Nitrogen on the Table

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

Special Report of the European Nitrogen Assessment

TFRN LRTAP Long-range Transboundary Air Pollution

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About the Task Force on Reactive Nitrogen (TFRN)

The TFRN was established by the Executive Body of the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (CLRTAP) with the "*long-term goal of developing technical and scientific information, and options which can be used for strategy development across the UNECE to encourage coordination of air pollution policies on nitrogen in the context of the nitrogen cycle and which may be used by other bodies outside the Convention in consideration of other control measures.*" The Task Force conducts its work through the contribution of several Expert Panels, with the present report prepared by the Expert Panel on Nitrogen and Food (EPNF).

The European Nitrogen Assessment (ENA) produced its first report in 2011 with a comprehensive analysis of the drivers, flows, impacts and policy options for better nitrogen management in Europe. The results of the ENA have been formally presented through the TFRN to the Executive Body of the CLRTAP. Special Reports of the European Nitrogen Assessment highlight key challenges and opportunities for action on nitrogen which may be used by the UNECE and other bodies.

About this publication

The present ENA Special Report has been prepared and peer reviewed as a scientifically independent process as a contribution to the work of the Task Force on Reactive Nitrogen. The views and conclusions expressed are those of the authors, and do not necessarily reflect policies of the contributing organizations. The report was edited by Clare Howard and Mark Sutton, with technical production and lay-out by Seacourt. We gratefully acknowledge kind inputs and support from other members of the TFRN Expert Panel on Nitrogen and Food: T. Garnett and J. Millward, as well as G. de Hollander, D. Nijdam, L. Bouwman (all PBL), S. Caldeira (JRC), Claudia S.C. Marques dos Santos Cordovil and Tommy Dalgaard for data, suggestions and support in preparing this report.

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ENA Special Report on Nitrogen and Food

Nitrogen on the table

The influence of food choices on nitrogen emissions, greenhouse gas emissions and land use in Europe

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Contents

FOREWORD

This report has its origins in the very first meeting of the Task Force on Reactive Nitrogen (TFRN-1), which took place in Wageningen, The Netherlands, May 2008. The Task Force had recently been established by the Executive Body of the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP), reflecting an emerging recognition of the importance of nitrogen in the environment.

Traditionally, the work of the LRTAP Convention had focused primarily on technical measures as a means to achieve national reductions in air pollution emissions. But, as the discussions of TFRN-1 developed, it became clear that total reactive nitrogen (N_r) emissions are also very sensitive to society's food choices. For some in the Convention this initially seemed an uncomfortable topic for discussion. The focus of such an inter-governmental framework was seen as being on the technical options to be implemented by source sectors, such as electricity generation, transport and agriculture. Was not dietary choice outside the remit of the Convention and too sensitive a matter to discuss?

Those initial discussions at TFRN-1 made it clear that dietary choice had to be part of the wider analysis with which the group was tasked. The parallel was quickly made with emissions of nitrogen oxides (NO_x) from transport: technical measures – in the form of three-way catalysts and engine improvements – had greatly reduced emissions per vehicle mile, but these gains had been significantly offset by a substantial increase in vehicle miles driven. The discussion about nitrogen and food was, in principle, no different (Sutton, 2008). The potential gains made by future adoption of low nitrogen emission practices in farming could easily be lost by an increase in consumption of high-nitrogen foods, which applied especially to livestock products (Steinfeld et al., 2006).

This thinking led to the development of new global scenarios (up to 2100) of a more balanced meat and dairy consumption in the developed world, as compared with a consideration of "food equity", where rates of dietary intake would increase among the world's poorest (Erisman et al., 2008)[1]. It also fed into the development of the European Nitrogen Assessment, ENA (Sutton et al., 2011a). The same week of TFRN-1 in Wageningen saw the first workshop of the ENA process, allowing its outcomes to be reported immediately to the Task Force. It became clear that the eventual ENA product would need chapters that considered future dietary aspirations, including consideration of a smaller meat consumption (e.g. 'healthy diet' scenario, Winiwarter et al., 2011) and the challenge to communicate nitrogen to society (Reay et al., 2011b).

The experience of launching the ENA has shown that there is huge merit in coupling discussions about agricultural technical measures with society's food choice aspirations. Few members of the public get excited to talk about improved manure management options. But everyone is interested in food. By discussing both together, there is the opportunity to engage the public in why they need to know about the nitrogen cycle. In this way, the scientific community can highlight the many benefits and threats of reactive nitrogen across the planet, ranging from food and energy security to threats to water, air and soil quality, climate and biodiversity. It also illustrates how a joined-up approach to managing the nitrogen cycle would lead to multiple benefits for society (Sutton et al., 2011a).

While publication of the ENA represented a key advance in raising the profile of these issues, it was not possible to bring all the threads to completion by that time. There were urgent matters in hand, especially in synthesizing the technical options for ammonia mitigation to support revision of the Gothenburg Protocol. These included options for revision of the Protocol's Annex IX (UNECE, 2011), updating the estimated costs of ammonia abatement (UNECE, 2011), revising the supporting Ammonia Guidance Document and Ammonia Framework Code (UNECE, 2012; Bittman et al., 2014, UNECE, 2015) and developing a new guidance document on national nitrogen budgets (UNECE, 2012). Effective progress in these actions was achieved by the Task Force working through its Expert Panel on Mitigation of Agricultural Nitrogen (EPMAN) and its Expert Panel on Nitrogen Budgets (EPNB).

1 An update of the Erisman et al. (2008) scenarios, which were based on the SRES approach (Special Report on Emissions Scenarios), has been made by Winiwarter et al. (2013) using the RCP approach (Representative Concentration Pathways).

In order to bring forward the scientific analysis on food choice relationships, the Task Force therefore agreed in 2009 to establish a new Expert Panel on Nitrogen and Food (EPNF) (UNECE, 2009, paragraphs 25-26). The Panel was subsequently launched in 2010 under the co-chairmanship of Mr Henk Westhoek (PBL, The Netherlands) and Mr Christian Pallière (Fertilizers Europe, Belgium).

The emerging messages from the work of the Expert Panel have already been reported to the LRTAP Convention's 'Working Group on Strategies and Review' (UNECE, 2012). Since then, the work has continued, allowing completion of the present full report, accompanied by two peer review papers (Westhoek et al., 2014; Leip et al., 2014). As a logical continuation of the European Nitrogen Assessment, we here publish the findings in the form of an 'ENA Special Report'.

Based on these outcomes, the Executive Summary of the present report was presented to the press in April 2014, supported with the further details given by Westhoek et al. (2014). The strong press interest and public feedback has clearly illustrated the power of the food choice debate in highlighting the role of nitrogen in the environment.[2]

Consistent with the mandate of the Expert Panel, the present report does not focus on how to achieve such changes in diets across European society. The task for the moment is to demonstrate the close relationship between our food choices, environmental pollution and human health indicators. The next step is to develop the discussion further with the public, politicians, international treaties and across academia, including between environmental scientists and nutritionists.

In this way, the LRTAP Convention's work on nitrogen provides a starting point for governments and society to discuss what is the right balance of effort: between implementing new technical measures in agriculture, reducing food waste etc. and fostering change in dietary choices. Whatever the outcome of that debate, it is clear from the present report that reducing European consumption of meat and dairy products would make a significant contribution to reducing nitrogen air and water pollution and greenhouse gas emissions. At the same time there is potential for significant human health benefits, while freeing up substantial areas of agricultural land to help meet global food security and energy security goals.

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Edinburgh, Wageningen, Aarhus and Lisbon, June 2015

2 See for example, Agriculture and Rural Convention (2014), Press Association (2014), Chertsey (2014), www.dNmark.org, Jones (2014), Kirby (2014), Midgley (2014), Vaugham (2014) and Webster (2014) and associated public discussion.

SUMMARY FOR POLICY MAKERS

Key findings

1. The European Nitrogen Assessment (ENA)[1] illustrated the role of agriculture as a major source of nitrogen losses. Despite the relatively high nitrogen use efficiency (NUE)[2] of agriculture in the European Union, **the current total loss of reactive nitrogen from European Union (EU) agriculture amounts to an estimated 6.5 - 8 million tonnes per year, representing around 80 % of reactive nitrogen emissions from all sources to the EU environment** [2.3.1 and 5.3.4].[3] These nitrogen losses are mainly in the form of ammonia to the air, of nitrate to ground and surface waters and of nitrous oxide (a powerful greenhouse gas).

2. **This report examines these losses from the EU agri-food system** further by (i) allocating nitrogen losses to food commodity groups (to determine nitrogen 'footprints') and (ii) by exploring the effect of alternative diets on nitrogen emissions, greenhouse gas emissions and land use.

3. **There are large differences between food commodities in terms of nitrogen losses per unit of protein produced. Plant-based foods, such as cereals, have relatively low losses while livestock products have much higher losses**. Nitrogen losses per unit of food protein from beef are more than 25 times those from cereals. For pig and poultry meat, eggs and dairy, the losses are 3.5 to 8 times those from cereals [2.3.2]. Corresponding values for nitrogen use efficiency (NUE) are low for meat and dairy products (5-30%) as compared with plant-commodities (45-75%).

4. **The results show that livestock production chains have a high share in nitrogen losses**. Around 81-87% of the total emissions related to EU agriculture of ammonia, nitrate and of nitrous oxide are related to livestock production [2.3.2]. In these values for livestock production the emissions related to feed production (as cereals and fodder crops) are included.

5. **The current average nitrogen 'footprint'[4] per person differs by a factor 2-4 between European countries, mainly as a result of differences in average food consumption patterns** [3.3.3]. Countries with high intake of animal products (such as France and Denmark) in general have considerably larger nitrogen footprints than countries with a low intake of animal products (such as Bulgaria and Slovakia). Overall for the EU-27, 52% of protein intake comes from meat, with 34% from dairy, 7% from eggs and 7% from fish and other seafood.

6. **The current average per capita protein intake in the EU is about 70% higher than would be required according to the World Health Organization (WHO) recommendations** [3.3.2]. This provides opportunities for a shift towards a change in European food consumption habits with lower nitrogen footprints, reducing adverse environmental impacts on water, air and soil quality, climate and biodiversity. The current intake of saturated fats is 42% higher than the recommended maximum dietary intake, leading to increased risk of cardiovascular diseases. As 80% of saturated fats originate from animal products, a reduction in animal products would in general be favourable to human health as well [3.3.2].

Scenarios and key outcomes

7. **In this study the effects of a number of alternative diets with lower intake of meat and dairy were assessed considering their impact on nitrogen losses from EU agriculture, as well as on greenhouse gas emissions, land use and human health**. A reduction in pig meat, poultry meat and eggs was explored in one set of alternative diets. In another, a reduction in beef and dairy was explored. The reduction in all types of livestock products was also explored, in each case considering the consequences of 25% and 50% reductions. These reduction percentages were chosen primarily to illustrate how the food system could respond under major change, which could be achieved by a range of possible intake strategies (e.g. changed frequency of meat and dairy consumption or reduced portion size). The effects on feed requirement, crop production, land requirements and nitrogen losses were examined.

8. **Reducing meat and dairy consumption frees up large areas of agricultural land in the EU providing new opportunities of how to manage this land**. We considered two alternative scenarios: Greening Scenario and a High Prices Scenario [5.2.3]. In the Greening Scenario, land no longer needed for feed production is used for the production of perennial biomass crops. Furthermore, the lower demand for grass is assumed to lead to an extensification of grassland use by lowering mineral N fertilizer input. In the High Prices Scenario, tight global commodity markets and therefore high cereal prices are assumed.

1 Sutton, M.A., Howard, C.M., Erisman, J.W., Billen, G., Bleeker, A., Grennfelt, P., van Grinsven, H., Grizzetti, B., (eds.) (2011) The European Nitrogen Assessment: Sources, Effects and Policy Perspectives. Cambridge University Press, Cambridge, pp. 612.

2 The nitrogen use efficiency is here defined as the ratio of nitrogen outputs to nitrogen inputs, all the way from the fertilizer input to nitrogen in final food and bioenergy products.

3 References in this summary (e.g., [1.1, 5.3.1]) refer to chapter and section numbers of this Special Report.

4 This footprint is calculated as the total nitrogen loss to the environment per unit of product.

Land no longer required for fodder production (including temporary grassland and a fraction of the permanent grasslands) is used for cereal production.

9. **In the Greening Scenario, a 50% reduction in livestock product consumption and production would reduce current European agricultural reactive nitrogen emission by 42% (Table S1, Figure S1)**. In this alternative diet, the ammonia emissions are 43% lower, nitrous oxide emissions are 31% lower and nitrate emissions are reduced by 35% [5.3.4]. The emissions are reduced most in alternative diets involving decreased beef and dairy production. In general, ammonia emission reductions are higher than the reduction in nitrous oxide and nitrate leaching. This is because ammonia emissions are mainly from livestock production, whereas both livestock and arable field-based activities contribute large shares of the nitrous oxide and nitrate emissions. Greenhouse gas emissions from agriculture are predicted to be reduced by over 42%. Bioenergy crops expand by 14.5 million, being equal to 40% of the projected use of bio-energy material in the EU in 2020 [5.3.6].

10. **In the High Prices Scenario, a 50% reduction in livestock product consumption and production would also reduce current European agricultural reactive nitrogen emission by around 37% (Table S1, Figure S1)**. In this alternative diet, the ammonia emissions are 40% lower, nitrous oxide emissions are 24% lower and nitrate emissions are reduced by 29% [5.3.4]. Greenhouse gas emissions from agriculture are predicted to be reduced by 19%. In this scenario, cereal export would increase from the current 3 million tonnes per year to over 170 million tonnes [5.3.8].

11. **In both scenarios, the requirement for imported soybeans, as meal currently used as animal feed, is reduced by 75% (Table S1)**. 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 [5.3.8].

12. **A shift to a more plant-based diet will lead to a large decrease in the nitrogen footprint of EU citizens**. 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% [4.3.3]. The current large differences in per capita nitrogen footprint between EU member states will also become smaller.

13. **The reductions in reactive nitrogen emissions will have benefits not only within the EU but at continental and global scales**. Both atmospheric ammonia and nitrates in water-bodies cross national frontiers, with the consequence that the dietary scenarios investigated make a significant contribution to reducing international pollution export. The reduced emissions of the greenhouse gases methane, nitrous oxide and carbon dioxide are relevant both at EU level and globally.

14. **The scenarios lead to food consumption patterns that are better aligned with international dietary recommendations**. All of the reduction scenarios lead to a reduced intake of saturated fats, the main source of which is animal products. Even though the reductions are significant, only the most radical scenario - representing a 50% reduction in all meat and dairy consumption, brings the average intake of saturated fats within a range recommended by the World Health Organization (WHO) [4.3.2]. This scenario represents a 40% reduction in the intake of fats. The same radical scenario is also the only one assessed where the average intake of red meat is reduced to being only slightly above the maximum recommended by World Cancer Research Fund (WCRF) (Table S1, [4.3.2]). Based on the current WHO and WCRF dietary recommendations, the results are clear: the reduced intake of red meat and saturated fats in these reduction scenarios means that public health risks would be reduced.

15. **The alternative diets would lead to major changes in EU agriculture, with the expectation of large socio-economic consequences**. Livestock production is currently responsible for 60% of the value-added on EU farms, and this revenue would be greatly reduced under the alternative diets [Chapter 6]. By contrast, the High Prices Scenario leads to increased cereal exports and associated revenue. The net farm-level economic effect would depend on world market conditions and especially whether the additional cereal can be sold at a price that is profitable for European farmers. In the scenario where additional cereals are exported, this might have beneficial effects on global commodity markets in terms of food security. However this also has the risk of suppressing production and thus market opportunities for local farmers in developing countries, which is avoided in the increased bioenergy scenario [Chapter 6].

16. **Considering the major benefits of reduced European meat and dairy consumption for environment, climate and human health, there is a need to explore further the market, educational aspects, and policy and other options which would enable the barriers-to-change to be addressed**.

Table S1 Summary of data on average food intake in Europe and environmental indicators under current conditions (based on 2004) and under a 50% reduction in the consumption of animal products [synthesis from 4.3.3 and 5.3].

