ENA Special Report on Nitrogen and Food

Nitrogen on the table:

The influence of food choices on nitrogen emissions and the European environment

General disclaimer: many data in this summary are still preliminary / needs still to be checked. They are therefore subject to potential changes. This is also true for the text of this summary.

Key findings

The European Nitrogen Assessment identified agriculture as a major source of nitrogen losses, despite the relatively high nitrogen efficiency of agriculture in the European Union. **The current total loss of reactive nitrogen from European Union (EU) agriculture amounts to 6.5 million tonnes per year, which is 78% of all reactive nitrogen losses.** This study allocated the nitrogen losses to food commodity groups. The results show that livestock production chains have a high share in nitrogen losses. Around 85% of the ammonia emissions to air and over 60% nitrate emissions to water are related to livestock production.

There are large differences between food commodities in terms of nitrogen losses per unit of protein produced. Plant-based commodities, such as cereals, have relatively low losses and livestock products having much higher losses. The nitrogen losses per unit of protein from beef are almost 25 times those from cereals. For pig and poultry meat, eggs and dairy the losses are 5 to 7 times those from cereals. Corresponding values for nitrogen use efficiency are small for animal commodities (5-30%) and considerably higher for plant-based commodities (56-79%).

The nitrogen 'footprint' per person differs widely between Member States, as a result of differences in average food consumption patterns. There is a two-fold difference in average per capita footprints between the countries with the lowest footprint (Bulgaria and Slovakia) and the highest (Denmark). Our estimates have been made with EU average data for the emissions per unit for the different food categories. When calculated with country specific data the results will be different, but we are confident that the general pattern will remain.

Current consumption in all European countries is in excess of protein requirements and exceeds recommendations for maximum saturated fat intake. This provides opportunities to a shift towards diets with lower nitrogen footprints.

We designed a number of hypothetical scenarios to assess the effect on nitrogen losses from EU agriculture resulting from a reduction in the production of livestock products arising from changes in consumption. A reduction in pig meat, poultry meat and eggs was explored in one set of scenarios. In another, a reduction in beef and dairy was explored. The reduction in all types of livestock products was also explored. For each of these commodity groups, and for the combined, 25% and 50% reductions were explored. The scenarios assume that production will be reduced in line with consumption and that the relative proportions of EU produced and imported supplies remains the same. The effects on feed requirement, crop production, land requirements and nitrogen losses were examined.

A 50% reduction in livestock product consumption and production reduces the agricultural reactive nitrogen emission from the current 6.5 million tonnes to 3.8. In this scenario, the ammonia emissions are 43% lower, and nitrate emissions are reduced by 35%. Reduction in reactive nitrogen emissions are higher in scenarios involving reductions in beef and dairy production. In general ammonia emission reductions are higher than the reduction in nitrogen leaching and run-off. This is because ammonia emissions are mainly from livestock production, whereas nitrate emissions are from field-based activities.

A shift to a more plant-based diet will lead to a large decrease in the nitrogen footprint of EU diets. In the most radical scenario assessed (a 50% reduction in the consumption of all meat and dairy products), the nitrogen footprint of the average diet will be reduced by 40%. The current large differences in per capita nitrogen footprint between countries will become smaller.

The reduction in ammonia emissions will lead to a reduction in nitrogen deposition, not only in the EU, but on a continental scale. Both in absolute and in relative terms, the reduction is the strongest in regions with high livestock densities. (to be elaborated – something will be add cost of mitigation of ammonia through technical measures)

The scenarios lead to food consumption patterns that are better aligned with dietary recommendations. The intake of saturated fats will be reduced in all reduction scenarios because animal products are the main sources of saturated fats. Even though the reductions are significant, only the most radical scenario with a 50% reduction in all meat and dairy consumption brings the average intake of saturated fats within a range recommended by the WHO. This scenario gives a 40% reduction in the intake of fats. The same radical scenario is also the only one where the average intake of red meat was close to the maximum recommended by WCRF. Overall and accepting that WHO and WCRF recommendations are valid, the results are clear: the reduced intake of red meat and saturated fats in these reduction scenarios means that public health risks will be reduced.

There are a number of other positive environmental effects resulting from the scenarios. Depending on the scenario, the greenhouse gas emissions from agriculture are reduced by 3% to 40%. The land use sub-scenarios demonstrate the opportunities for a large increase in cereal exports. If the arable land and temporary grassland released from livestock production in the 50% animal products consumption reduction scenario is used for cereal production, net cereal exports increase from the current 20 million tonnes to over 200 million tonnes. The requirement for imported soybeans (as meal), currently used as animal feed, is reduced by 75%. In these circumstances, the combination of increased export of cereals with reduced import of soy has great implications for global commodity markets, which in turn influence global land use change. Alternatively, bioenergy crops could be produced on the land no longer required for European food production. Depending on the consumption change scenarios, 9 to 14.5 million hectares is made available for bioenergy crops.

The scenarios would lead to drastic changes in EU agriculture, with probably large socio-economic impacts. The scenarios would lead to a large reduction in livestock production. As this production is currently responsible for 60% of the value-added on EU farms, revenue from livestock production will be greatly reduced. Furthermore, the 'higher prices' scenario with increased cereal exports assumes a large increase in cereal production. The farm-level economic effect depends on world market conditions and especially whether this can be sold at a price that is profitable for European farmers. Where cereals replace livestock, the additional cereal production will be exported, which might have beneficial effects on global commodity markets in terms of food security. However there is also the risk of suppressing production and thus market opportunities for local farmers in developing countries.

1. Introduction

This study was conducted by members of the Expert Panel on Nitrogen and Food in the Taskforce on Reactive Nitrogen on Reactive Nitrogen (TFRN). This group reports to the Working Group on Strategies and Review of the UNECE Convention on Long-range Transboundary Air Pollution.[1] The aim of the panel's work is:

To investigate the effects of changes in consumption towards agricultural commodities with lower nitrogen footprints on consumer diet composition, and intake of proteins and saturated fats.
To investigate the effects of dietary change with corresponding production changes on the emission of reactive nitrogen, as well as on other aspects such as land use, greenhouse gas emissions and agricultural production in general.

