

Agriculture is an important source for CH_4 with dairy farming the largest contributor. CH_4 emissions associated with dairy farming come from the cow itself as a result of the enteric fermentation and from sub floor manure storage. Veen (2001) estimates that 70-80 % emissions come from the cow and the remainder from the manure. The emissions per cow are in the order of 100 kg per year and are influenced by among others the digestibility of the feed, but are independent of the milk production. This implies that increase of the production per cow leads to a decline in the emissions per liter. The milk production per cow in the Netherlands is 7,400 liter milk per year, while in other European countries this value is much lower (4,387 in Ireland, 4,451 in Poland (FAO, 2003)). This shows that one liter of milk from a Dutch cow goes together with the emissions of 14 grams of methane, while the milk from an Irish cow goes together with the emissions of 23 grams of methane. A further increase of the production per cow provides a reduction option.

Another reduction route involves feed composition. More digestible feed and addition of extra fats to the feed are potential options to reduce the CH_4 emissions due to enteric fermentation (Veen, 2001). However, for a proper functioning digestive system about 20% of the feed should consist of roughage (Veen, 2001, CVB, 2003). In the intensive dairy farming systems in the Netherlands, the percentage of roughage is very near to this percentage, so that not much room for improvement can be found here. The addition of extra fats to the feed also shows some complications. Since the BSE-crisis, animal fats are no longer allowed in feed and the addition of vegetable fats to the feed has been found to have negative effects on milk quality (protein and fat concentrations). This implies that not many improvements can be expected with respect to changes in feed composition in the short term.

There may be options to reduce manure related emissions, with research on possible options now being carried out (Novem, 2004). However, presently not enough information exists to estimate the magnitude of the reductions in this category.

A change in the opposite direction (increase of the CH_4 emissions), however, is also possible. As mentioned in the introduction of this chapter a shift to less intensive production systems (organic) could be employed. This change to less intensive production systems is a method to reduce the large effects of production systems on the other environmental themes.

De Boer (2003) did a comparative analysis of the environmental impacts associated with conventional versus organic milk production systems. She showed that the impacts on acidification and eutrophication per hectare were lower in the organic systems. However, her results showed that CH_4 emissions increased. Huis in ‘t Veld and Monteny (2003) show similar results. The increase was caused by lower production per cow, the higher percentage of roughage in the feed (organic agricultural practices require 80% roughage in the feed) and the other type of stable (bedding) practiced in organic farming. Huis in ‘t Veld and Monteny (2003) also showed that in the organic system the CH_4 emissions per litre milk more than doubled (from 20 g per litre to 50 g per litre milk), however this measurement involved only one farm, rendering such values therefore only an indication.

Less extreme changes in intensive dairy farming than a switch to organic farming also have negative effects on CH_4 emissions. To reduce nitrate emissions, farmers tend to fertilize less, which results in a slower start of the crop, which makes farmers harvest later to obtain the same yield. But later harvesting results in a lower digestibility of the feed (Veen, 2001). Here an important trade-off between different environmental themes becomes evident, namely methods to reduce eutrophication tend to increase the emissions of methane.

Options to reduce N_2O emissions

N_2O emissions result from de-nitrification processes in soils and in slurry on the farm. Most N_2O emissions occur from soils after application of manure/fertilizer. The highest emissions are found when manure is applied with sod injection techniques (Velthof et al., 2003). The simplest way to reduce N_2O emissions is to apply fertilizer to the soil surface, instead of injecting it into in the soil. However, these sod-injections techniques reduce NH_3 emissions by about 30% relative to soil surface application. Here a trade-off between acidification and climate change is observed.

Presently only a small part of the nitrogen applied to the soil is actually taken up by the crop (at a maximum 70% but frequently values in order of 20% of the applied nitrogen are found - Meisinger and Randall, 1991). The nitrogen that is not taken up by the crop, nor is stored in the soil is lost to the surroundings, causing eutrophication as nitrate, acidification as NH_3 or climate change as N_2O. Better nitrogen management practices that increases the fraction of the nitrogen that is taken up by the crop seems the best route to go since all environmental themes benefit.

Cleaner production from the consumers perspective

From the consumer perspective cleaner production involves changes in the complete production chain instead of developments only in agriculture as analyzed in the previous paragraph. The Kramer study mentioned earlier also provides information on this. He analyzed options to reduce emissions within the complete production chain including: agriculture, industry, packaging, transport, trade, consumption and waste management. His analysis is based on the agreements between the various sectors and government with respect to energy use efficiency improvements. Table 12.3 shows some of the outcomes.

Table 12.3 Greenhouse gas reduction percentage along the food production chain (%)

Sector	*Reduction*
Agriculture	6.0
Industry	8.4
Retail	3.0
Transport	0.6
Kitchen appliances	5.5
Sustainable energy	3.0

Source: Kramer (2000).

The changes in agriculture involve increasing production per cattle (reduction of the CH_4 emissions, more efficient use of fertilizers (reduction of the N_2O and CO_2) and large energy savings in horticulture. In industry they involve a general increase in energy use efficiency with 30-35% gains by the year 2010 relative to 1990. In the retail sector this general energy efficiency improvement leads to an energy reduction of 3%. The improvements in transport are the results of a combination of more energy efficient trucks, better driving practices, etc these measures lead to a reduction of 7% of the emissions related to transport. Transport improvements play a minor role in the overall reduction amounting to 0.6%.