Aspect	Unit	Reference	-50% meat, dairy and eggs[1]	
Protein				
Average daily intake	g per person per day	83	75	
Proportion of animal origin[2]	%	60%	36%	
Saturated fats				
Average daily intake	g per person per day	36	22	
Compared with the RMDI[3]	%	142%	86%	
Red meat				
Average daily intake	g per person per day	88	47	
Compared with the RMDI[4]	%	207%	107%	
		Reference	**High Prices Scenario**	**Greening Scenario**
Environment				
Total losses of N_r (EU)	Million tonnes per year	6.5	4.1	3.8
Losses of NH_3 N to air		2.8	1.6	1.6
Losses of N_r to water		3.3	2.1	2.0
Losses of N_2O N to air		0.37	0.27	0.25
Losses of N_2		6.7	4.2	3.9
GHG emissions (EU)	Million tonnes per year	464	347	268
NUE[5] food system (EU)	%	22	47	41
Agriculture				
Soy imports (as beans)	Million tonnes per year	34	8	8
Cereal exports	Million tonnes per year	3	174	54
Additional production of bioenergy	EJ per year	-	-	2.3
Potential contribution to EU bio-energy projection for 2020	%			40

[1] sheep and goat meat are not reduced
[2] including fish and other seafood
[3] RMDI = Recommended Maximum Dietary Intake
[4] RMDI as advised by the World Cancer Research Fund and American Institute for Cancer Research (WCRF, AICR (2007))
[5] Nitrogen use efficiency of the total food system (total output of N in the form of food crops and livestock products /total input of N into agricultural system) including direct emissions from agricultural production of N_2O, CH_4 and CO_2

Figure A

Nitrogen flows in the agricultural food system in EU27, reference 2004 based on Miterra data

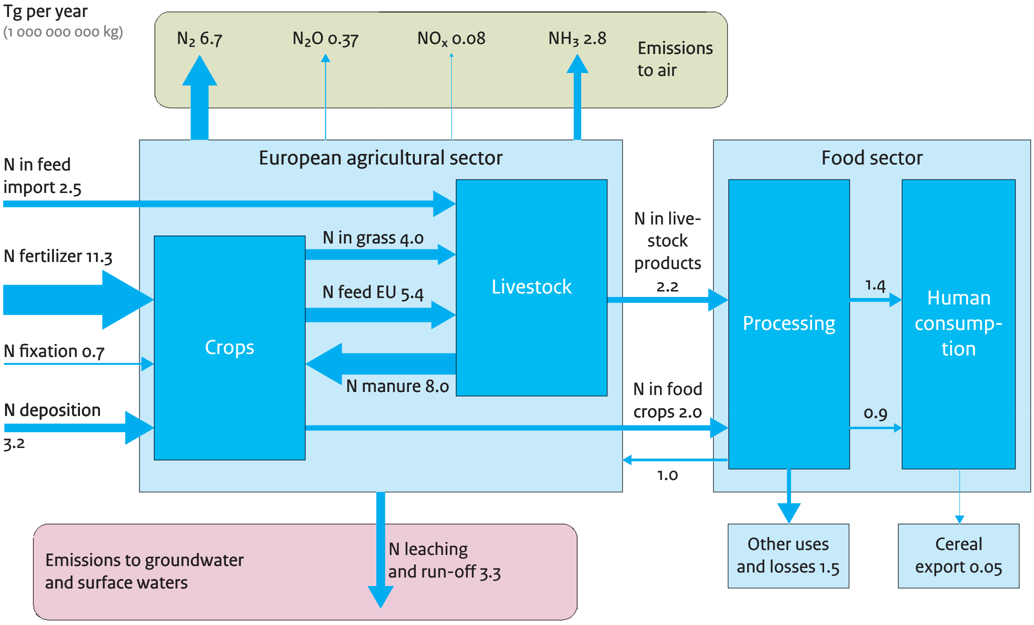

Figure B

Nitrogen flows in the agricultural food system in EU27, -50% all meat and dairy Greening scenario

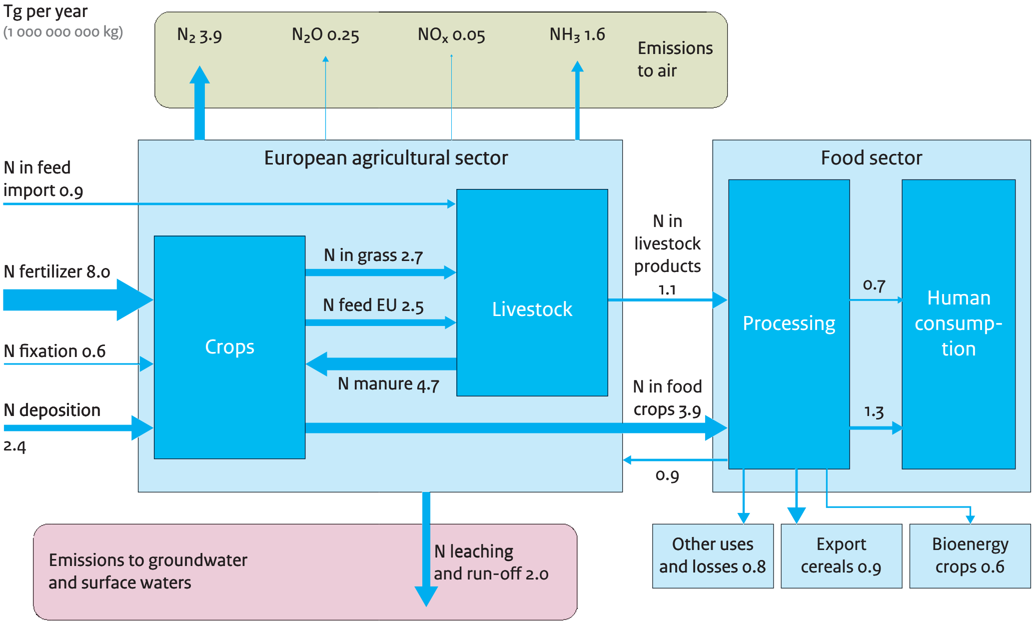

Figure S1 (A and B) Nitrogen flows in the EU agricultural and food system in the reference situation for 2004 **(A)** and in case of the alternative diet with 50% reduction in consumption of meat, dairy and eggs in the Greening Scenario **(B)** and in the High Prices Scenario **(C, see next page)**. Values shown here are based on application of the MITERRA model.

Figure C

Nitrogen flows in the agricultural food system in EU27, -50% all meat and dairy High prices scenario

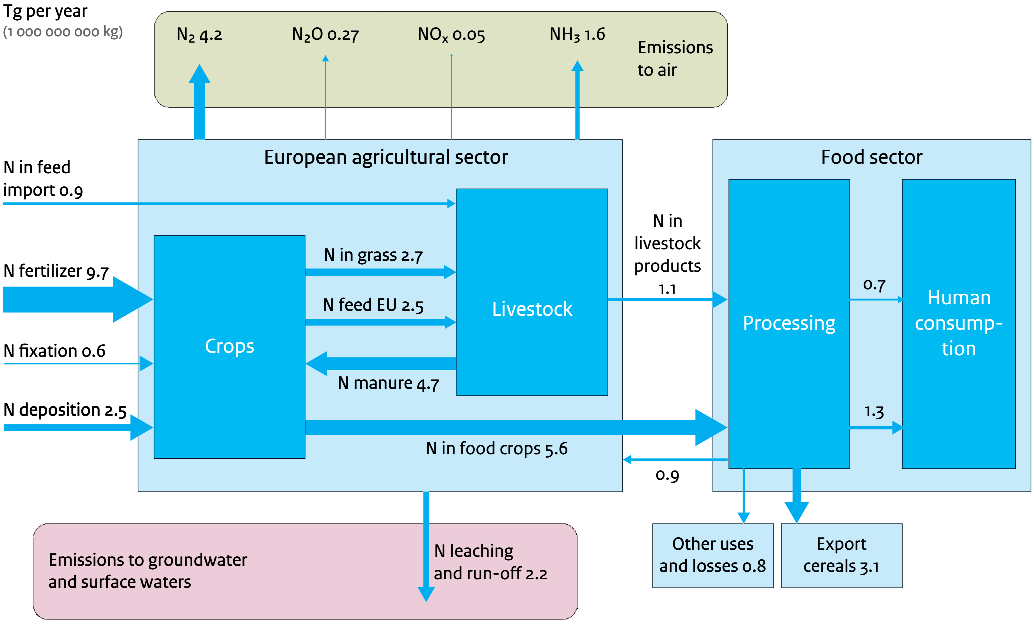

Figure S1 continued (C) Nitrogen flows in the EU agricultural and food system in the case of the alternative diet with 50% reduction in consumption of meat, dairy and eggs in the High Prices Scenario **(C)**. Values shown here are based on application of the MITERRA model.

1 INTRODUCTION

In Europe, agriculture is the major source of emissions of reactive nitrogen[1] (Sutton et al., 2011a). On the one hand, nitrogen is an essential element for crop and animal production, as well as for human life. Crops need nitrogen in the form of nitrate or ammonia to grow. This nitrogen can stem from different sources, as mineral fertilizer, manure, organic matter or bacteria. Animals and humans need proteins, of which nitrogen is a key component. On the other hand, nitrogen emissions can be harmful for humans and for biodiversity, and have negative effects on many natural resources.

Agriculture is the dominant source of emissions in Europe for each of nitrates to ground and surface waters, as well of emissions of ammonia and nitrous oxide to the air (ENA, 2011). High nitrate concentrations in drinking water are considered a risk to human health. In surface waters and coastal zones nitrogen enrichment causes eutrophication, which leads to biodiversity loss, algae blooms and fish kills. Emission and consequent deposition of ammonia leads to loss of terrestrial biodiversity, while nitrous oxide is a powerful greenhouse gas. Due to policy interventions, economic circumstances and technological improvements nitrogen emissions from agriculture in Europe have decreased since their peak in around 1985. Nevertheless, in many areas in Europe nitrogen emissions are still causing problems with regard to either human health or loss of biodiversity.

In the European Nitrogen Assessment seven key actions were identified to reduce nitrogen emission. With respect to agriculture the following four key actions are most relevant:

1. Improving nitrogen use efficiency in crop production;
2. Improving nitrogen use efficiency in animal production;
3. Increasing the fertilizer N equivalence value of animal manure;
4. Lowering the human consumption of animal protein.

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, exploring the potential of the first three actions.

This report focuses on the potential consequences of lowering the human consumption of animal protein in Europe. The potential achievements from such dietary changes should be seen as complementary to the outcomes of the first three key actions listed above. It is a matter for society to decide on the relative effort placed on the different key actions, as informed by scientific evidence on the opportunities and their relationships.

While agriculture is the main source of nitrogen emissions in Europe, it has also been shown that livestock production is the key driver of total nitrogen losses (ENA, 2011). Ammonia emissions mainly originate from stables and manure storages and spreading. Livestock manure is also a major source of nitrate leaching, for example due to wrong timing of manure application, or due to over-application of manure. Although much research has been done on emissions of GHG and land use related to animal products, little research has been done to investigate the nitrogen footprint of different food products (Leip et al, 2014). Even less studies have explored the effects on nitrogen emissions of large scale dietary shifts. This report aims to fill this gap, by analysing current nitrogen flows and emissions, as well as the nitrogen footprints of different types of food. Based on a set of assumptions, the report explores how alternative diets by European citizens would alter nitrogen pollution and its relationship with other relevant issues.

1 The term 'reactive nitrogen' refers to all types of nitrogen form other than unreactive nitrogen (N_2), which makes up nearly 80% of the world's atmosphere. Reactive nitrogen (also termed, N_r) includes nitrates, ammonia, nitrous oxide, nitrogen in proteins etc.

In Chapter 2 we focus on the current nitrogen emissions from agriculture. In this chapter the following questions are addressed:

1. What are the emissions of reactive nitrogen related to the EU agricultural sector as a whole?
2. What are the emissions of reactive nitrogen per EU agricultural subsector?
3. What are the emissions of reactive nitrogen per unit of produce for the most important food commodities?

Further information concerning this chapter has been reported by Leip et al. (2014).

Chapter 3 explores the historic and current composition of European diets, with a focus on animal protein. It also assesses current diets in the light of dietary recommendations.

In Chapter 4 and 5 the consequences of a hypothetical shift in European diets are explored, by assessing diets with a 25 to 50% lower consumption of animal products. By using biophysical models and methods, the effects on nitrogen emissions, greenhouse gas emissions as well as land use are evaluated. Chapter 4 focuses on the dietary aspects; Chapter 5 on the environmental outcomes. Further information concerning this chapter has been reported by Westhoek et al. (2014).

Finally, Chapter 6 places the results of Chapters 2 to 5 in a broader context, discussing the potential economic consequences and the question of how these dietary shifts could be brought about.

For practical reasons including the availability of data and suitable models, this study was confined to EU-27. Livestock production and 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 (Leip et al., 2011a).

2 CURRENT NITROGEN EMISSIONS FROM THE EU AGRICULTURAL SECTOR AND BY FOOD COMMODITY

2.1 Introduction

Agricultural activities are intrinsically linked to the use and loss of reactive nitrogen, including both intended and unintended nitrogen flows (Sutton et al., 2011a,b). Examples of intended use of reactive nitrogen are fertilisation of crops (either with mineral fertilizers or manure) to increase yields, and the feeding of animals. Unintended losses of reactive nitrogen occur, for example, from manure in housing systems or manure management systems, or upon application of manure to agricultural land or from grazing animals. In addition, the application of mineral fertilizer leads to losses of reactive nitrogen, both to the atmosphere and to ground and surface waters.

Reactive nitrogen (N_r) emissions to the atmosphere from agriculture occur mainly in the form of ammonia (NH_3). About 95% of total ammonia emissions to the atmosphere over Europe are of agricultural origin. However, other N_r gases are also emitted, such as nitrogen oxides (NO_x) and nitrous oxide (N_2O) (Leip et al., 2011b). The main source for overall NO_x emissions is the use of fossil fuel derived energy and thus the agricultural proportion of total NO_x fluxes is only 3%. However this does not include the use of fossil fuel required to cultivate the crops, house the animals, transport feed and food, and finally distribute to the consumer, prepare and dispose. In addition NO_x is also emitted from agricultural soils.

Nitrogen emissions to the hydrosphere occur from agricultural sources (mainly diffuse) and from sewerage systems (mainly point sources). N_r emissions to ground and surface waters are mostly in the form of nitrates (NO_3^-), but also in the form of ammonium and dissolved organic nitrogen. These losses are closely linked to the level of nitrogen surplus (input of nitrogen minus output in useful products). High rates of nitrogen surplus – the total loss of nitrogen to the environment – are closely related to the presence of livestock (Leip et al., 2011a).

Finally, N_r is lost from the agri-food chain by denitrification back to di-nitrogen (N_2). Such N_2 losses are closely associated with denitrification to form N_2O. Although N_2 emission does not contribute to radiative forcing of climate, the emission rates of N_2 are typically at least ten times larger than those of N_2O. Denitrification to N_2 therefore represents as significant loss of available N_r pools, indirectly contributing to climate forcing because of the CO_2 equivalent used to produce N_r in the first place.

In this chapter we focus on three main questions:
1. What are the N_r emissions related to the EU agricultural sector as a whole?
2. What are the N_r emissions per EU agricultural subsector?
3. What are the N_r emissions per unit of produce for the most important food commodities?

This analysis provides the foundation to establish a baseline scenario against which different dietary scenarios are considered in Chapters 4 and 5.

2.2 Methodology

We specified losses of reactive nitrogen for twelve main food commodity groups, which cover about 97% of EU food crop production. 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). Emissions from fish and fish products are not simulated in the models used and have therefore not been included.

Even though the assessment is restricted to food produced within the EU, the emissions of imported feed are considered. The relevance of this approach is that for a commodity such as beef or eggs the emissions related to the feed production are taken into account as well as the nitrogen emissions related to the livestock part of the production. 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.

All data presented refer to the time period 2003-2005 which is the current 'base year' of the models employed. Quantification of nitrogen losses from the agricultural sector is done on the basis of the agri-economic model CAPRI (Britz and Witzke, 2012). The calculations presented in Chapter 5 also use MITERRA-EUROPE. Both the CAPRI and MITERRA-EUROPE models have previously been used in assessing the contribution of the European livestock sector to anthropogenic greenhouse gas (GHG) fluxes in Europe (Leip et al., 2010; Lesschen et al., 2011; Weiss and Leip, 2012).

2.2.1 Nitrogen losses from the agricultural sector

The CAPRI model uses a mass-flow approach to represent the nitrogen cycle in agricultural systems (Figure 2.1) (Leip et al., 2011a; de Vries et al., 2011a). Emissions of reactive nitrogen occurring in earlier stages, such as during the storage of manure, are subtracted from the nitrogen pool before calculating emissions at a later stage, such as following the application of manure. Emission factors used are consistent with methodologies developed by IPCC (IPCC, 2006) or the GAINS model (Klimont and Brink, 2004; Winiwarter, 2005).

2.2.2 Cradle to farm gate life-cycle assessment

In a life-cycle assessment (LCA), emissions occurring at various stages during the life of a product are cumulatively attributed to the product, on the basis of a defined 'functional unit' (ISO, 2006a, 2006b; Food SCP RT, 2013). The functional unit is the marketable mass of the product, for example 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 carcass meat. The 'life' of a product includes all the inputs required to produce the product, from the land on which it grows to the emissions related to production of mineral fertilizer and emissions during the transport of feed products to emissions occurring on the farm through the use of fuel for cultivating the soil and on-farm energy use. Such an approach is thus called a 'cradle-to-farm gate' LCA (Food SCP RT, 2013).