A major driver behind the study is the understanding that more than 95% of the ammonia emissions stem from the agricultural sector. Agriculture is also a main source of other forms of reactive nitrogen, such as nitrate and nitrous oxide. The TFRN has explored the possibilities and effects of a range of technical measures applied in agriculture to reduce emission of ammonia and other forms of reactive nitrogen. Over the past 20 years, much research has been done and techniques have been developed and deployed to reduce these emissions and improve nitrogen use efficiency in agricultural production systems. In other words, a great deal of attention has been paid to reducing emissions on the 'supply' side. In contrast, relatively little research has been done to look at 'demand side' measures within the food system. This is the focus of this report.

For practical reasons including the availability of data and suitable models, this study was confined to the EU-27. Livestock production consumption in the EU are tightly linked and EU livestock production is largely for European consumption with relatively little trade across the EU's border.

Because protein contains about 16% nitrogen, food production and consumption and the nitrogen cycle are intrinsically linked. Protein production is linked either directly or indirectly to ammonia polluting air, nitrate and other nitrogen compounds polluting water, and nitrous oxide which is a trace gas with a global warming potential of 298, compared with CO_2. The recent ENA report presents a thorough overview of the effects of nitrogen emissions on the environment.[2] To support primary protein production in crops, European agriculture uses 11.2 million tonnes of mineral fertiliser N. In addition, the provision of animal protein in Europe requires supplies of high protein soy meal.

2. Approach and scenario design

2.1 Life-cycle assessment and functional units

To assess how different diets or diet choices affect the losses of reactive nitrogen, we allocated the these losses to the main twelve food commodities groups. These commodity groups cover about 95% of the products consumed in the EU-27. Six of these food commodity groups are plant-derived (cereals, potato, fruit and vegetables, sugar, vegetable oils and pulses) and six are from animals (dairy products, beef, pork, eggs, poultry meat, and sheep and goat meat). The allocation was done using results from the CAPRI-modelling system on the basis of a life-cycle approach where the emissions occurring at various production stages are cumulatively attributed to the commodity group. In this case, the functional unit is defined as the marketable mass of the commodity, e.g. one kilogram of beef or cereals, as it is sold at the 'farm gate' or – in the case of meat products – at the gate of the abattoir as carcase meat. Even though the assessment is restricted to food produced

[1] www.clrtap-tfrn.org and live.unece.org/env/lrtap/ExecutiveBody/welcome.html
[2] The European nitrogen Assessment http://www.nine-esf.org/ENA-Book

within the EU, the emissions of imported feed used are considered. The implication of this approach is that for a commodity such as beef or eggs, not only the nitrogen emissions related to the livestock part of the production, but also the emissions related to the feed production, are taken into account. This means that the emissions related to the commodity-group ‘cereals’ only relate to that part of the cereals which are directly consumed by humans. Emissions from cereals and other products used to feed livestock are allocated to those livestock.

From a consumption perspective, the key question is the emissions per functional unit of the various food groups consumed. The functional unit of food is however not easy to define, as the different components of our diet serve different purposes. Moreover, the nutritional value of the different foods differs widely, partly correlated to dry matter content. In the context of this study, a kg of protein is a functional unit that serves comparison.

2.2 Describing consumption and diet

FAO statistics were used to determine the quantity of commodity used by the Member States’ food systems. This served as the foundation of the analysis of commodity consumption and food intake. Estimates of relationship between the commodity ‘supply’ and the intake of the relevant food groups established in previous research were used to estimate per capita intake for each Member State.

2.3 Modelling

The scenarios were analysed using the MITERRA-Europe model, which calculates annual nutrient flows and GHG emissions from agriculture in the EU-27. Main input data were derived from CAPRI (crop areas, livestock distribution, feed inputs), GAINS (animal numbers, excretion factors, NH3 emission factors) and FAO statistics (crop yields, use of mineral fertiliser, animal production).

Feed requirement was determined by means of a spreadsheet model. The effect of the scenarios on nitrogen deposition was calculated by scaling current deposition maps. All calculations were performed on a Member State basis.

2.4 Scenario design

The effect of changes in food consumption patterns and consequent changes in agricultural production and related emissions of different types of reactive nitrogen (as ammonia and nitrous oxide to air, nitrate and other coumpounds to water) was investigated using scenarios. The consumption scenarios are based on changes in consumption with parallel changes in EU production as set out in Table 1. The reduction of meat and dairy consumption in the scenarios leads to a lower intake of energy (calories) and proteins from these commodities. This is compensated for in terms of energy by a higher intake of cereals.

These consumption scenarios affect the demand for animal feed and thus the land needed for animal production. Two sub-scenarios for land needs were designed:

1) A ‘high prices’ world, where it is assumed that the agricultural sector is geared to produce (and export) as much cereals as possible. This means that tillable land that is presently being used for forage (e.g. forage maize), temporary grassland and fertilised permanent grassland are assumed to be used to produce cereals.
2) A ‘greening’ world, where it is assumed that land previously used for feed (and not required for substituting food crops), fodder (e.g. forage maize) or temporary grassland will be used to produce bioenergy crops. The crops used are canary reed, switchgrass, miscanthus, poplar or willow, depending on the location. The total primary energy production would be 1600-2300 PJ. All permanent grassland is maintained and nitrogen fertilisation is reduced to reduce production and emissions.