The use of energy efficient kitchen appliances (refrigerators etc.) in households is estimated to result in a 5.5% reduction. A national shift to sustainable energy is expected. Assuming that by 2010 that 5% of the total Dutch energy consumption originates from renewables, this would result in an extra 3% reduction in the greenhouse gas emissions related to food. The simultaneous implementation of all these options results in a 26% reduction of the greenhouse gas emissions associated with food.

It is striking that reduction in the non-agricultural parts of the chain has the largest impact on the emissions related to food. The effects of changes in household consumption are of the same magnitude as the changes in agricultural production. This consumer side analysis provides new insights in options to reduce emissions. It might be far easier to exchange all refrigerators in the households with more efficient units than to introduce large changes in the agricultural production systems that also have negative trade-offs to the other environmental themes.

CONCLUSIONS

Several options exist to reduce greenhouse gas emissions related to the production of food. At first glance their impact on the total emissions seems large (over 50% reduction), however a more detailed analysis shows that for most trade-off's to other parts of the system are very large. When the effects in other parts of the system are also taken into account, the overall reduction potential turns out to be small.

From the production perspective discontinuing agricultural production would imply an important decline in national greenhouse gas emissions, but it was shown that as a consequence of this decision, food would be grown elsewhere and then transported over a longer distance, which in turn implies an overall increase of the emissions related to food.

From the perspective of the consumer it was shown that refraining from eating meat and dairy would lead to an important decline in emissions, but since meat and dairy fulfill important nutritional and emotional functions in the food package these goods can only be replaced to a certain extent. It was estimated that at most 10% reduction of the emission could be expected through changes in the food package.

The analysis in this chapter also identifies the existence of options in between the agricultural production sector and the consumer: the production chain in between, which includes the food industry, retail and a consumer with respect to cooking practices. Analysis shows that this 'in between' sector shows the largest potential to decrease the greenhouse gas emissions related to food production. Finally it was shown that presently recognizable developments in the agricultural system like a shift to organic agriculture, and the implementation of techniques to decrease ammonia emissions tend to increase emissions of methane and nitrous oxide.

These findings are developed within the context of the Dutch production system. Since this is an a-typical system the findings here are not entirely applicable to the global situation. The food consumption patterns studied are relatively luxurious. Reduction of the meat consumption as analyzed in this chapter is not an option on a global scale since largest share of the world population is hardly eating meat. Globally a shift in the other direction is likely to be observed, namely an increase of the meat consumption.

Also the shift to organic or less intensive production systems as observed in the Netherlands agricultural sector is a-typical for the global situation. As mentioned earlier, the Dutch production system is one of the most intensive production systems in the world. The largest share of global food production originates from extensive production systems. On a global scale food production is likely to intensify (generating higher yields per production unit). This intensification is of importance with respect to the methane emissions related to meat and dairy production. Emissions of methane are related to the number of the livestock and more or less independent of the production of an individual animal. Increasing the milk production per cow, as is expected to happen, will reduce methane emissions per litre.

A third important difference is the fact the rice is not cultivated in the Netherlands. On a global scale rice is an important crop and its cultivation goes together with large emissions of methane.

A fourth difference is the existence of a large food industry which uses a lot of energy. In less industrialized countries this industry hardly exists. Households buy basic agricultural products (grains, milk) and convert them into food items themselves (Home baking etc.). The potential for energy reduction as is found for the Dutch system does not exist outside the developed world. In practice, it can even be expected that with increased development within the developing world such food industries will emerge, leading to increased energy use related to food.

The fact that the Netherlands system is a-typical, however, does not imply that relations found in this chapter are of no use. As mentioned in the introduction, global food production has to increase to fulfill the demands of the growing population and the consumption shifts induced by income growth. The largest share of this increase has to be met through production intensification. The lessons revealed in the Netherlands study with respect to the environmental consequences of agricultural intensification can provide tools to prevent these errors from being made on a global scale.

In the Netherlands, only several decades after the introduction of chemical fertilizers it became clear that the emissions to the environment associated with the use of chemical fertilizers caused acidification and eutrophication. In turn, measures were taken to reduce the effects. Only recently the N_2O emissions associated with chemical fertilizer use were recognized portending future measures.

The global agricultural intensification will go together with increased use of chemical fertilizers. To prevent that the Dutch mistakes from being made on a global scale attention to improved fertilizer management is essential.

With respect to CH_4 emissions increased per animal milk production reduces the emissions per litre. The values used in this chapter indicate that the difference between extensive and intensive production may be 50%. This would imply that intensification may reduce the emissions associated with the production of milk.

In the Netherlands the shift to more luxurious diets came together with the emergence of a large food industry. This industry uses a lot of energy, and plays an important role with respect to the CO_2 equivalent emissions attributed to food. A global shift to more luxurious diets may not only imply an increased agricultural production but also a large increase in energy used in the food supply chains. Up to now increased energy requirements of the more luxurious diets gained limited attention.

The above analysis shows that a lot of effort is needed to prevent increases in food production and consumption from having adverse effects on the global environment. However, it also shows that agricultural intensification can result in a large increase of the food production in a relative short time span. The intensification in the Netherlands led to a doubling in production in less than 50 years. This is an indication that the required 50% increase of the global food production in the coming decades is not impossible.

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