An LCA model (as implemented in CAPRI, Weiss and Leip, 2012) considers the emissions related to the use of energy, as well as those from imported feed-product energy, as combustion of fuel leads to the emissions of NO_x. Table 2.1 gives a complete list of emission sources considered in this study.

In an LCA, decisions need to be made on the allocation of fluxes of N_r in the cases where one production activity leads to more than one product. For example, one dairy cow produces milk and meat once slaughtered, but also produces calves that may be used for either meat or (mainly) milk production. The production of sheep and goat meat, sugar and oils, yields by-products such as wool, molasses, and oil cakes, which are not considered here. A large part of the useable proteins (in the case of sugar and oils virtually all the nitrogen in the products) is contained in the by-products and the product (e.g. oils) is used for its energy content. Allocation of emissions is done on the basis of biomass, and emission intensities per unit of nitrogen are calculated for the primary crop (e.g. rape seed). Wool as a by-product is considered in the CAPRI model. Table 2.2 gives more details on the allocation methods used.

Table 2.1 Emission sources considered in this study (adapted from Weiss and Leip, 2012).

Emission source	Livestock rearing	Crop/feed production	UNFCCC sector
• Livestock excretion			
• Manure management (housing and storage)	X		Agriculture
• Deposition of N by grazing animals	X		Agriculture
• Manure management (housing and storage)	X		Agriculture
• Indirect emissions following N-deposition of volatilized NH_3/NO_x from agricultural soils and leaching/run-off of nitrate	X		Agriculture
• Use of fertilizers for production of crops dedicated to animal feeding crops (directly or as blends or feed concentrates, including imported feed)			
• Manufacturing of fertilizers		X	Energy/Industry
• Use of fertilizers, direct emissions from agricultural soils		X	Agriculture
• Use of fertilizers, indirect emissions following N-deposition of volatilized NH_3/NO_x from agricultural soils and leaching/run-off of nitrate		X	Agriculture
• Cultivation of organic soils		X	Agriculture
• Emissions from crop residues (including leguminous feed crops)		X	Agriculture
• Feed transport (including imported feed)		X	Energy
• On-farm energy use (diesel fuel and other fuel electricity, indirect energy use by machinery and buildings)	X	X	Energy
• Pesticide use		X	Energy
• Feed processing and feed transport		X	Energy

Table 2.2 Allocation methods of the emission sources applied in this study.

Activity	Products	Allocation method
Cereal cultivation	Grain and straw	N content
Oilseeds	Oil cakes and vegetable oils	Mass
Sugar beet	Sugar and molasses	Mass
Cattle		
Sheep and goat	Meat and milk	All animal raising activities are allocated to meat; emissions in the 'dairy cow' phase are allocated to milk and meat according to the N-content in annually produced meat and the offspring per year. No emissions are allocated to leather products, wool or to any product other than meat or milk
Poultry	Eggs and poultry meat	Emissions from chicken are allocated to meat; emissions from hens are allocated to eggs and meat according to the N-content in the eggs and the annually slaughtered meat

2.3 Results

Figure 2.1 presents an overview of the nitrogen flows in the agricultural and food sector across EU-27 (Leip et al., 2014). Around 15 million tonnes of nitrogen (equivalent to 15 Tg N) is taken up by biomass annually on agricultural land, and used as livestock feed, food, fibre or fuel. This is driven by a supply of nitrogen to agricultural land of 21.2 million tonnes N per year, mainly in the form of mineral fertilizers (10.9 million tonnes N per year) and the input of manure nitrogen (7.2 million tonnes N per year). At the same time, about 7.0 million tonnes N per year are extracted from agricultural production, for other societal use, which is supplemented by an import of 2.3 million tonnes N per year, mainly in crop products. Finally, only 2.3 million tonnes N per year are consumed by European citizens, while more than 10 million tonnes N per year is emitted from agricultural systems to the atmosphere or hydrosphere in Europe.

2.3.1 Nitrogen losses from the agricultural sector

The close link between livestock and crop production systems through the exchange of feed and manure with emissions of nitrogen compounds to the environment from both sub-systems can also be seen in Figure 2.1. Agriculture supplies around 2.7 million tonnes N per year in animal products and 3.9 million tonnes N per year in vegetable products, out of which 3 million tonnes N per year are processed to animal feed (not shown) or for other purposes. Only 2.3 million tonnes N per year are actually consumed by European citizens, therefore slightly more proteins are consumed in animal products than in vegetable products (see Chapter 3).

The geographical distribution of the emission rates of the two main agricultural pollutants to the atmosphere and the hydrosphere (Figure 2.2) clearly represents the pattern of agricultural intensity. Hot-spots in the Netherlands, Brittany, Northern Italy and North Germany where livestock production specifically is very intensive can be seen, while regions characterised by extensive production systems and/or specialisation in crop production show lower emissions (de Vries et al., 2011b; Leip et al., 2011a).

2.3.2 Emissions by food commodity group

Calculations made using the CAPRI model indicate that each year European agricultural production systems cause total losses of reactive nitrogen amounting to 2.8 million tonnes N as ammonia, 6.3 million tonnes N leached to aquatic systems, 0.46 million tonnes N as N_2O and 0.43 million tonnes N as NO_x.

Livestock production systems dominate the losses of reactive nitrogen, being responsible for an estimated 81% of agricultural nitrogen input to aquatic systems and 87% of the NH_3 fluxes from agriculture production to the atmosphere (Figure 2.3). The four food commodity groups which dominate the nitrogen losses are beef, dairy, pork and cereals. Cattle are estimated to be responsible for 69% of N_r losses from animal product food commodities considered, and 56% of all losses (still a high proportion) when all twelve food commodity groups are considered. Pork contribute an estimated 17% of the agricultural N losses and 14% of the total losses, respectively.

Cereals contribute the bulk of N_r losses from vegetable products for direct human consumption (57%), but only 10% of total food-related emissions. Relatively high shares of vegetable emissions are also related to the production of oil products (16%) or fruits and vegetables (12%).

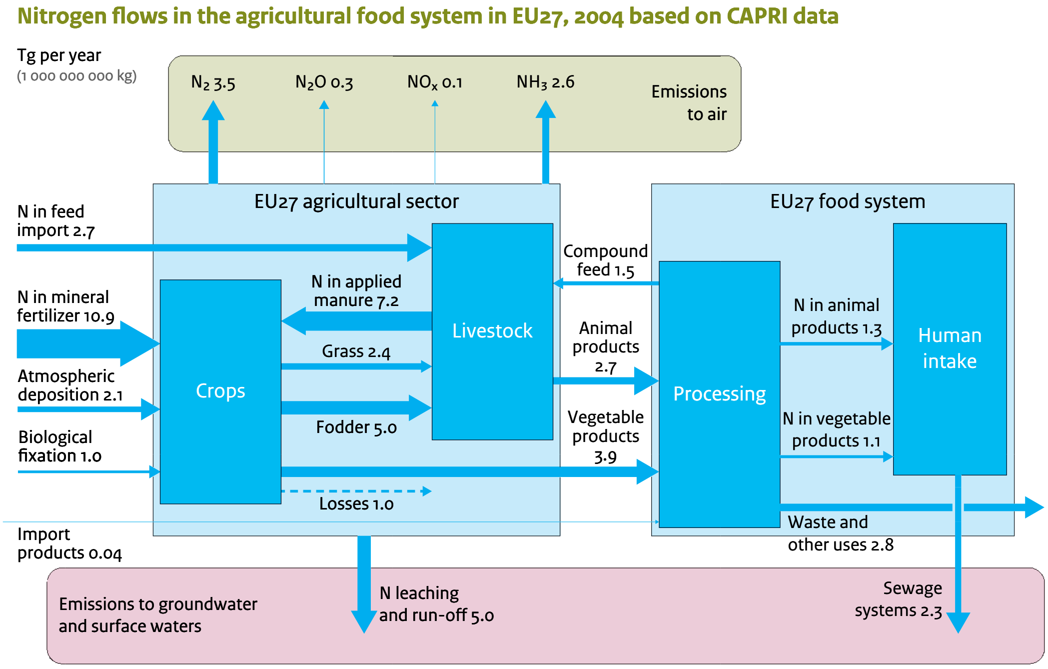

Figure 2.1 Flows of nitrogen in agricultural systems in EU-27 based on the CAPRI model. The flows show the transport of nitrogen between the livestock and crop production systems, the environment and the consumer. (For further details see Leip et al., 2014). These numbers update the agricultural component of the European nitrogen budget in ENA (Leip et al. 2011a).

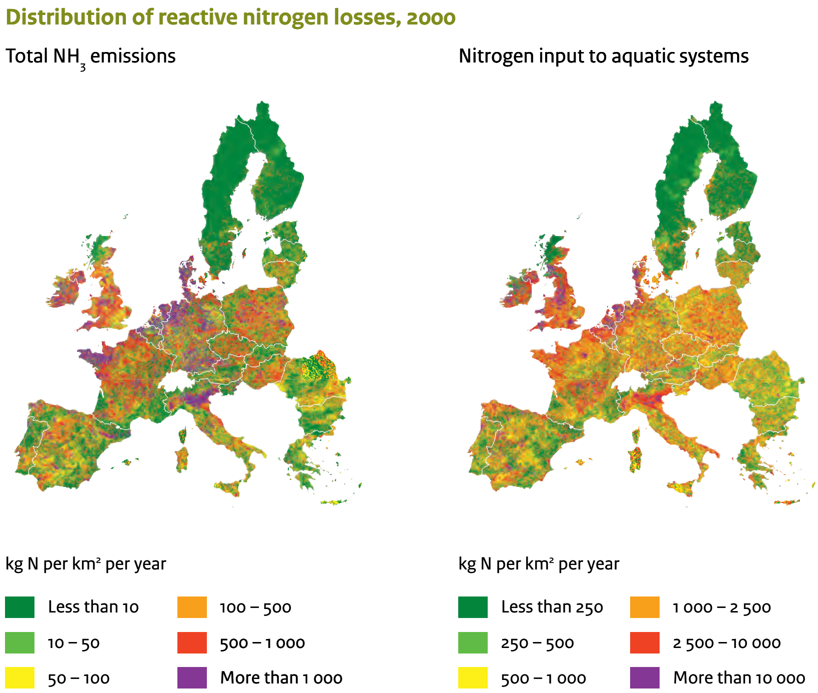

Figure 2.2 Geographical distribution of NH_3 emission (left) over EU-27 and total input to the aquatic system (right) [kg N km^{-1} yr^{-1}]. Based on Leip et al. (2011a) and Leip (2011), using the Indicator Database for European Agriculture.

Emissions of NO_x are particularly high for energy-intensive crops such as oilseeds and fruits and vegetables. For these crops, the share of NO_x of total N_r emissions is 11% for oilseeds and 22% for fruits and vegetables. Emissions of N_2O account for around 4-7% of total N_r losses for all food commodity groups considered in which the share for crop products (6%) is generally higher than for animal products (4%).

Figure 2.4 (left) shows that the share of nitrogen in 12 main food commodity groups expressed as gross agricultural production is very different from that expressed as estimated human consumption. This latter value corresponds to the amount of product that is offered to the consumers. This value is different to actual human intake, as losses still occur between purchase and intake (see also Chapter 3). The total gross production amounts to 9.1 million tonnes of N, excluding grassland and dedicated feed crops such as fodder maize and fodder beet. In particular cereals are used both to feed the

Emissions of reactive nitrogen in EU27, 2004

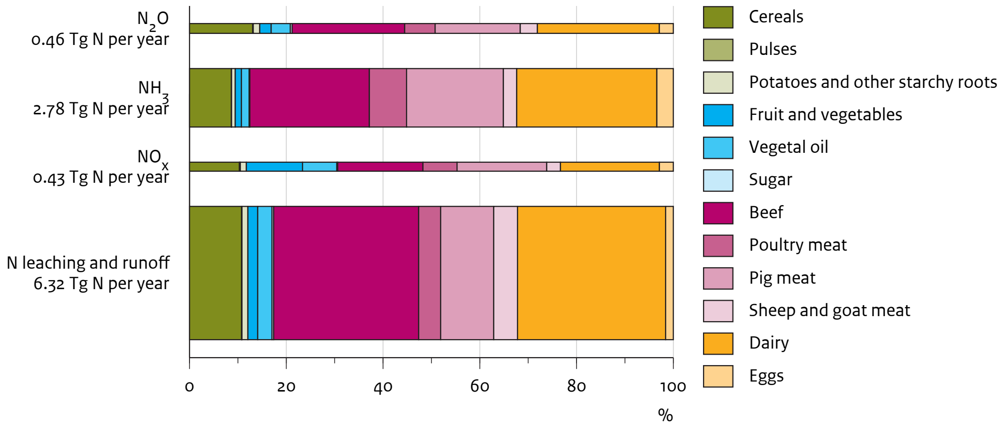

Figure 2.3 Share of reactive nitrogen emissions for the twelve main food commodity groups as calculated using the CAPRI model. The width of the bars indicates the emissions per source. Note that these emissions include also emissions caused outside the EU by cultivation of imported feed products. 1 Tg = 1 million tonnes. This figure includes the direct N_r emissions from agricultural activities (see Leip et al.,2014, Figure 3) plus N_r emissions from energy linked to food production.

Nitrogen in agricultural production and consumption in EU27, 2004

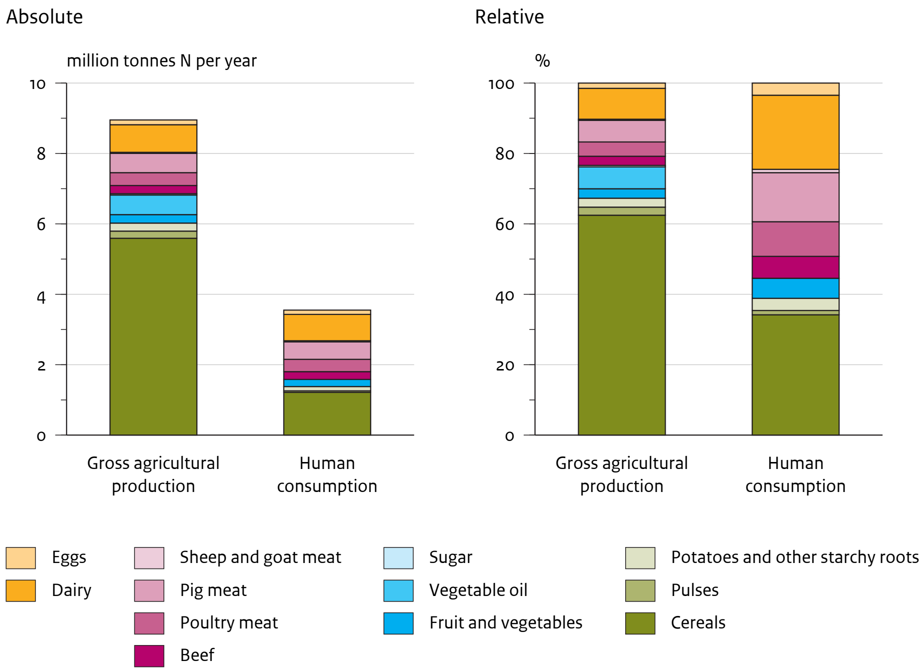

Figure 2.4 Absolute nitrogen content (left panel) and share of nitrogen (right panel) in 12 main food commodity groups in 'gross production' (left bars) and 'human consumption' (right bars) as defined in the Eurostat market balance (right panel). Conversion losses in animal production (from feed to meat and dairy) are the main cause of the 'gap' between gross production and human consumption. According to this approach, the additional effect of food losses between purchase and actual intake is not included, so that actual human consumption is even less. The values shown here exclude grassland and dedicated feed crops such as fodder maize and fodder beet, but food crops that are used as livestock feed are included in the vegetable commodity groups.

animals and to supply human food. In terms of protein supply, cereals represent around 60% of the total, however they represent only around 30% of the total proteins consumed (Figure 2.4, right). Overall, these 12 food commodity groups supply about 3.9 million tonnes of nitrogen to the consumer.

The share of protein supplied to the consumer ('Human Consumption') that comes from animal sources (55%) is more than double that in the total agricultural production (23%) (Figure 2.4, right). This in part reflects the fact that the protein from many plant products are used as livestock feeds (e.g. molasses and oil cakes).