In elaborating the scenarios, a number of assumption were made, which are therefore part of the scenario design. The most important of these are:

- Lower intake of meat and dairy is compensated by higher cereal consumption on a food calorie intake basis. If the protein intake drops below the recommended intake, pulses are added to the diet.
- Animal diets are not changed as we applied a proportional reduction over the main feed components (protein rich feed, energy-rich feed, roughage and fodder maize). However, within these main components, the total level of use of domestic by-products is maintained and imports (as soy bean meal) are reduced. Within the component 'roughage', it is assumed that the production of roughage from arable land or from temporary grassland are the first to be reduced.

It is known that EU farmers currently apply more nitrogen (in the form of organic and mineral fertilisers) than is recommended. The first step was therefore to reduce fertilisation to a level which balances fertiliser application to meet the needs of the crop considering the supply from the soil. This step was also necessary to have a good reference for the scenarios, as fertilisation calculated in this way is assumed in scenarios.

Table 1 Scenarios (in some graphs still have names such as Scen1– this will be harmonised)

Scenario	**Human consumption**	**Livestock production**	**Land needs**
Reference	Present situation	Present situation	Present situation
Reference – BF[1]	Present situation	Present situation	Present situation
-25% beef and dairy (Scenario 1)	Reduction of beef and dairy consumption by 25%	Reduction of cattle (numbers) by 25%	Two sub-scenarios: 'High price' or 'greening'
-25% pig and poultry (Scenario 2)	Reduction of pig meat, poultry and eggs consumption by 25%	Reduction of pig and poultry production (numbers) by 25%	Two sub-scenarios: 'High price' or 'greening'
-25% all meat and dairy (Scenario 3)	Reduction of all meat, poultry and eggs consumption by 25%	Reduction of cattle, pig and poultry production (numbers) by 25%	Two sub-scenarios: 'High price' or 'greening'
-50% beef and dairy (Scenario 4)	Reduction of beef and dairy consumption by 50%	Reduction of cattle (numbers) by 25%	Two sub-scenarios: 'High price' or 'greening'
-50% pig and poultry (Scenario 5)	Reduction of pig meat, poultry and eggs consumption by 50%	Reduction of pig and poultry production (numbers) by 25%	Two sub-scenarios: 'High price' or 'greening'
-50% all meat and dairy (Scenario 6)	Reduction of all meat, poultry and eggs consumption by 50%	Reduction of cattle, pig and poultry production (numbers) by 25%	Two sub-scenarios: 'High price' or 'greening'

[1] BF = balanced (nitrogen) fertilisation: fertilisation according crop requirements / recommendation as implemented in the Miterra-model

3. Results - present situation

3.1 EU agriculture and nitrogen losses

Arable land and permanent crops covered about 29% of the total land area in the EU-27 in 2009, and permanent meadows and pastures accounted for an additional 16%. This gives a total of 188 million hectares. This agricultural land is generally productive due to favourable climatic and soil conditions, the skills of European farmers, and to the use of modern technologies such as pesticides and mineral fertilisers. Presently, the EU is more or less self-sufficient in indigenous crops and all major livestock products. The EU is a net importer of vegetable oils and oil meals (mainly palm oil, soy beans and soy bean meal), beef and sheepmeat. The oilseed meals are used as animal feed. From a nitrogen perspective, the most important import the equivalent of 37 million tonnes of soy bean meal (as meal or soybeans) which is the meal from about one fifth (to be checked) of the world soy crop. The EU is a net exporter of relatively small quantities of cereals, pig meat and dairy. European agriculture uses 11.2 million tonnes of mineral fertiliser nitrogen each year.

Nitrogen losses from EU agriculture

The main agricultural inputs into the European nitrogen cycle are the mineral fertiliser N (11.2 million tonnes N) and the nitrogen in the imported food and feed (ca 3.5 million tonnes) and nitrogen deposition (to be checked). The main outputs are nitrogen in plant products for human consumption (1.4 million tonnes per year) and in livestock products (3 million tonnes per year). 12,8 million tonnes is lost to the environment from agriculture each year. About half (6,3 million tonnes) of it is in the form of the harmless N_2, but the rest is lost in various forms of polluting reactive nitrogen (ammonia, nitrate and nitrous oxide), totalling 6.5 million tonnes nitrogen The ammonia emissions amount to 2.6 million tonnes accounting for 95% of total ammonia emissions. Yearly, around 2.9 million tonnes nitrogen are lost to aquatic systems as nitrate, while 0.26 million tonnes nitrogen is emitted to the atmosphere in the form of nitrous oxide (N_2O).

Partitioning nitrogen losses in the food system

Overall, livestock production systems are responsible for 62% of nitrogen lost to ground and surface waters and 85% ammonia emissions. The production of beef and dairy causes 44% of all nitrogen emissions from food, and pig meat accounts for 17%. Cereals make the bulk of emissions from plant-based commodities, which is mainly due to the large area used for cereal production, and the important role of cereals in the diet, including as alcoholic drinks.

3.2 Emissions per functional unit

When expressed per kg protein, beef has by far the largest nitrogen emission, both for ammonia and leaching and run-off to surface and groundwater (Figure 1). The emission intensity of four other livestock products (pig and poultry meat, eggs and dairy) are lower and similar ,to each other whereas the emission intensity of cereals, potatoes and legumes in relation to the protein supplied is significantly lower than all livestock commodities. The results presented are EU average data, but these are in fact subject to large variability among countries and within each country.

Considering the whole commodity production cycle, nitrogen use efficiency estimates are low for animal products (5-30%) compared with plant-based products (56-79%).

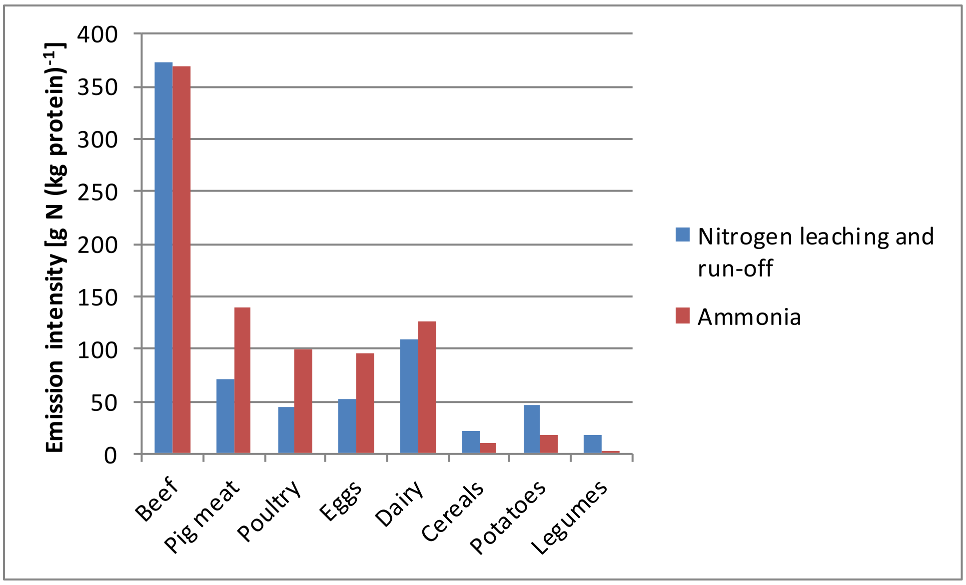

Figure 1 Emissions intensities for leaching and run-off to water and ammonia emissions to air for seven food categories in g nitrogen per kg protein as calculated with the CAPRI model.

3.3 Nitrogen footprint of EU diets

The nitrogen losses associated with the average EU diet depend greatly on the contribution of the different food categories. Nitrogen emissions associated with the livestock products dominate the nitrogen 'footprint' of the European diet (Figure 2). There are large differences between Member States in nitrogen footprint, mainly related to the quantity of animal products consumed. The nitrogen footprint of the Danish diet is the largest footprint. The one of Bulgaria and Slovakia is less than half the Danish value.

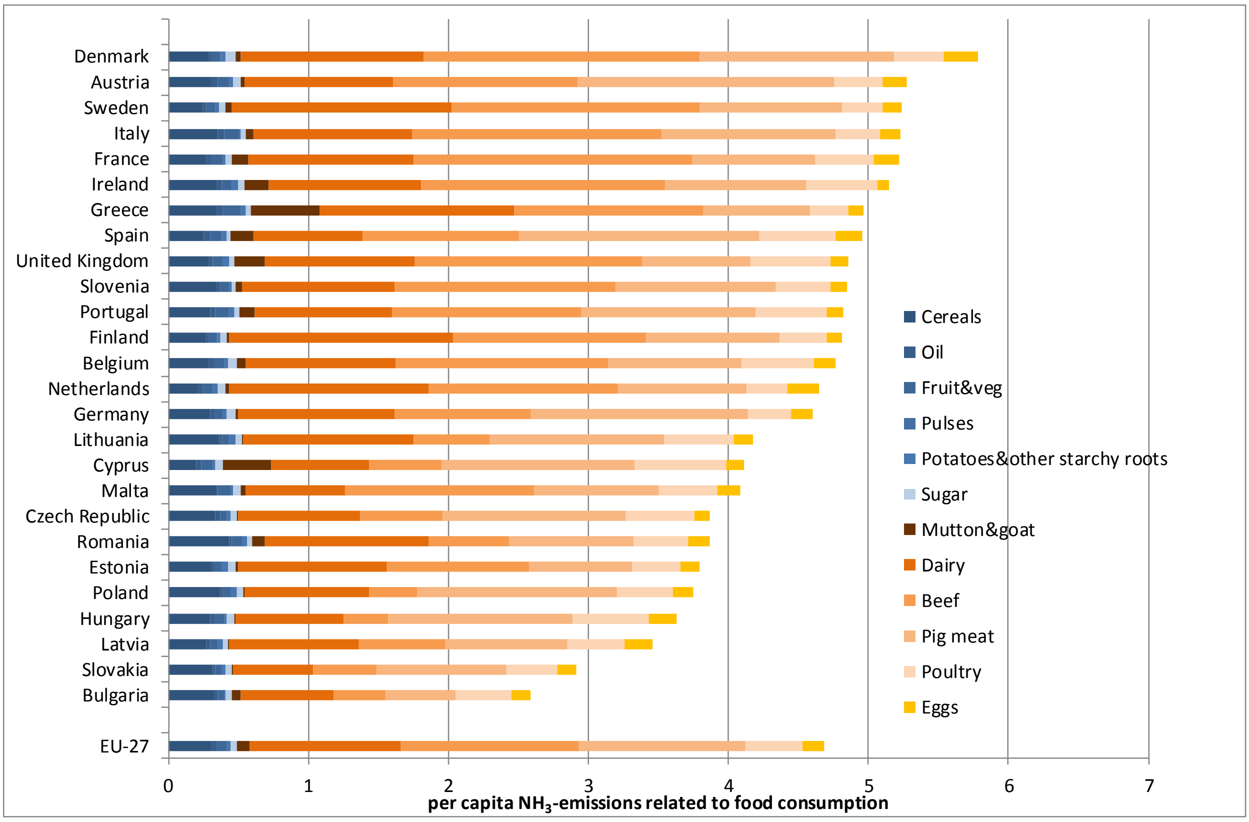

Figure 2 Per capita ammonia emission s of food commodities consumed (kg N-ammonia per capita) for the different Member States (final version might be in total reactive N loss)

3.4 EU diets and dietary recommendations

The current per capita energy and protein intakes are in most EU Member States higher than recommended in dietary guidelines. On average, EU citizens consume 70% more protein than is recommended, with large difference between Member States. Consumption is particularly high in the richer parts of the EU where large quantities of protein of animal origin are consumed. Through the higher consumption of plant-based proteins in countries with lower per capita income, the average total protein intake is similar across the Union.