2.3.3 Emission by functional unit of produce

Emission intensities (or unit emissions), expressed per functional unit of product (Figure 2.5), show that producing one kilogram of beef or meat from sheep and goats requires the use of 200-340 kg reactive nitrogen, which is a factor of 200

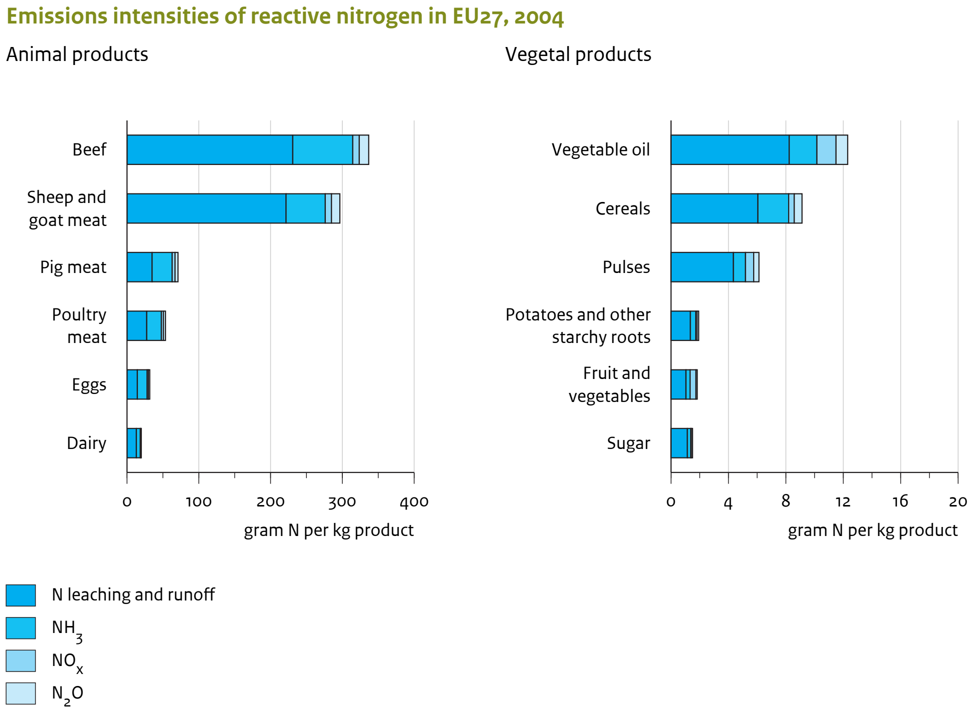

Figure 2.5 Emission intensities per kg food product for N_2O, NO_x, NH_3 and N leaching and run-off for the twelve main food commodity groups (six animal products, left; six vegetal products, right), based on the CAPRI-model (Leip et al., 2014).

larger than for potatoes and fruits and vegetables. The estimated emission intensities for potatoes, fruit and vegetables are in the range of 1.0-1.9 kg reactive nitrogen per kg product. Also the emissions related to pig meat, poultry and eggs are considerably higher than those of crop products. The highest emissions in the group of crop products are from oils, followed by cereals and leguminous crops (with some differences in this sub-group between the models). The lowest emissions are calculated for sugar beet, potatoes and fruits and vegetables.

Some products contain a lot of water, with a relatively low nitrogen (and thus protein) content. For example, dairy products have much lower nitrogen content compared with meat. Therefore, the nitrogen emission intensities are also expressed relative to their nitrogen content, as shown in Figure 2.6, which is partly reflective of the characteristic protein concentrations of different products. Dairy products have a low protein content compared with other animal products, and their emission intensities are around 2.5-3.8 kg N_r emissions per kg nitrogen in milk. This is at a similar level to the emission nitrogen intensities of pig meat, but higher than the emission N-intensities of poultry meat and eggs. A similar effect is seen for emission nitrogen intensities for the fruits and vegetables.

Figure 2.7 shows the nitrogen use efficiency (NUE) of the twelve main food commodity groups as calculated using the CAPRI model. The NUE is defined as the ratio of useable products resulting from an economic activity compared to the total nitrogen input that is invested (Leip et al., 2011b). As nitrogen investments, inputs of nitrogen to the soil are considered for vegetable products (mineral fertilizer, manure, atmospheric deposition, biological nitrogen fixation, and nitrogen in crop residues), and animal feed for animal products. NUE can be estimated for the actual production activity (soil or animal) or at a farm level.

The NUE of crops are between 45% and 76% in the European Union and are – as all agri-environmental N_r-indicators – subject to large variability among countries and within each country (Leip et al., 2011c, 2011b). Nevertheless, agricultural production systems in Europe belong globally to those with a relatively high efficiency (Bouwman et al., 2009; FAO, 2010a).

Usually, a farm-level NUE is defined for a mix of products that exits the farm while internal flows of nitrogen in manure, feed, and crop residues are considered neither as in- nor as output flows. In the current assessment, the 'farm concept' is applied to individual products, assuming that the required feed is produced within the farm and manure is recycled up to the level that is required for growing the feed. Crop residues are considered as internal flows in the 'farm budget', while in the soil budget concept they are used as fertilizer – and as such also as useable products.

The NUE at the animal level measures how much of the nitrogen in feed is recovered in animal products (also called feed nitrogen recovery, see Sutton et al., 2011b, Figure SPM.6). The animal-NUE ignores the fact that part of the excreted nitrogen is used as fertilizer, but also losses that occur at the stage of feed production. Figure 2.7 shows that these two factors do not completely compensate and result in a NUE for animal products at the farm level which is about 20% lower than the NUE at the animal level.

Emission intensities of reactive nitrogen per unit of nitrogen in food products in EU27, 2004

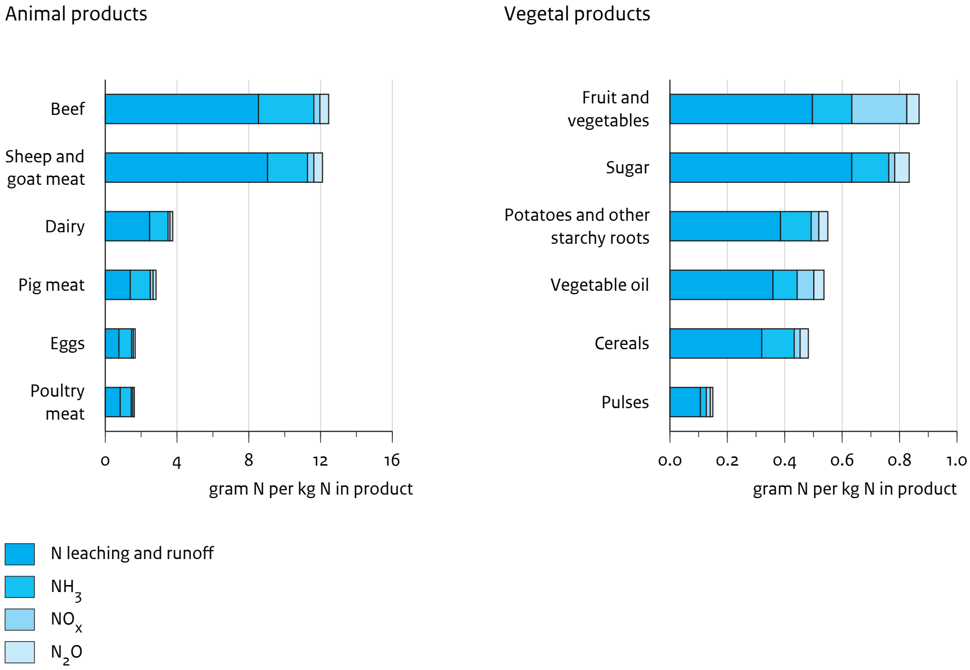

Figure 2.6 Emission intensities per unit of nitrogen in food product for N_2O, NO_x, NH_3 and N leaching and run-off for the twelve main food commodity groups (six animal products, left; six vegetal products, right) , based on the CAPRI-model (Leip et al., 2014).

Nitrogen use efficiency in EU27, 2004

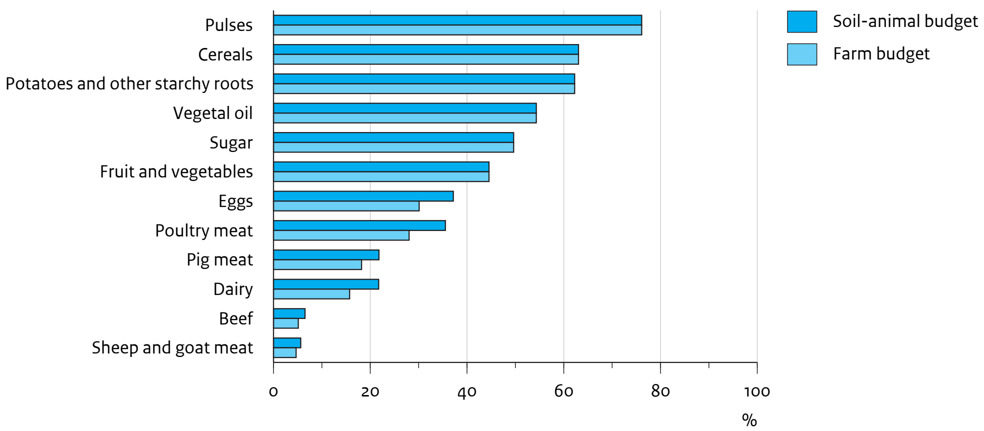

Figure 2.7 Nitrogen Use Efficiency (NUE) for the twelve main food commodity groups (kg N in product per kg N input). The NUE is defined here as the ratio of useable products resulting from an economic activity compared to the total nitrogen input that is invested. For animal products, the NUE is given both at the definition of the 'animal' (feed conversion) and at the level of a 'farm'. The estimated N inputs account for all sources of new nitrogen required in the food commodity production chain including fertilizers, biological nitrogen fixation, atmospheric deposition as well as net inputs of manure, while outputs here include feed, food and bioenergy products.

The lower values of farm NUE for animal products than the animal NUE (feed conversion efficiency) is less than what would be expected on the basis of the animal-budget NUE and the soil-budget NUE of feed crops (also fodder are performing at a similar level than shown here for the food crops), which demonstrates the benefit of integrated production systems.

2.4 Discussion

While the results presented in this chapter are based on the CAPRI model, Leip et al. (2014) have compared the results with similar calculations with the MITERRA model. Although the two models are not completely independent, there are some differences in methodology. One of the main differences is that in MITERRA the feed intake and excretion were from different sources, i.e. feed intake from CAPRI and N excretion from GAINS, which can lead to mismatches for some countries and animal types. CAPRI on the other hand has, by definition, a closed animal N budget, as the excretion is the result of the feed intake minus the N in livestock products and waste.

Differences between the models also result from different assumptions about the fraction of N_r leaching to the groundwater. This term is about twice as high if simulated with the CAPRI model than if simulated with the MITERRA model (de Vries et al., 2011a). The CAPRI model calculates the fraction of nitrogen lost to the groundwater on the basis of the IPCC (2006) approach, while the MITERRA model uses an own nitrogen leaching and runoff module (Velthof et al., 2009).

Results on the level of the EU-27, as presented in this chapter using CAPRI are fairly similar to estimates calculated with MITERRA. Differences at country level can however be considerable. Both models agree in the tendency for higher N_r losses from animal products compared to vegetal products.

2.5 Summary and conclusions

Despite a relatively high efficiency of agriculture in the European Union, the production of food in Europe contributes considerably to losses of N_r to the environment. Total losses amount to between 7.2 and 10.4 million tonnes of reactive nitrogen, depending on model assumptions. Leip et al. (2011a) estimated total N_r losses to the environment of 17.7 million tonnes of N_r; hence, food production in Europe is responsible for about half the total emissions of reactive nitrogen in European countries.

This study allocated the nitrogen losses to food commodity groups. The results show that livestock production chains have a high share in nitrogen losses. Over 80% of the agricultural ammonia emissions to air and nitrogen 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 have much higher losses. The nitrogen losses per unit of protein from beef are estimated at 20 times those from cereals. Poultry meat, which has the lowest nitrogen emissions intensity from the animal product groups considered, still represents up to twice as much as that from fruits and vegetables for the same quantity of protein intake. Corresponding values for nitrogen use efficiency are small for animal commodities (6-37%) and considerably higher for plant-based commodities (45-76%).

Beef and dairy products account for 56% of total N_r emissions in Europe, and the production of all animal products causes 82% of total N_r emissions from agriculture (Figure 2.3). Cereal production is the dominant source of emissions amongst vegetable products. With an emission intensity 6-9 g nitrogen per kg product cereals are also major sources of nitrogen per unit if compared to other vegetal products, second only to oils (10-12 g N_r per kg product), but this is still much smaller than the most emission-intensive meat from ruminants (up to 300 g N_r per kg product). However, per unit of protein, cereals perform equally or better than most other crops with about 0.45 g N emission per kg N in the product. An exception are leguminous crops, with only 0.10-0.15 g N emission per kg N in the product, which is reflected in their higher nitrogen use efficiency.

3 PRESENT AND HISTORIC EU FOOD CONSUMPTION

3.1 Introduction

In this chapter we analyse the past and present food consumption in the EU, with a focus on meat and dairy consumption. We focus on meat and dairy, as the conclusion of Chapter 2 is that these products are responsible for the largest share of any sector to total nitrogen losses into the environment.

Health impacts are another reason to focus on meat and dairy. On the one hand, meat and dairy produce are rich sources of vitamins (such as vitamin B12), as well as minerals such as iron, calcium and zinc. On the other hand, Western diets are characterised by a high intake of animal products, which leads to an intake of saturated fats and red meats that is above current dietary recommendations (Linseisen et al., 2009; Ocké et al., 2009; Pan et al., 2012).

First, the historic and present situation in the EU is analysed to get a better insight into the present situation. This provides a basis to analyse the diets of a range of European countries.

Current diet patterns are then discussed in relation to health recommendations. Section 3.2 briefly describes the methodology, with the results presented in Section 3.3.

3.2 Methodology

Supply for consumption of a commodity

The food supplies available for human consumption in a country were taken from FAO Food Balance Sheets (FAO, 2010b). In these statistics the supply for human consumption was calculated from the production in a country plus the export and minus import. Corrections were made for changes in stocks, use as feed for livestock or use for seed and losses during storage and transportation. The data are based on national agricultural statistics and trade. The FAO data on consumption represent the annual food *supply* available for human consumption at country level.

The food supply according to FAO was grouped into the same food commodity categories as used in the former chapter. In addition, a remaining category "others" was included, which contains offal, animal fats, honey, coffee, tea, spices, cocoa and nuts.

Intake of commodities

Not all the food commodities supplied for human consumption are eaten, as part of the commodity is not edible or is wasted. These losses were noted in Chapter 2, but not included in the calculations at that point. Here we take account of these losses in the calculation of the intake. This calculation was necessary for the estimation of the implications of the diet on human health including comparison with nutritional guidelines.

Losses were defined as all wastes and items left of the commodity after the supply for consumption, as reported by FAO (FAO 2010b). These losses occurred during processing, in retail, preparation and after eating. Losses were partly edible and partly inedible (like bones and peelings). For example in the case of meat consumption, FAO express the consumption in carcass weight at slaughterhouse exit level (i.e. excluding offal and hide, but including most bones). Processing, retail and household losses all take place after the carcass weight has been established and therefore, had to be discounted in the calculation of consumer intake.

The losses after supply were determined mainly on the basis of information published by Kantor (1997) and Quested and Johnson (2009). Kantor (1997) determined the edible losses in households and retail to be 27%. The edible losses are the losses excluding bones and peelings. Quested and Johnson (2009) determined the edible losses in households to be 14% and the total losses (i.e. edible and inedible) to be 22% (only in households). We used the average of these estimates for the edible losses, setting average edible losses in households and retail at 20% and the total losses (i.e. including bones and peels) at 28%. We recalculated the losses for different categories (such as meat, bread) from these authors in reference to the new determined average (Table 3.1). Some assumptions had to be made as the description of a category in the literature was not exactly the same as the commodity. For example losses of bread were used in the determination of the losses of cereals.

Intake of nutrients, calories and fats

We calculated the intake of proteins, saturated fats and calories on the basis of FAO statistics on the supply of certain nutrients by commodities (FAO, 2010b). In these statistics FAO has already corrected for the inedible losses, therefore we only corrected for edible losses (Table 3.1).

Table 3.1 Estimated food losses per food category as set in the present calculations.

	Edible losses (%)	Edible and inedible losses (%)
Cereals	35	35
Vegetable oil	24	28
Fruit & vegetables	22	55
Pulses	17	20
Potatoes & other starchy roots	24	57
Sugar	23	28
Dairy	11	11
Beef	14	29
Poultry	14	29
Pig meat	14	29
Sheep and goat meat	14	29
Eggs	11	11
Fish and other seafood	14	29
Others	20	28

Comparison of the method with an alternative approach

The calculated intake data of commodities and nutrients based on FAO supply minus losses were compared to country studies that monitor actual food intake by surveys. These surveys differ between countries due to differences in methodology and incomplete time series. For example, the European Concise Food Consumption Database, compiled by the European Food Safety Authority, does not contain complete time series for all EU countries (EFSA, 2013). Elmadfa (2009) has presented a more complete overview of the intake of nutrients (e.g. total protein) from individual food consumption surveys. As surveys are known to underreport the intake by about 10% (Ocké et al., 2009), we corrected the results from these surveys. Taking into account this underreporting, the protein intake calculated from supply minus losses, proved to be very close to the intake from surveys (difference is about 3%) (data not shown).