The intake of saturated fats is higher than the maximum recommended. These fats are mainly consumed in the form of animal products. The per capita intake of red meats is also higher than recommended. With regard to red meat consumption and saturated fat intake, the consumption reduction scenarios align with established health recommendations.

4. Results - scenarios

4.1 Scenario effects on food consumption

The total intake of protein decreased in all consumption reduction scenarios as the cereals containing less protein replace the energy in the animal products (Figure 3). However, in all scenarios the average protein intake in the EU remains higher than requirements. In the 25% beef and dairy reduction scenario, the intake is still 60% greater than required. Even in the scenario with a 50% reduction in all animal products, the average intake of proteins is still more than 50% higher than requirements. As prescribed, cereal consumption increased with decreasing intake of meat and dairy products.

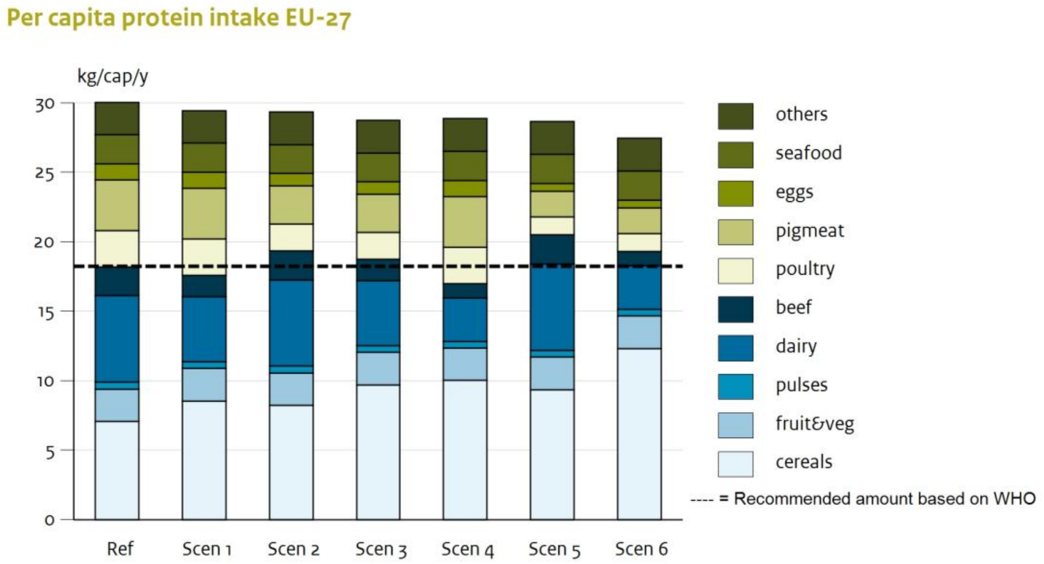

Figure 3 Effect of different scenarios on protein intake from various food commodity categories.

The intake of saturated fats is reduced in all reduction scenarios as a result of the reduced animal products consumption as animal products. Only the 50% reduction in all meat and dairy intake scenario reduced saturated fat intake to below the maximum recommended by WHO.

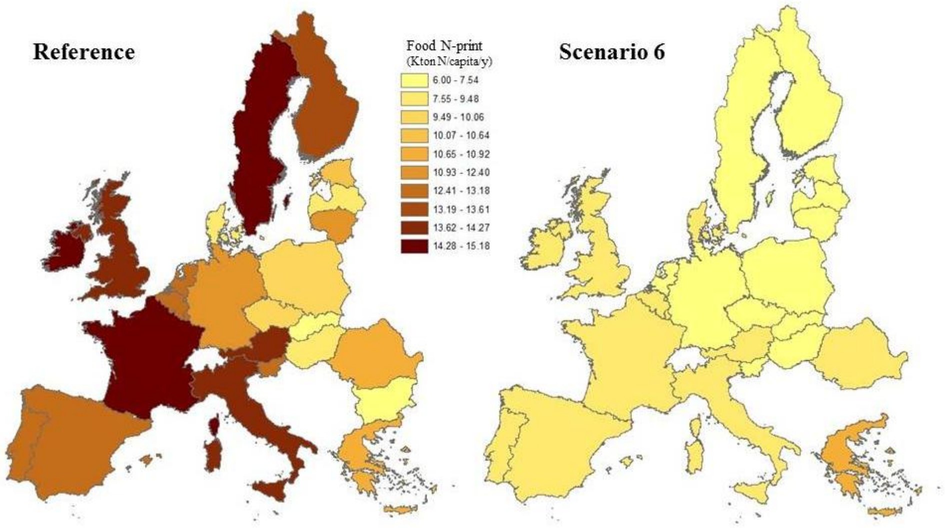

Figure 4 Member States' per capita food nitrogen footprint of current food consumption patterns (Reference) and those in a scenario with 50% lower meat and dairy consumption (Scenario 6)

4.2 Scenario effects on livestock and livestock feed requirements

Livestock production and numbers are reduced by 25% or 50% depending on the reduction scenario. In the 25% beef and dairy reduction scenario, arable land needs for forage decrease by 65% while grass from temporary grassland decreases by 10%. Energy-rich feed imports decline by 2% and soy bean imports decline by 17%. Cereal use decreases by 9%. In the 25% pigs and poultry reduction scenario, energy-rich feed and soy bean imports fall by 21% and cereal use in feed by 17%. In the 25% all meat and dairy reduction scenario, the combination of both 25% reduction scenarios leads to a reduction of 22% in energy-rich feed imports, 38% less imported soy and a 26% reduction in cereals used as animal feed. The 50% all meat and dairy reduction scenario gives a 75% reduction in soy meal use, energy-rich feed imports are reduced by 46% and cereal use in animal feed by 52%.

4.3 Scenario effects on land use

In the 'high-prices' world land use sub-scenario, the lower demand for forage to feed beef cattle and dairy cows results in about 2 million hectares of temporary grassland and about 10 million hectares of arable land previously used for feed production become available for other uses in the 25% reduction scenario. In the 50% beef and dairy reduction scenarios, about 9 million hectares of intensively managed grassland are released for other uses. In addition, 14 million hectares of arable land used to produce fodder (including fodder maize) is released for other uses. It is assumed that tillable land will be cultivated with cereals leading to a 40% increase in cereal area, from 60 to 84 million hectares.

In the '*greening*' world land use sub-scenario, it is assumed that neither extensive grassland (21 million hectares) nor fertilised grassland area (44 million hectares) contract. In the '*greening' world*, the lower forage demand for beef cattle and dairy cows from grassland in the beef and dairy and the all meat and dairy reduction scenarios leads to an extensification of grassland management and lower grassland yields. The use of arable land for forage decreases from about 19 million hectares in the reference situation to about 9 million hectares in the 25% beef and dairy (and all meat and dairy) reduction scenarios and to about 4 million hectares in the 50% beef and dairy (and all meat and dairy) reduction scenarios. As the released areas of arable land are cultivated with energy crops about 10 million hectares (minus 25%) or 14.5 million hectares become available for energy crops.

4.4 Scenario effects on nitrogen use and emissions

The missions of reactive nitrogen will be reduced from the current 6.5 million tonnes to 3.8 in the 50% all meat and dairy consumption reduction scenario. The reduction in nitrogen losses attributable to food consumption are proportionally greater than the reduction in nitrogen fertiliser use for this food production. Use of mineral fertilisers in Europe for European food consumption will drop from the current 11.2 million tonnes to 8.0 million tonnes when balanced fertilization is applied in the scenario with 50% reduction of all meat and dairy consumption.

All consumption reduction scenarios lead to a reduction in ammonia and nitrous oxide emissions to air and nitrogen leaching and run-off (Figure 4). Emission reductions are proportionally higher in scenarios involving reductions in beef and dairy production. Reductions achieved range from about 8% of ammonia, 2% of nitrous oxide and 4% of nitrogen leaching and run-off in the 25% pigs and poultry reduction scenario to a reduction of 43% of ammonia and 35 % of nitrates in the 50% the all meat and dairy reduction scenario in the ‘greening’ world. In general, the differences between the ‘high price’ and ‘greening’ land use sub-scenarios in terms of emissions is small. The reduction in ammonia emission is slightly higher than the reduction in nitrogen leaching and run-off. This is because ammonia emissions are stronger related with livestock production, whereas nitrogen leaching and run-off is related to field based activities.

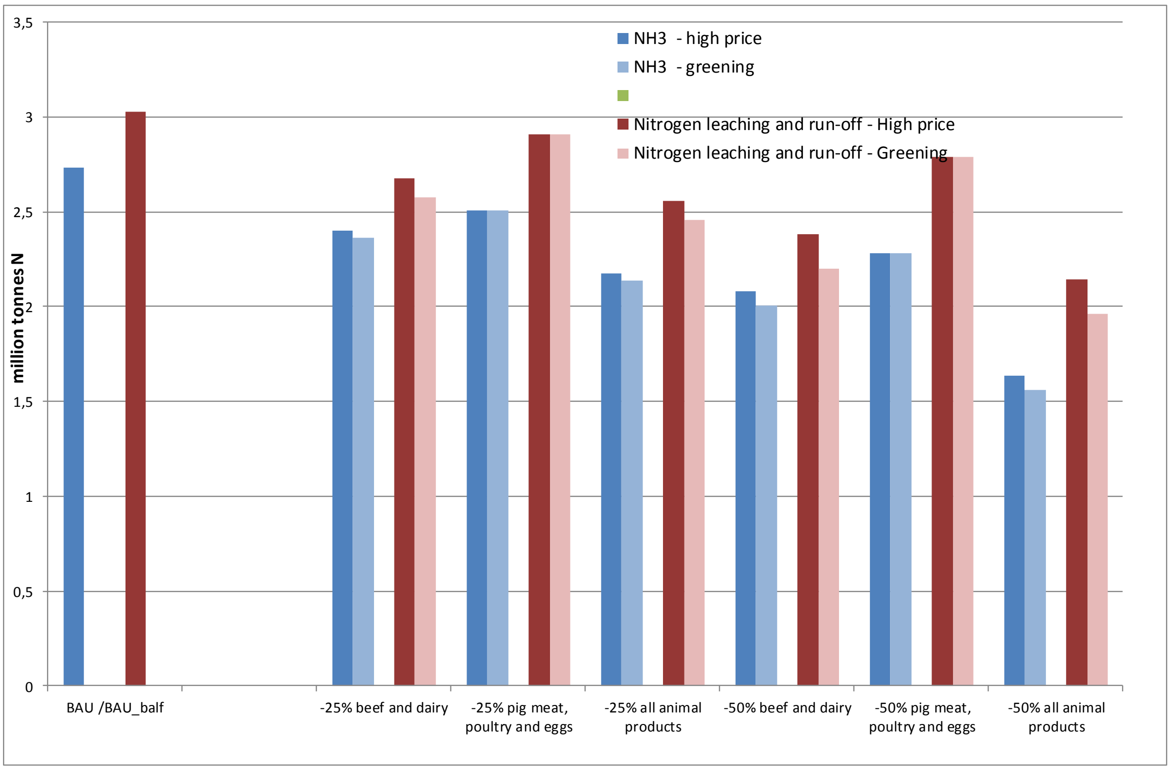

Figure 4 Emissions of reactive nitrogen in the EU (million tonnes) from agriculture in the reference (BAU – BAU_balf) and in the various consumption reduction scenarios. BAU_balf is the reference scenario with balanced fertilization.