3.3 Results

3.3.1 Development of meat consumption from 1960 to present

Consumption of meat and dairy

Over the last 50 years meat and dairy consumption has increased significantly (Figure 3.1). The total consumption of animal products increased but on product level there are some differences. The most marked changes are the steep increase in the consumption of pig and poultry meat, as well the increase in dairy. Notably the consumption of poultry meat has risen sharply; the per capita consumption in 2007 was more than four times that of 1961 (Figure 3.1). This is probably related to the emergence of large-scale broiler farming systems, which have reduced prices considerably. The convenience trend may also have contributed, as poultry products are usually quicker to prepare.

Beef consumption increased slightly between 1960 and 1980, but it has shown a noticeable decline since the early 1990s. This may be partly due to the BSE crisis in the 1990s (Roosen et al., 2003), but also to the relatively longer preparation time of beef than other meats and the fact that beef is generally more expensive than chicken or pig meat.

Protein intake

The per capita consumption of protein provides an aggregated way of viewing the consumption of both animal and plant derived foods (Figure 3.2). The results show that the consumption of proteins has changed over time; the consumption of animal proteins sharply increased, whereas for plant-based proteins it has decreased. The share of vegetable proteins has decreased even more than it appears, because of the increase in total protein consumption over time. The average consumption of animal protein, per capita, is currently 50% higher than in the early 1960s. Growing prosperity and wider availability of animal proteins together with low product prices, have played an important role in this change. Meat, eggs and dairy products have all become more affordable. Meat and dairy products were previously luxury items that only a few people could afford in their daily diets. Presently, the average European consumer eats twice as much animal protein than the global per-capita average (Westhoek et al., 2011). Also the average consumption of all proteins per person is higher (Westhoek et al., 2011).

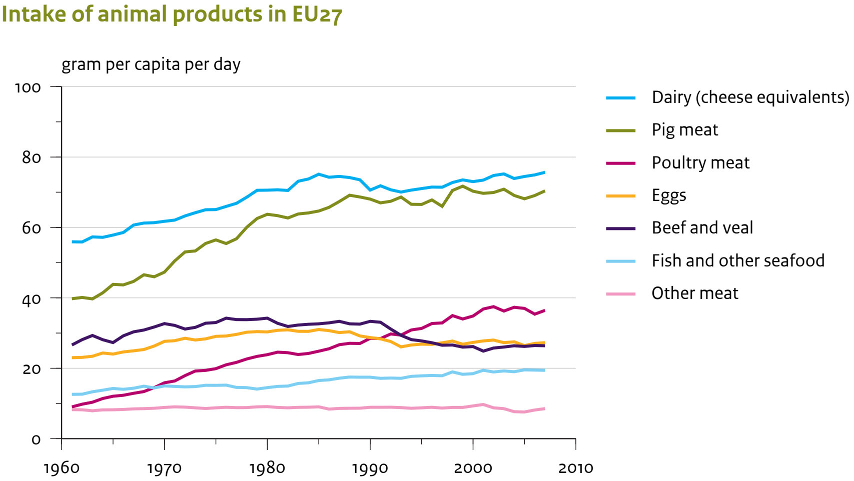

Figure 3.1 Per-capita consumption of meat, eggs and dairy in the EU-27 since 1961. Source: Westhoek et al. (2011).

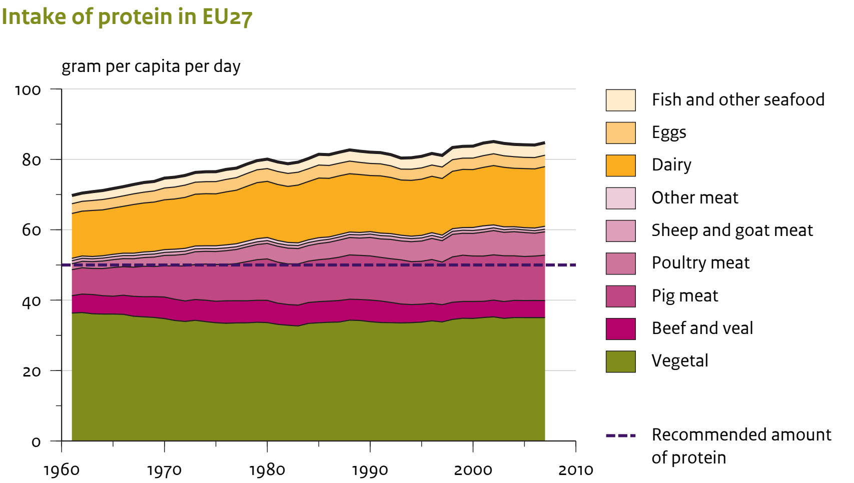

Figure 3.2 Per-capita protein consumption in the EU since 1961. Source: Westhoek et al., 2011.

3.3.2 Consumption per country

There are some clear differences between old (EU-15) and new EU Member States (Figure 3.3). The per capita consumption of animal products in old Member States is generally higher than in new ones. France, Denmark, Austria, Portugal, Sweden and Spain show the highest consumption of meat. Overall, pig meat is the most consumed type of meat in Europe, constituting about half of all the meat consumed. Most of the pig meat is consumed in countries which also have the highest levels of meat consumption.

Accounting for a quarter of the meat consumption, the share of chicken consumption is currently greater than that of beef. Per-capita consumption is the highest in Cyprus, the United Kingdom and Hungary. France and Denmark have the highest beef consumption. Sheep and goat meat are not consumed in large quantities in Europe, and their consumption is mainly attributed to southern Europe and the United Kingdom (Figure 3.4).

Much lower consumption of animal proteins is generally found in the new Member States. In those countries the consumption of vegetable proteins is higher than the European average, which at least partially compensates for the lower intake of protein from meat, dairy and eggs. (Figure 3.5 and Figure 3.6).

The total energy intake in the form of calories differs between countries (Figure 3.4). Just as with the consumption of proteins the energy intake in old Member States is also higher than in new ones. As well as the differences in total energy intake there are also differences in energy sources (Figure 3.4). In the whole EU, fish, pulses, sheep and goat are not very important sources of calories, except for a few countries : Portugal, Cyprus and Greece.

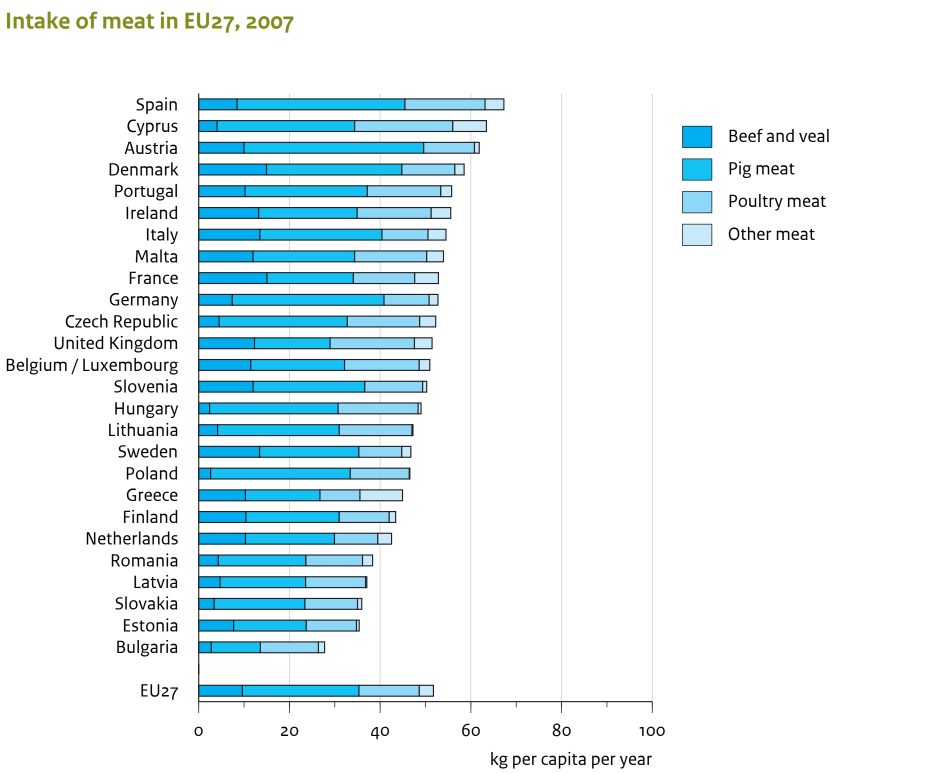

Figure 3.3 Meat consumption in EU Member States. Source: Westhoek et al., 2011.

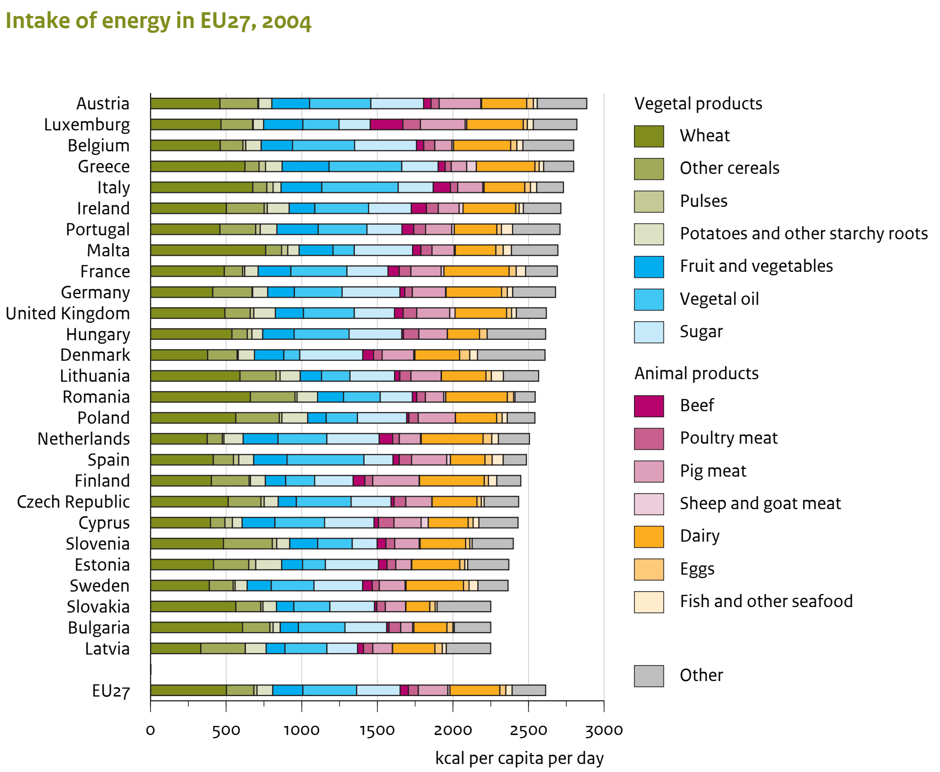

Figure 3.4 Sources of energy-intake in EU countries. Calculation based on data from FAO, 2010b.

An indicator of overconsumption of energy is the share of a national population that is overweight or obese (as indicated by Eurostat, 2010). In the EU the share varies from 37% in France to 61% in the United Kingdom (Eurostat, 2010). People are overweight if the body mass index (BMI) is between 25 and 30 kg/m^2 and obese if the BMI is higher than 30 kg/m^2.The prevalence of overweight people has risen strongly in the EU in the past decades (EU platform on diet, 2005). We see also an increase in average energy supply; in 1965, the average energy supply was 15% lower than in 2007.

Protein intake 70% higher than necessary according to WHO guidelines

In the EU, meat and dairy produce are primary sources of energy and also of proteins. The protein consumption in the EU is higher than recommended in WHO guidelines – as much as 70% higher (Figure 3.2 and Figure 3.5). Although there are differences in protein consumption levels between countries, the consumption levels in all are higher than required according to WHO (Figure 3.5). Overall for the EU-27, 52% of protein intake comes from meat, with 34% from dairy, 7% from eggs and 7% from fish and other seafood.

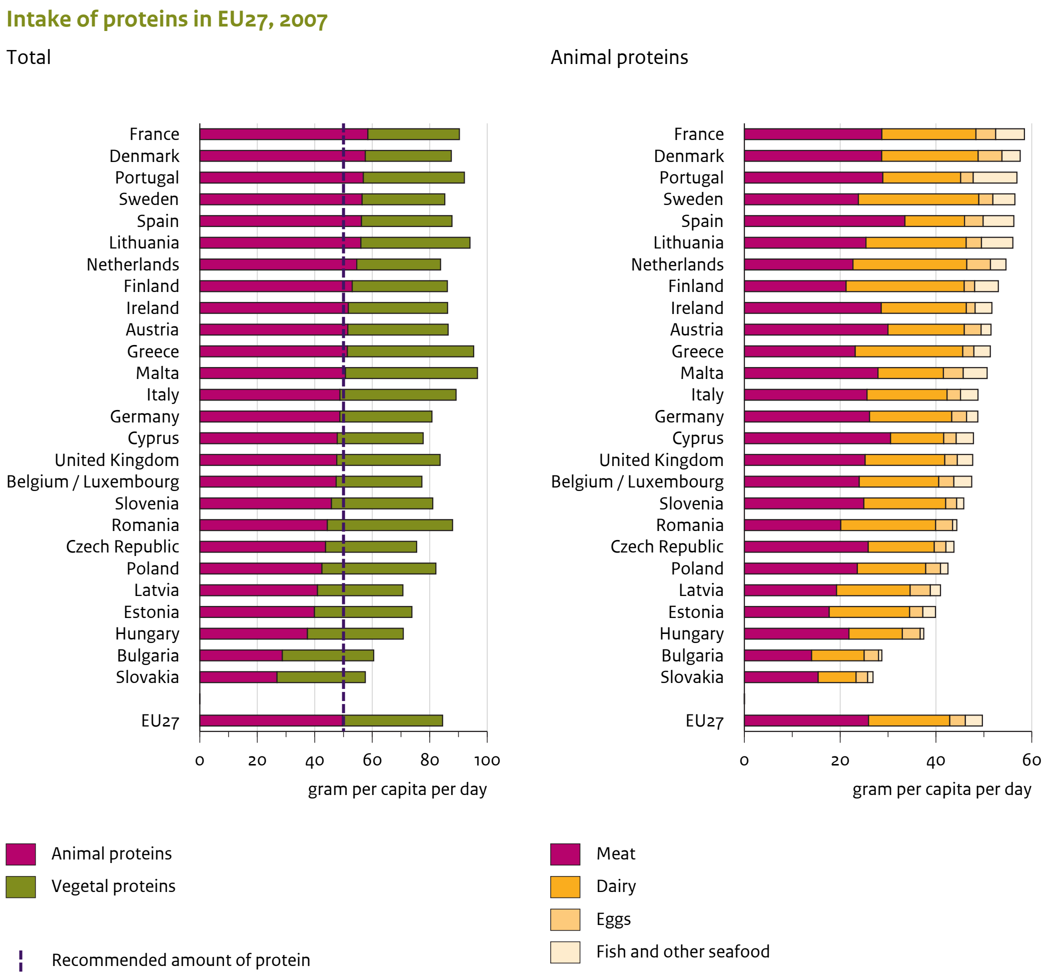

Figure 3.5 Left: Total protein intake in EU countries. Right: Intake of animal proteins in EU countries. Source: Westhoek et al., 2011.

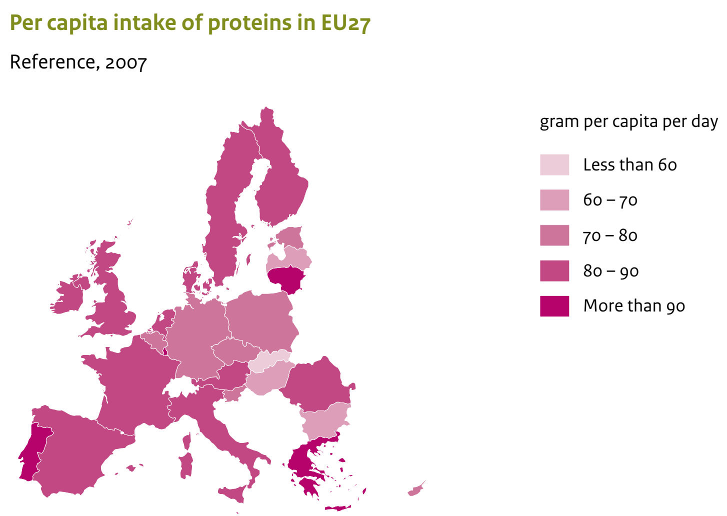

Figure 3.6 Average per capita protein intake from all sources (plant and animal-based) per country. Source: Westhoek et al., 2011.