As ammonia emissions will be reduced in the scenarios, this will also lead to a reduction of nitrogen deposition. The maps clearly show that not only deposition levels (and thus incidences of exceedance of critical loads) in the EU will decrease, but also far beyond the EU the effect is visible (Figure 5). Both in absolute and in relative terms, the reduction is the strongest in regions with high livestock densities.

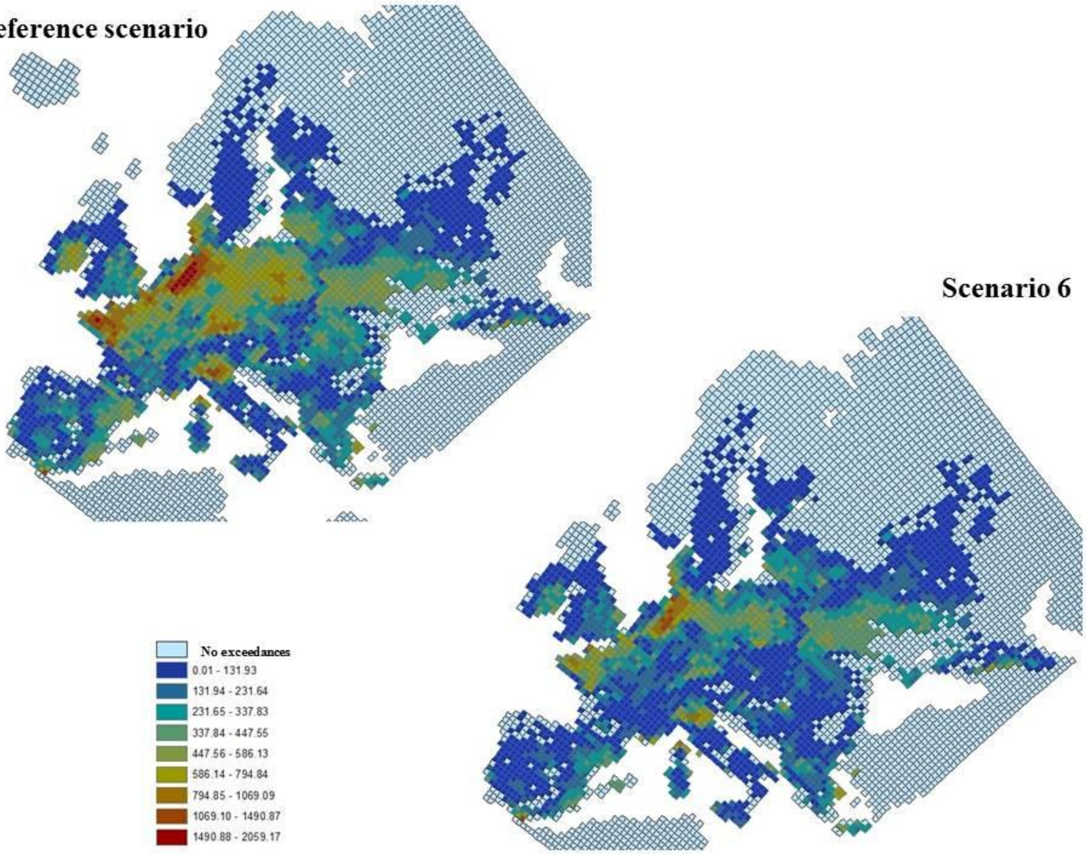

Figure 5. Average Accumulated Exceedance as calculated with GAINS in the Reference scenario and scenario 6 (50% reduction of all meat and dairy).

4.5 Scenario effects on greenhouse gas emissions and on commodity import and export

Effect on greenhouse gas emissions from EU agriculture

The scenarios have a significant effect on greenhouse gas emissions from the EU agricultural sector. The agricultural greenhouse gas emissions are reduced by between 3% and 40% , depending on the reduction scenario (Figure 4.1). The lowest emissions occur in the 50% reduction in all meat and dairy scenario where the greenhouse gas emission from agricultural production (i.e. excluding pre-farm and post-farm emissions) is around 250 million tonnes CO_2eq. compared to 410 million tonnes CO_2eq. in the reference scenario. The impact of the scenarios is the largest on methane emissions, as these emissions are almost directly related to the number of ruminants.

Trade in crop commodities

As result of the scenarios, the total EU demand for cereals (human food and animal feed combined) will decrease by between 5 and 52 million tonnes depending on the scenario. In the *greeningland use scenario*, where the cereal production remains constant, the additional amount available for export is equal to this 52 million tonnes in the case of 50% reduction in all livestock products. In the *high price land use* scenario and the same consumption reduction scenario, the EU cereal production is increased to over 400 million tonnes annually. In this scenario over 200 million tonnes would be available for export.

The use of soymeal is lowered from around 34 million tons to a minimum 8 million tonnes. This would imply that the area of land being currently being used in the Americas to produce this feed for Europe would be reduced as well.

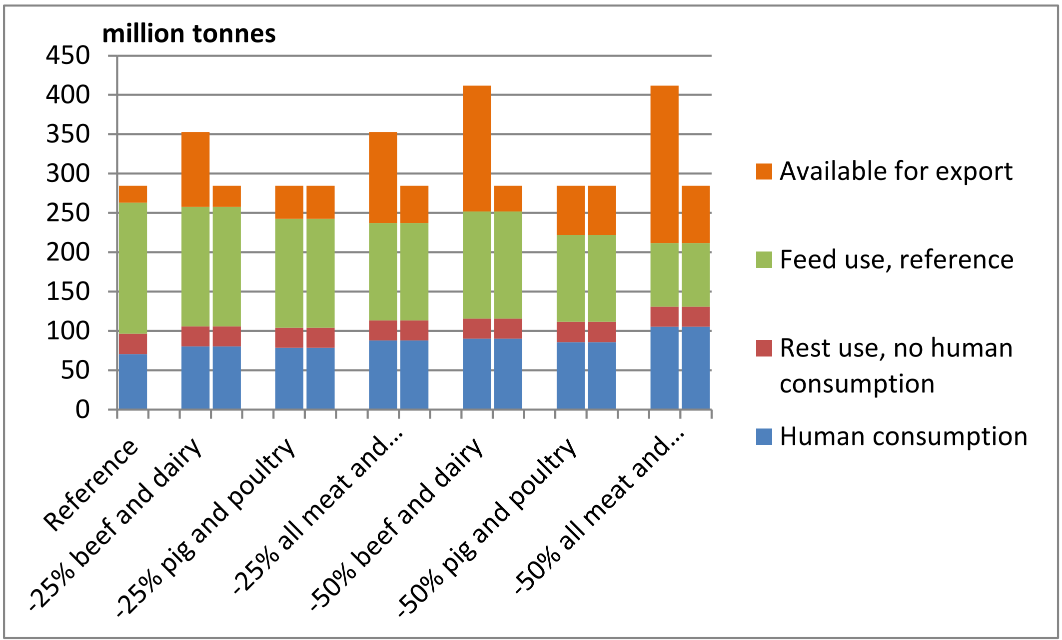

Figure 6 Cereal balance for the EU, with direct food demand, demand for non-food uses, feed demand, and the quantity available for export. Left bars: High prices scenarios; right bars: Greening scenarios

In the greening land use scenario, it is assumed that the production of bioenergy will increase. The area of arable land which could be converted is 10.3 million hectares in case of a 25% reduction in beef and dairy consumption and 14.5 million hectares in with a 50% reduction.

Wider environmental, economic and social consequences of scenarios

All of the consumption reduction scenarios would have very large socio-economic consequences for the EU livestock sector (including the pre-farm and post-farm parts of the sector. The annual added-value of the EU livestock sector amounts to more than 143 billion euro, being about 60% of the total value added in EU agriculture. The added value of the beef and dairy combined amounts around 79 billion euro, the pig sector 31 billion. The combined annual added value of the poultry and egg sector is almost 23 billion euro. A reduction of meat, eggs and dairy production would lead to a stop to livestock production on many farms.

There would be a knock-on effect on the arable sector, as the demand for feed materials would be reduced. Although it is assumed that arable production will be largely maintained and that the surplus of cereals will be exported, the question is whether there is export market can compensate for the reduction in value added by the livestock sector. In the scenarios it is assumed that meat and dairy will be mainly replaced by cereals in the human diet. If this were in the form of higer value plant-based commodities as vegetables and fruit, this would generate more income for the farming sector. Of course, the corollary of a reduction in agricultural revenues is a reduction in consumer spending on food. The reduction in livestock products with their replacement with cereals reduces spending on basic food stuffs. This spending might be transferred to foods with greater post-farm added value.

5. Discussion

The systematic quantification of the emissions arising from food commodity production has provided a rich source of data for various commodities and production systems e.g. the life cycle inventory of major commodities produced in the UK. A few studies have extended use life-cycle inventory and land-use data to examine the consequences of dietary change on agricultural greenhouse gas emissions and land needs for individual countries. The effect of Europe's pattern of protein consumption has also been examined. This is the first study that has examined the effect of consumption and production change on the nitrogen cycle and associated needs for agricultural land.

Like Audsley et al., we take a deterministic approach focused on the causal and technical relationships between commodity production and emissions in the food system. The foundation is our understanding of the emissions from the European food system as it currently functions from a combination of life-cycle inventory models. However, we extend beyond this using the MITERRA-Europe model, which calculates annual nutrient flows and GHG emissions from agriculture in the EU-27 and CAPRI.

This largely deterministic approach is taken to address 'what if' questions through scenario analysis. The scenarios are neither predictions nor endorsements of particular futures. Real world responses to changes consumption in line with these scenarios are much more complex. They would be largely determined by economic responses in relation to resources released from livestock production for European markets (as demonstrated by PBL's Protein Puzzle). Indeed, a reduction in European consumption of livestock products may result in European production switching to world markets in which case the personal N footprints of European decline but the N emissions and other negative effects of production remain.

This type of work often raises the response that either the consumption change scenarios cannot be achieved and/or that there may be unintended negative environmental consequences, for example of allowing livestock production on semi-natural grassland to contract. It is not the purpose of this research to advocate for or to achieve the type of consumption change tested. However, the research identifies one very good reason why consumption my change in the direction indicated: the better alignment of diets with health recommendations. The consumption of key livestock products is already declining in some European countries and this research shows that such a decline can bring environmental and resource use benefits. The research also shows that a contract market for livestock products can be combined with retention of the use of semi-natural grassland for livestock production.

The scenarios and the system simplification that is necessary to examine them do reveal clear messages. The clearest is that a switch from animal to plant-based diets brings a wide range of environmental and resource use benefits and better alignment of diets with current health recommendations. In summary, there are no specific down-side risks to public goods if production is scaled back in line with demand. In addition, such change releases land resources in particular which, depending on subsequent use, can bring a number of additional direct and indirect public benefits. In agreement with Audsley et al. (2010) who looked only at effects on the UK, the amount of arable land required to produce additional crops for direct human consumption is less than land released in feed and fodder production. The studies also agree on the overall effect on the nitrogen cycle – they indicate that in moving back from the current livestock product consumption to 50% of current consumption, reactive nitrogen emissions will be reduced by about 35-40%. In other words, in our current agricultural and food system, reactive nitrogen emissions are closely correlated with the livestock component of the diet in energy terms.

This study went beyond the Audsley et al study in identifying the location of public benefits. The benefits for emissions are mostly in countries now subject to high nitrogen emissions due to intensive animal production. The potential health benefits through better alignment with dietary recommendations are more universal.

Our research shows that there is a large synergy in positive effects of consumption changes towards less animal products to reduce nitrogen pollution, reduce greenhouse gas emissions, improve the use of agricultural land, and to improve public health.