Red meat consumption is twice as high as the maximum limit

Animal product consumption, and in particular red meat consumption has been associated with an increase in health problems such as colorectal cancer (WCRF and AICR, 2007, Norat et al., 2005). Red meats are beef, pig, sheep, goat and horse meat. For red meat the recommended maximum daily intake (RMDI) advised by the World Cancer Research Fund for a population average is 300 g per week of red meat per capita (about 43 g per day), of which little to none should be processed meats (WCRF and AICR, 2007). This is equivalent to a maximum recommended individual intake of about 70 g per person per day. For a population the average recommended maximum intake per person is lower than the daily individual intake because there are also individuals within a population who consume lower amounts of red meat.

The consumption of red meat in Europe is on average more than twice as much as the recommended limit of 16 kilograms per year. On average, Europeans consume about 37 kilograms per capita of pig meat and beef. In the EU-15 this value is 39 kilograms per capita per year. Austria leads with 50 kilograms per year, and Bulgaria consumes the least with 14 kilograms per year (Figure 3.3).

Saturated fat consumption is more than 40% higher than the maximum limit

In addition to consumption of red meat, consumption of saturated fats should be limited due to the increased risk of cardiovascular diseases. Therefore the World Health Organization proposed that the share of saturated fatty acids should not exceed 10% of the energy intake (WHO 2003; WHO 2008a; WHO 2011). Given current energy intake in the EU, this is equivalent to a recommended maximum dietary intake (RMDI) of 25.5 g per person per day or 9.3 kg per year (Westhoek et al., 2011).

According to our estimates the consumption of saturated fats in Europe is currently 42% higher than the RMDI (Figure 3.7). As 80% of saturated fats originate from animal products, a reduction in the consumption of animal products would therefore reduce the intake of saturated fats and would be favourable for human health.

The consumption of animal saturated fats differs by more than a factor of two between European countries. As shown in Figures 3.7 and 3.8, per-capita consumption of saturated fats is highest in France, Belgium, Luxembourg and Denmark. Only in Estonia and Bulgaria the consumption is less than the RMDI.

Comparing food intake with guidelines for protein, energy and saturated fat

European diets provide a high intake of protein, dominated by animal protein and relatively high intake of saturated fat, also mainly originating from animal products. Compared with the guidelines of WHO and WCRF already noted (WHO,

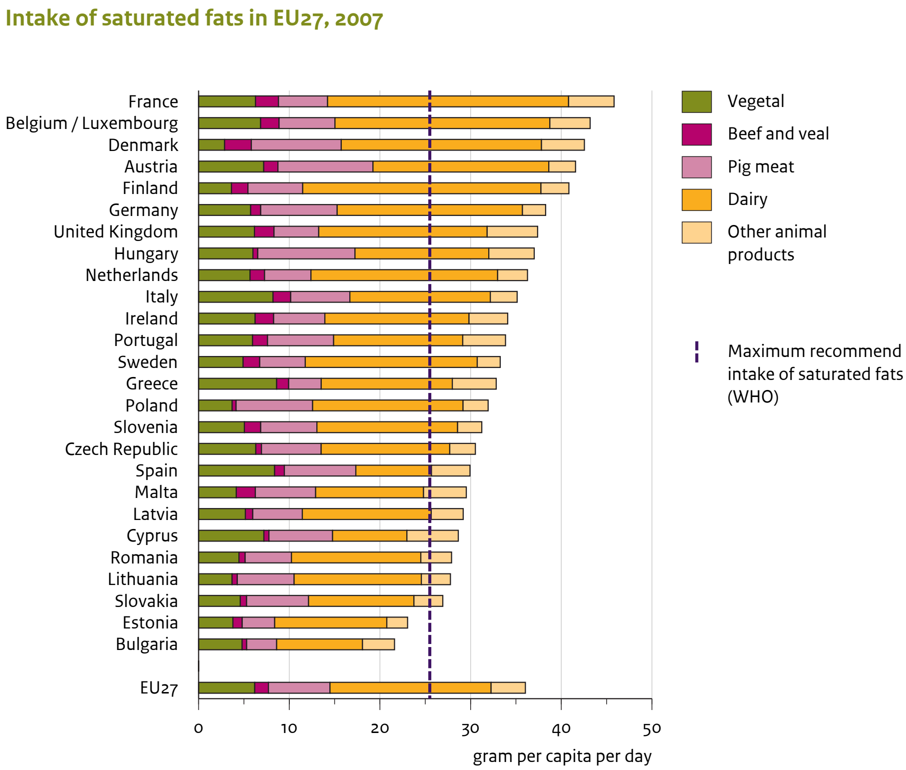

Figure 3.7 The consumption of saturated fats in European countries. In most countries the consumption of saturated fats is more than the recommended maximum dietary intake (RMDI). Source: Westhoek et al., 2011.

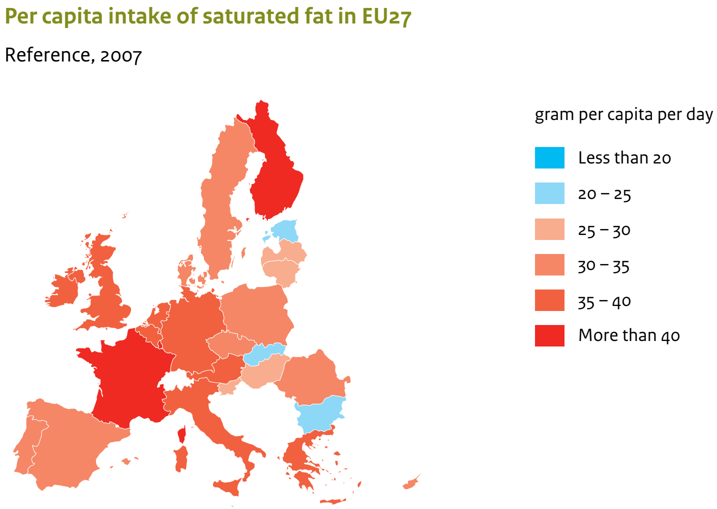

Figure 3.8 Intake of saturated fat. Source: Westhoek et al., 2011.

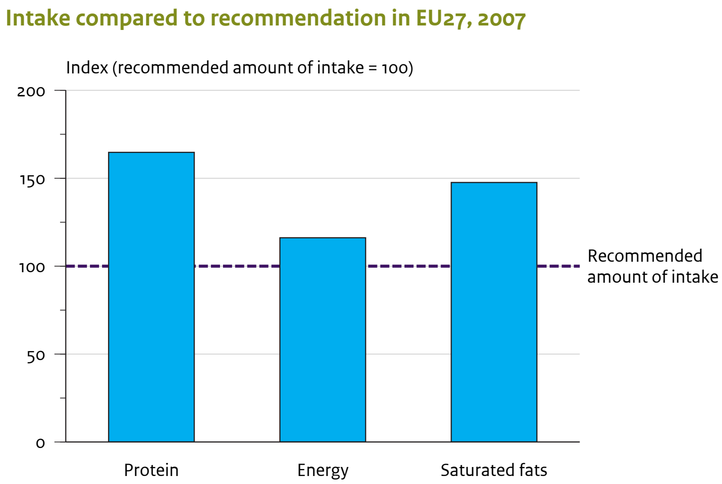

Figure 3.9 Current (2007) intake of protein, calories and saturated fats in the EU compared to dietary recommendations. For proteins, this concerns the recommended intake, whereas for saturated fats it relates to the maximum recommended intake.

2007, WCRF and AICR, 2007) the average European citizen consumes 70% more protein and 10% more energy than the recommended daily intake (RDI) and 42% more saturated fat than the recommended maximum daily intake (RMDI) (Figure 3.9). On average, Europeans consumed too many calories, proteins and saturated fats.

Determinants of the consumption of animal products

In general, the data suggest that a higher income corresponds to a higher consumption of animal proteins (Figure 3.10). While some rich countries such as Sweden, the Netherlands and Finland – show a relatively low level of meat consumption (Figure 3.3), total protein consumption remains high, being compensated by higher consumption levels of dairy products (Figure 3.5).

The products of choice are determined by cultural aspects and the supply of nationally produced foods. According to Harris (1998), eating habits are determined by technological, social-demographic, ecological and institutional factors. In addition to price, prosperity and availability, other factors explain minor differences in consumption, the most important of which is consumer awareness of the production, which can correspond to a lower consumption of animal products (Regmi and Gehlhar, 2001; Schroeter and Foster, 2004).

Furthermore, higher levels of emancipation of women (Luomala, 2005; Schroeter and Foster, 2004) and higher population age (Regmi and Gehlhar, 2001) apparently also correspond with lower consumption of animal products. There is also a relationship between certain food crises and decreasing consumption, as in the response to the BSE crisis and the outbreak of animal diseases (Regmi and Gehlhar, 2001; Van der Zijpp, 1999). Urbanisation, on the other hand, is correlated to a higher consumption of animal products. Despite these other influencing factors, prosperity apparently still largely determines the level of consumption of animal products (Figure 3.10).

Relation between GDP per capita and consumption of animal protein in EU27, 2007

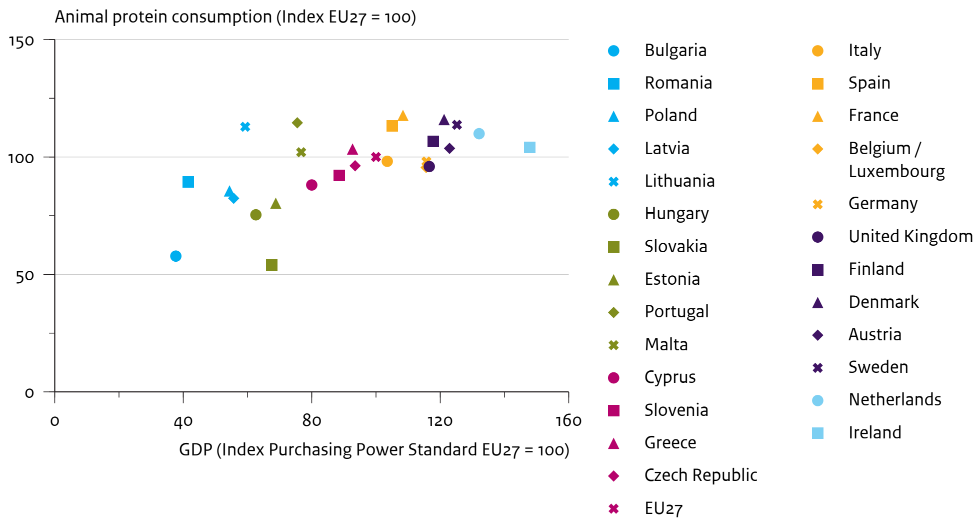

Figure 3.10 Consumption of animal products in relation to GDP per capita. Source: Westhoek et al., 2011.

3.4 Conclusions

- Diets in the EU have changed significantly in the past five decades. The average consumption of meat and dairy has increased considerably, notably that of dairy, pig meat and poultry meat. Overall, total per capita protein intake from meat, eggs and dairy in the EU has increased by 50% since 1961.
- There are distinct differences in consumption patterns between countries. The difference in meat consumption between different countries in Europe amounts to more than a factor of two. In the new Member states the consumption of animal products is still lower than in the old Member states. However, in southern countries (previously with a traditional Mediterranean diet), the consumption has drastically changed to a current diet with high amounts of meat and dairy.
- The intake of protein in the EU-27 is 70% higher than would be required according to WHO recommendations. Excessive intake of protein is not directly linked to known health threats.
- The current dietary patterns have implications for human health. Intake of red meat in the EU-27 is double the recommended maximum daily intake according to the World Cancer Research Programme. The intake of saturated fats is 42% higher than the recommended maximum dietary intake, leading to increased risk of cardiovascular diseases.
- In addition to eating more than enough protein and saturated fats, EU citizens are also consuming more calories than needed. The intake of energy is about 10% higher than needed resulting in an increasingly overweight and obese population.

4 ALTERNATIVE DIETS

4.1 Introduction

Chapter 2 has demonstrated that 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 per unit product compared with livestock products. Chapter 3 has shown that the average consumption of animal protein is currently 50% higher than early in the 1960s and that the total average protein intake is 70% higher than recommended. Related to this relatively high intake of meat, dairy and eggs, the intake of saturated fats is on average 42% higher than recommended.

Together, these two facts raise the question: What would be the consequence for the environment and human health if consumers in the EU were to replace part of the intake of meat, dairy and eggs with more plant-based foods?

This chapter focuses on potential alternative diets and their implications for food demand within the EU as well as for human health. This is done by exploring a number of alternative dietary scenarios. The chapter describes which alternative diets were developed in the study and the potential health benefits of these dietary scenarios. Chapter 5 focuses on the environmental consequences of these alternative diets.

4.2 Methodology

To investigate the consequences of dietary change based on reductions in the consumption of meat, dairy and eggs, six alternative diets for the EU-27 were developed. These diets consist of a 25% or 50% reduction in the consumption of beef, dairy, pig meat, poultry and eggs compared with present rates of consumption. This reduced consumption is compensated by a higher intake of cereals to illustrate how the food system and associated emission change with an increased fraction of plant-based food. In practice, such alternative diets would be expected to be associated with a range of possible mixes of plant-based food. The re-allocation to cereals used here allowed us to assess the main implications of reducing meat consumption, while leaving open for possible future work the analysis of different plant-based food mixes.

As ruminants (cows, sheep and goats) vary in a number of aspects (feed source, environmental footprint per unit protein) from monogastric animals (pig and poultry) it was decided to develop several alternative diets in the study. In two diets, only the consumption of pig meat, poultry meat and eggs is reduced (by either 25 or 50%), in two further alternative diets the consumption of beef and dairy is reduced (again either 25 or 50%). Finally two alternative diets are constructed in which the total consumption of meat, dairy and eggs is reduced by either 25 or 50%, which results in six alternative diets (Table 4.1). It is assumed for our calculations that the dietary changes would be implemented directly, i.e. we did not assume a transition period. While, in practice, dietary shifts occur gradually, this approach allowed us to address the question of what would be the consequences if diets changed significantly in Europe.

Consumption levels of sheep and goat meat were maintained at current levels in the alternative diets, because of their important role in conserving extensive grasslands in their present state, as these often have both a high biodiversity and cultural value (Paracchini et al., 2008). Also the consumption of fish was maintained at the same level.

Table 4.1 Alternative diets as constructed for this study, and their relationship with changes in livestock production in the EU.

Alternative diet	Human consumption	Livestock production
Reference	Present situation	Present situation
–25% beef and dairy	Reduction of beef and dairy consumption by 25%	Reduction in cattle (numbers) by 25%
–25% pig and poultry	Reduction in pig meat, poultry and egg consumption by 25%	Reduction in pig and poultry production (numbers) by 25%
–25% all meat and dairy	Reduction in all meat, poultry and egg consumption by 25%	Reduction in cattle, pig and poultry production (numbers) by 25%
–50% beef and dairy	Reduction in beef and dairy consumption by 50%	Reduction in cattle (numbers) by 50%
–50% pig and poultry	Reduction in pig meat, poultry and egg consumption by 50%	Reduction in pig and poultry production (numbers) by 50%
–50% all meat and dairy	Reduction in all meat, poultry and egg consumption by 50%	Reduction in cattle, pig and poultry production (numbers) by 50%

The analysis was performed for a base year of 2007. The food supply in each country in 2007 was taken from FAO (FAO, 2010b). The calculation from supply to intake is described in Section 3.2. As this study is based on data for commodities as they enter the post-farm human food chain, a 50% reduction in the weight of eggs consumed, for example, represents a 50% reduction in both directly consumed eggs as well as in eggs in processed food products such as bakery products and pasta.

It is expected on the basis of the analysis in the previous chapter of diets in Europe that a 50% reduction in livestock product consumption would still align reasonably well with public health guidelines regarding the intake of proteins, micro-nutrients and vitamins. It is assumed that the compensation for reduced intake of meat, dairy and eggs by increased intake of cereals is made to maintain broadly similar food calorie intake. If the energy-compensation with cereals results in enough proteins (according to requirements of WHO, see Chapter 3) no further replacements were made. In the cases where the protein intake dropped below the recommended level, some pulses - which are high in protein - were included in the alternative diet. This was only necessary in the case in Hungary for a diet with a 50% reduction in all animal products.

The calculations were carried out for each EU Member State and aggregated to the EU-27 level. For countries that currently have a low consumption of meat and dairy, consumption was not reduced below the mean EU consumption in the alternative diet (see figure 3.3 for countries below the average EU-27 consumption). So, in countries with currently low rates of meat and dairy consumption, a lower reduction was assumed, with proportionally higher reduction rates for other countries.

4.3 Results

4.3.1 Food intake

Table 4.2 presents the results of implementing the six alternative diets. It shows (along with further tables) that the average cereal consumption increases by around 50% in the alternative diet with 50% reduction in consumption of meat, dairy and eggs. The smallest increase in cereals in the alternative diets (10%) occurs for the 25% reduction in pig and poultry consumption.

Figure 4.1 shows the aggregated food supply for EU-27. The values in Figure 4.1 are based on product weight. As dairy contains more water than its replacement (cereals) the total amount is not constant over the various diets. Per country data are included as Annex 1.

Table 4.2 Average per capita consumption of selected[1] food commodity groups in the reference and the six alternative diets (g person^{-1} day^{-1}).

	Reference	–25% beef and dairy	–25% pig and poultry	–25% all meat and dairy	–50% beef and dairy	–50% pig and poultry	–50% all meat and dairy
Cereals	256	291	283	319	326	311	382
Pulses	4	4	4	4	4	4	4
Dairy (milk basis)	554	416	554	416	277	554	277
Beef	23	17	23	17	12	23	12
Poultry	32	32	24	24	32	16	16
Pig meat	62	62	47	47	62	31	31
Sheep and goat meat	3	3	3	3	3	3	3
Eggs	28	28	21	21	28	14	14

[1] The use of sugar, potatoes, fruit and vegetables and fish is assumed to remain constant and is therefore not presented here.

4.3.2 Impacts on human health

Proteins

The protein intake in the reference situation is 70% higher than the recommendation as set out by the World Health Organization (WHO, 2007) (Chapter 3). The protein intake in the alternative dietary scenarios is up to around 10% lower compared with the reference (Figure 4.2), as cereals contain fewer proteins than animal products. Nonetheless, the average protein intake in the EU is still higher than required by the WHO in all of the dietary scenarios.

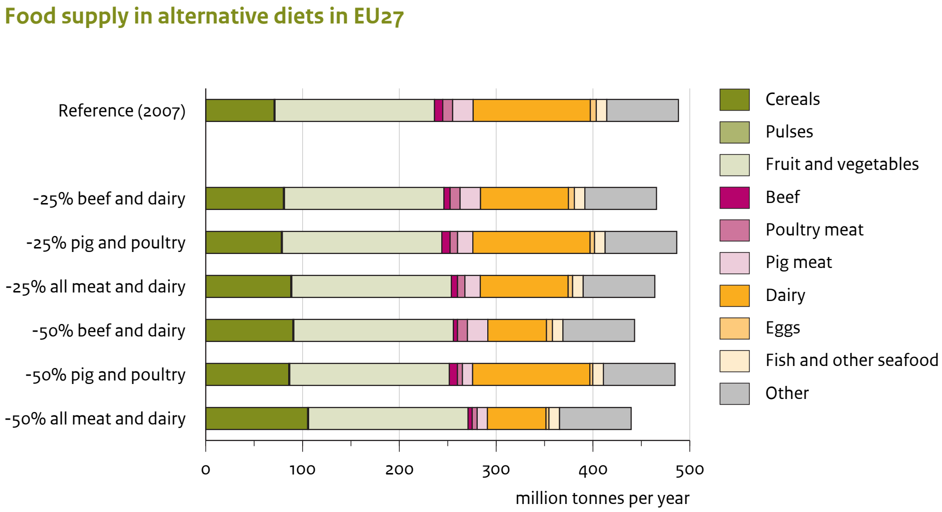

Figure 4.1 Food supply in the alternative diets analysed in this study.

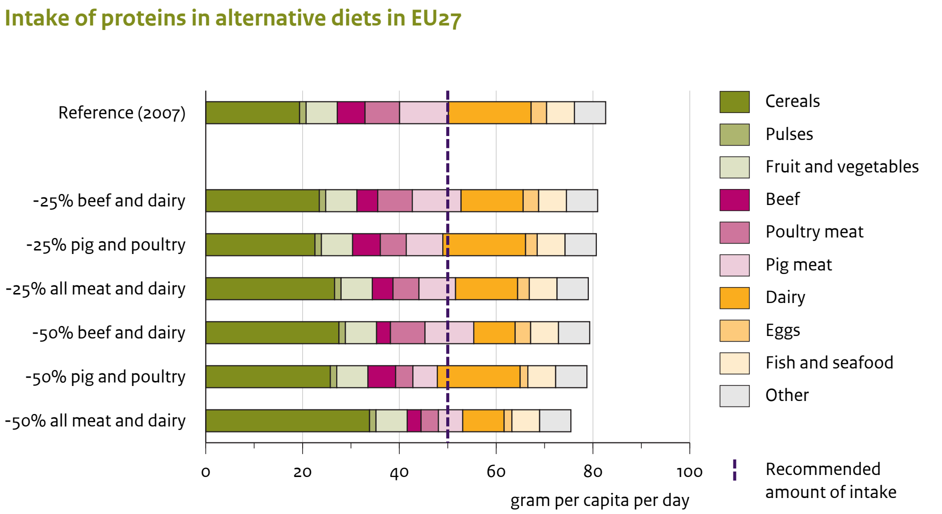

Figure 4.2 Average protein intake under the six alternative consumption diets.

In the diet with -25% beef and dairy the protein intake is still 60% higher than required. Even in the diet with -50% of all animal products the average intake of proteins for the EU is still more than 50% higher. With regard to dietary composition, the share of plant-based proteins in the alternative diets is higher as the animal proteins were reduced and replaced with plant-based proteins.

The results on a country basis show that there are still differences in protein intake between the different countries, but the differences are smaller than before the introduction of the alternative diets (Figure 4.3). A number of countries (France, Finland, Portugal, Greece, Lithuania) still show relatively high protein intakes even in the dietary scenario with 50% reduction in all meat and dairy (Figure 4.3, right). However, in none of the countries is the protein less than that recommended by WHO, even in this dietary scenario with the highest reduction.

Saturated fats

The intake of saturated fat in the reference is 42% higher than the recommended maximum dietary intake (RMDI) proposed by the World Health Organization, corresponding to a RMDI for saturated fat of 25.5 g per day in Europe (Chapter 3). The reduction of animal products in the alternative diets results in a considerable reduction of saturated fats in the alternative diets as animal products are major sources of saturated fats in the European diet.

The diets with 25% reduction in animal products or a 50% reduction in some animal products still have higher contents of saturated fats than the RMDI. Only in the alternative diet with a 50% reduction of all animal products, is the proportion of saturated fat close to the RMDI for the EU as a whole (Figure 4.4). There are still differences however, between countries. In countries such as Italy, France, Austria, Belgium and Romania, the intake of saturated fat is still higher than the RMDI, even in the diet with 50% reduction of all animal products (Figure 4.5). In this dietary scenario, intake of saturated fat is reduced by up to 40% in some EU member states (Figure 4.4).

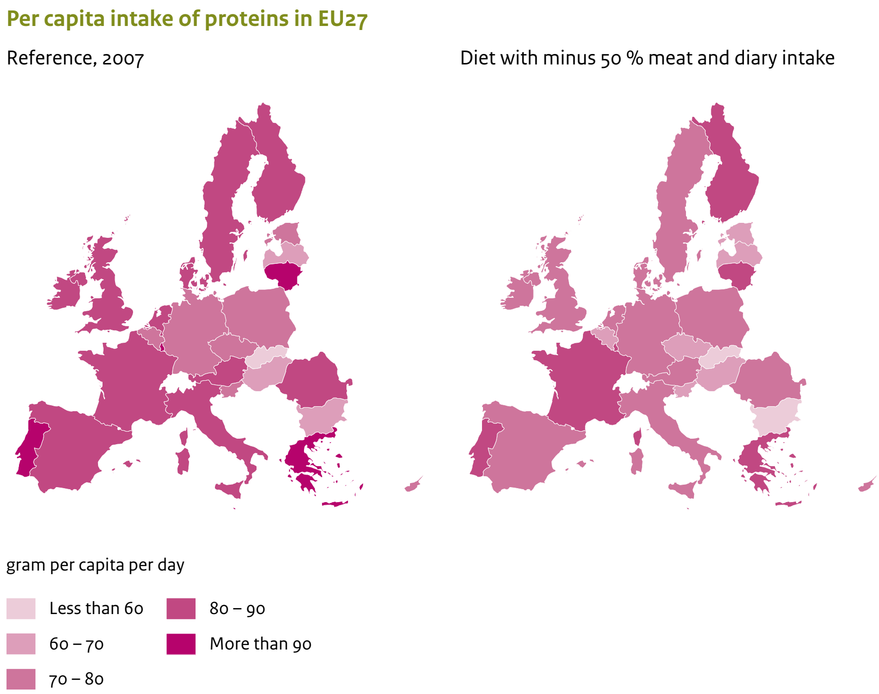

Figure 4.3 Average total protein in the EU Member States in the alternative diet with 50% reduction in all animal products compared to the reference. WHO (2007) recommends a protein intake of 50 g per capita per day, which is exceeded in all countries, even in the dietary scenario with the largest reductions.

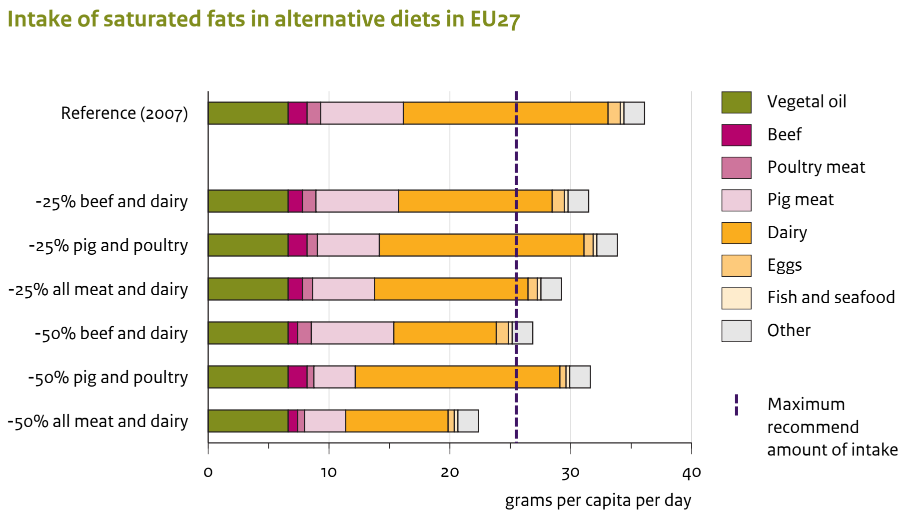

Figure 4.4 Average per capita intake of saturated fats the EU-27 according to the alternative diets. The maximum intake of saturated fats is that recommended by WHO (2011).

Red meat

Currently the average consumption of red meat in the EU is more than twice as high as the recommended maximum daily intake (RMDI) for a population as advised by the World Cancer Research Fund, being an average (for a whole population) of 43 g per person per day (WCRF and AICR, 2007) (Chapter 3). This is equivalent to a maximum consumption of 70 g per day for an individual. By definition red meat includes beef, sheep, goat and horse meat as well as pig meat. This implies that in all the alternative diets the intake of red meat is reduced. The average intake in the EU-27 in the diet with *50% reduction of all animal products* is still a little higher than the RMDI (107%). In the other diets the intake of red meat ranges from 130% to around 207% of the RMDI. The extent of the reductions vary across Europe, with a lower % reduction in countries where sheep and goat form a significant part of the diet since intake of lamb and goat were not changed in our alternative diets.

Health benefits

Expected health benefits of the alternative diets are mainly generated by the lower intake of saturated fats and of red meat. Diets rich in saturated fat are associated with an increased risk of cardiovascular diseases (CVD), as well as stroke. In the WHO European region around 25% of total mortality can currently be attributed to CVD and 15% to stroke, in total ~3.8

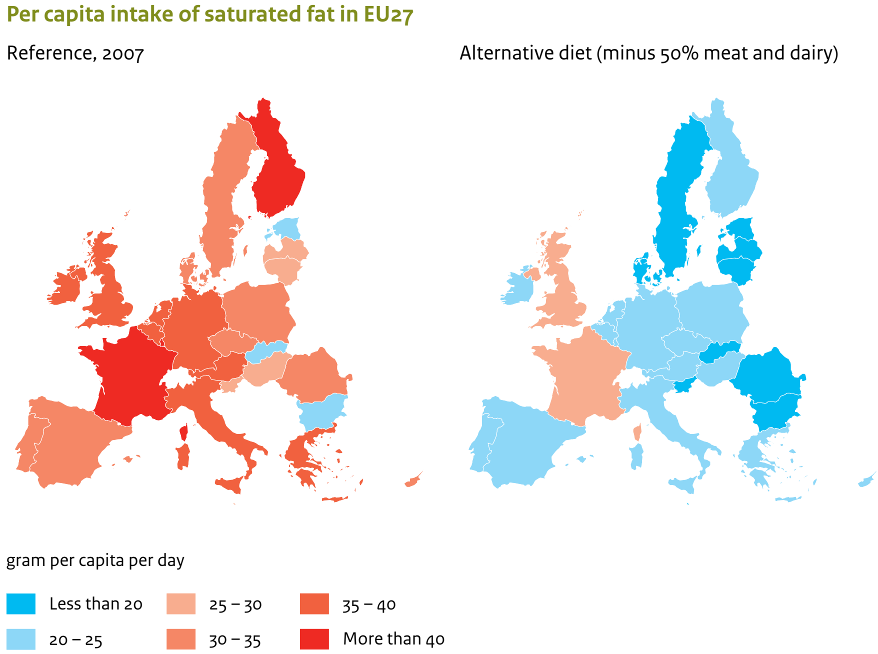

Figure 4.5 Intake of saturated fat in the diet with 50% reduction in all animal products compared with the reference.

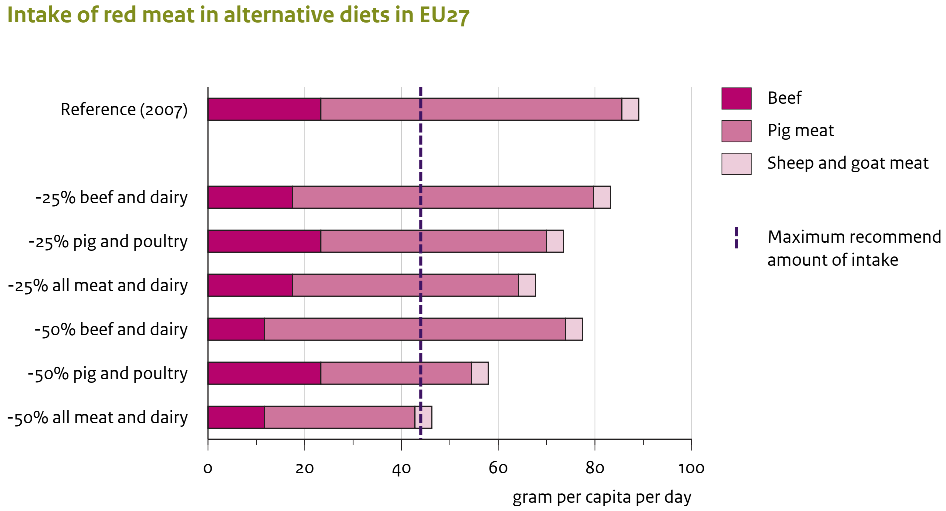

Figure 4.6 Per capita intake of red meat in the alternative diets. The values are compared with the population average value of the recommended maximum daily intake (RMDI) from WCRF and AICR (2007).

million deaths annually (WHO, 2008b). Analyses of population attributable risk as reported by (Danaei et al., 2009; Friel et al., 2009; Lock et al., 2010; O'Flaherty et al., 2012 and Pan et al., 2012) suggest that the magnitude of dietary change calculated in our alternative diets may potentially reduce CVD and stroke mortality by 4 to 15%, depending on current dietary patterns, reduction scenarios and background incidence. Given the large uncertainties, this would be an important subject for further research.

There are also clear indications that the intake of red meat is associated with an increased risk of colorectal cancer (Norat et al., 2002). The disease burden of colorectal cancer (CRC) in WHO European region (at 250,000 annual deaths, 2.5% of total mortality) is substantially smaller than the CVD burden. However, projections reveal a steady increase of disease burden in the coming decades (WHO, 2008b). Several analyses indicate that diets low in red meat may reduce colorectal cancer mortality by as much as 7-15% (Chan et al., 2011; Gingras and Béliveau, 2011; Larsson and Wolk, 2006; Norat et al., 2005; Norat et al., 2002; Parkin, 2011; WCRF and AICR, 2007). The reduction in livestock production and subsequent reduction in emissions (see Chapter 5) may also have indirect health benefits, related to a lower use of antibiotics (Marshall and Levy, 2011), water quality (nitrates) and improved air quality (NHx contribution to particulate matter) (Moldanova et al., 2011).

4.3.3 Impact on nitrogen footprint

To assess how different diets or diet choices affect nitrogen footprint related to the consumption of food, these losses were calculated as an EU average for the main twelve food commodity groups (Leip et al., 2014). These commodity groups cover about 97% of the products consumed in the EU-27. The nitrogen footprint is calculated as direct N-losses (in the form of N_r and N_2) to the environment that are directly related to the production processes of the twelve food commodities. In these calculations EU average data for the twelve commodity groups were used, as due to the large trade in food commodities across the EU, the use of national footprint data would not be reasonable. Moreover the national commodity-specific data show considerable variation and are associated with a higher uncertainty (Leip et al., 2014).

In the reference situation, countries with a high intake of animal products, and especially with a high intake of beef and sheep and goat meet (Denmark, France, Greece, Italy and Ireland) we find a per capita nitrogen footprint of over 30 kg per person per year (Figure 4.7, left map). Countries with low intake of animal products (see also Chapter 3) such as Bulgaria, Hungary, Latvia, and Slovakia have a per capita footprint of less than 15 kg per person per year.

The per capita nitrogen footprint in the alternative diet with *50% reduction of all animal products* has been reduced in all countries (Figure 4.7), under the assumption that the reduced consumption was related to a proportional reduction in the domestic production. Only in Greece it is still 24 kg N per capita due to the high consumption of sheep and goat which is not reduced. In other countries with currently a high intake of meat and dairy (as Denmark, France and Sweden) the estimated per capita nitrogen footprints in the alternative diet is almost halved compared to the reference situation.

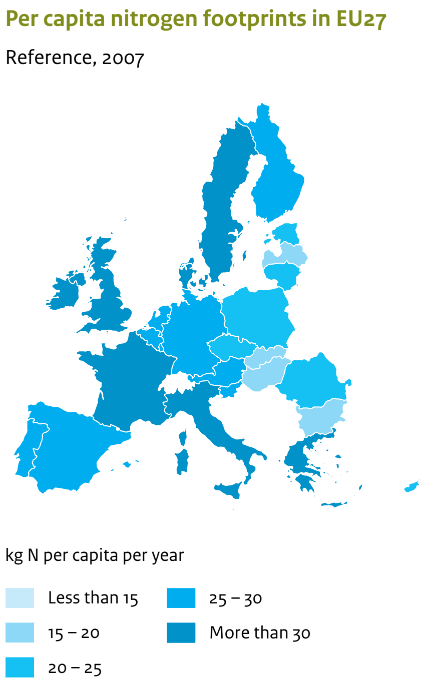

Figure 4.7 Per capita nitrogen footprints related to food production for European countries in the reference scenario and for the alternative diet with 50% reduction in all meat and dairy. The nitrogen footprint is calculated as direct N-losses (in the form of N_r and N_2) to the environment that occur for the production process of food.

4.4 Discussion

This chapter describes several alternative dietary scenarios for Europe and then evaluates the health implications of these scenarios. The scenarios reflect new situations, addressing the question of what if there was substantial reduction in intake of different meat, eggs and dairy products in Europe. By contrast, these scenarios do not address the process of transition to these alternative diets, which would in practice be gradual. In Chapter 6 we reflect on potential motives and mechanisms of dietary change.

The assumption that the lower meat, eggs and dairy intake is compensated by a higher cereal intake while maintaining total dietary energy intake is a relatively conservative approach with respect to health impacts. The current average per capita energy intake is 10% higher than needed (Chapter 3) so that a full calorific replacement of livestock products would not be necessary. Moreover, health benefits could be expected if this energy replacement were to be partly in the form of fruit and vegetables, since in most European countries the average intake of these is currently below the recommended level (Elmadfa 2009). In general the environmental effects of fruit and vegetables are higher compared to those of cereals but are lower compared to those of dairy and meat (see also Chapter 2) (Garnett, 2013; Nemecek and Erzinger, 2005; Nemecek et al., 2005) so the environmental benefits would be smaller.

A possible alternative replacement of animal products with other carbohydrate rich commodities (e.g. potatoes, pulses) would not necessarily lead to expected different health impacts because in all diets, the average protein intake in the EU remains higher than requirements under all the dietary scenarios. In the same way, environmental effects of alternative carbohydrate rich commodities (e.g. on nitrogen pollution, greenhouse gas emissions and land use) are expected to be similar to cereals (Chapter 2).

Additional health benefits could be expected if meat is replaced by fish because the current average consumption of fish in the EU is lower than the WHO recommendation. However, fish consumption could have negative impacts on marine biodiversity and fish stocks. Farmed fish is also related to N-emissions and other terrestrial environmental impacts such as greenhouse gas emissions and land use (Westhoek et al., 2011).

Effects of the dietary changes on the intake of micro-nutrients were not investigated. As the current intake of, for example calcium and iron is already low in most EU countries (Elmadfa, 2009), this aspect certainly requires further attention. According to WCRF, health benefits are also to be expected if little or no processed meats are included in the diets (WCRF and AICR, 2007), but no assumptions were made about processed food.

It was chosen to maintain at least 50% livestock products in the alternative diets. It is possible to comply with the dietary guidelines with a vegan diet (meaning a 100% reduction of the intake of animal products), but this requires more attention from all people in order to have a balanced and varied diet. A 50% reduction enables the accommodation of variations in diets within the population, as currently not all individual diets are well-balanced. If the average intake on population level of proteins, iron and vitamins would just match dietary guidelines, there is a risk of deficiency on an individual level (Elmadfa, 2009; Mensink et al., 2012). A population average matching dietary guidelines implies some people consume more than the average and others consume less and thus less than necessary. These considerations, however, certainly do not imply that larger reductions would not be possible.

4.5 Conclusions

- We constructed alternative diets in which the intake of meat, dairy and eggs is reduced by 25 to 50%, associated with an increase in cereal consumption by 10 to 49% in order to maintain the same overall energy intake.
- The alternative diets result in a slightly lower intake of total proteins, but even in the diet with the lowest protein intake (-50% all meat and dairy) the protein intake is still 50% higher than recommended intake according to the WHO guidelines.
- The intake of saturated fats is significantly lowered in the alternative diets. In the diet with 50% reduction of all meat and dairy the intake of saturated fats is reduced by over 40%, bringing it below the recommended maximum dietary intake of WHO. In the reference situation this maximum recommended intake is on average exceeded by 40%. Diets rich in saturated fats increase the risk of cardiovascular diseases. The resulting 40% reduction in saturated fat intake is consistent with an estimated 4-15% reduction in cardiovascular mortality.
- In the same diet (50% reduction of all meat and dairy) the intake of red meat (meat of beef, pigs, sheep and goat) is reduced below the recommended maximum dietary intake of the World Cancer Research Fund, which was set to reduce the incidence of colorectal cancer.

5 ENVIRONMENTAL EFFECTS OF ALTERNATIVE DIETS

5.1 Introduction

In this chapter we quantify the environmental and other effects of the alternative diets as presented in Chapter 4. The chapter focuses on how emissions of reactive nitrogen and greenhouse gases respond to changes in EU agriculture (livestock production, feed use, land use, cereal production) under the different alternatives. The effects on nitrogen deposition are also assessed.

The translation of alternative diets into effects on EU agriculture is not straightforward, as several other contrasting scenarios could develop. First, there is the question whether a reduced meat and dairy consumption in the EU would lead to a reduced meat and dairy production in the EU, or to a higher export of meat and dairy. In our approach it is assumed that the changes in meat and dairy consumption are paralleled by equivalent changes in the size of livestock production. Secondly, a lower livestock production results in a lower feed use, which leads to alternative ways of using land no longer needed for feed production. Two contrasting land use change scenarios were therefore also examined to address these alternatives.

5.2 Methodology

5.2.1 Overview

As the quantification of the effects of the alternative diets on the environment required a large number of steps, a brief overview is first presented, before the methodology of each step is described in more detail. An overview of the steps needed to calculate the final results is presented in Figure 5.1; this scheme also shows the models and datasets used, as well as key assumptions.

We assumed that the six alternative diets result in a different size and composition of the livestock production in Europe (Chapter 4). As a consequence of the reduced livestock production, less feed is needed. As less feed is needed, the land no

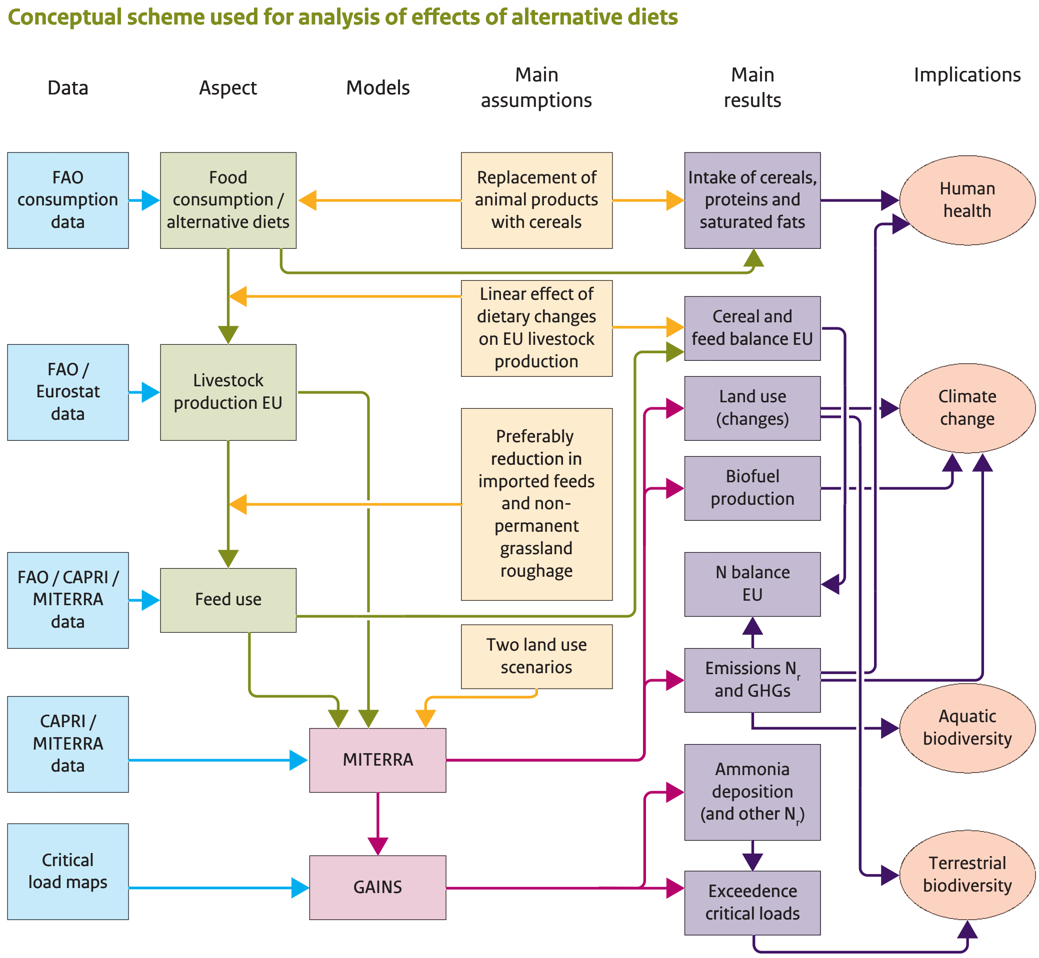

Figure 5.1 Overview methodology: steps taken to analyse the effects of the alternative diets.

longer required to produce this feed may be used in an alternative ways. To address this effect we explored two land use scenarios, assuming either a **greening world** or a **high prices world**.

The effects on reactive nitrogen and greenhouse gas (GHG) emissions, land use and use of fertilizers and manure were assessed with the MITERRA-Europe model. The effect on N deposition in Europe was assessed by using data from the GAINS-model. The reference year of our study was 2004, which is the base year currently used by CAPRI-model. The MITERRA-model uses CAPRI-data for its reference siutation. Also for the feed use in the reference situation data from CAPRI-model were used (Figure 5.1).

5.2.2 Adjusting EU livestock production and feed demand

According to the alternative diets, the number of beef, dairy cows, pigs and poultry was reduced by either 25% or 50%, following our assumption in the scenarios that dietary change in Europe is proportionately reflected in production. This reduction was implemented per country.

The reduction in livestock production is followed by an assumed linear reduction in animal feed use. Data for feed use in the reference situation were based on the MITERRA-Europe and CAPRI model datasets (see section 5.4.2). Table 5.1 gives an overview of the feed items used and their percentage reductions for the alternative diets. All feed items are adjusted according to their energy and nitrogen (or protein) content in order to fulfil the animal's nutritional requirements. In the scenario approach we applied, it is assumed that imported by-products, mainly soy bean meal, are reduced as much as possible, whereas domestic by-products are in principle not reduced.

Total protein-rich feed use was decreased by 25% in the case of a 25% reduction in livestock numbers and by 50% in the case of a 50% reduction in livestock numbers. These changes were achieved in the scenarios by first reducing imported feed (i.e. soy bean meal), while as much as possible retaining domestic protein-rich feed at the same level as the reference situation for all the dietary scenarios.

The same approach was applied to the reduction of energy-rich feed. We reduced the total cattle demand for forage by 25% in the 25% beef and dairy reduction diets and by 50% in the 50% beef and dairy reduction diets. To achieve this, proportionately higher reductions were made in the use of fodder from arable land (including temporary grassland), with lower reductions in the use of grass from permanent grassland. This approach was intended to assure that the land released

Table 5.1 Percentage reductions of feedstuffs in the dietary scenarios compared to reference.

Feed category	Feed subcategory	-25% scenarios	-50% scenarios
Protein-rich feed		25%	50%
	Domestic (oil seed cakes)	0%	0%
	Imports (soy beans and soy bean meal)	calculated based on protein requirement	calculated based on protein requirement
Energy-rich feed		25%	50%
	Domestic (molasses)	0%	0%
	Imports (molasses, corn gluten feed, cassava)	calculated based on energy requirement	calculated based on energy requirement
Forage		25%	50%
	Fodder on arable land (including temporary grassland)	>25%, depending on energy requirement	>50%, depending on energ requirement
	Grass from permanent grassland	<25%, depending on energy requirement	<50%, depending on energy requirement
	Grass from natural grassland	0%	0%
Fodder maize		25%	50%
By-products	From dairy industry	25%	50%
	Other feed, Straw	0%	0%
Root crops		0%	0%
Milk for feeding		25%	50%
Cereals		calculated based on energy requirement	calculated based on energy requirement

from forage production is suitable for arable production, be it for cereal production in a 'high price' world or for biomass production in a 'greening' world (see below).

Fodder maize was reduced by 25% in the 25% beef and dairy reduction diets and by 50% in the 50% beef and dairy reduction diets. The amount of by-products from the dairy industry and of milk used for feeding was assumed to decrease proportionally with the numbers of beef cattle and dairy cows. The amount of cereal was finally calculated, based on the energy requirement.

5.2.3 Land use scenarios

The substantial change in the demand for feed under our alternative diet scenarios would result in a net reduction in the amount of land needed for food and feed production, thus opening up opportunities for land to be used for other purposes. There are numerous ways in which this land could be used. We assumed that the land will still be used for agricultural production, and within this assumption we developed to two contrasting scenarios.

In a High Prices Scenario, tight global commodity markets and therefore high cereal prices are assumed. In this scenario we assumed that land no longer required for fodder production, i.e. fodder and fodder maize area (including temporary grassland) and a fraction of the permanent grasslands, is used for cereal production (see Table 5.2). Part of the former feed cereal production is used to produce food cereals for the increasd levels of human cereal consumption. The cereal surplus is assumed to be exported.

Conversely, in a Greening Scenario lower cereal prices and an emphasis on environmental issues are assumed. Land no longer needed for feed production is used for the production of perennial biomass crops (i.e., Miscanthus, Switchgrass, Canary Reed, Willow and Poplar). In this scenario, we assumed that the lower demand for grass leads to an extensification of grassland use by lowering mineral N fertilizer input, which is also associated with lower yields. Released fodder area is used for perennial energy crop production. The cereal area is assumed to remain constant. Less feed cereals are needed, but on the other hand, cereal consumption by humans increases. The balance between the food and feed cereal needs, leads to changes in the exported amount of cereals.

It should be stressed that the two presented scenarios are only two of many alternatives uses of land use change. While it is not possible to assess the probability of the different scenarios occurring they are sufficient to illustrate the key opportunities that arise as a result of a reduced need to feed livestock populations.

Table 5.2 Alternative use of land released from feed production in the sub-scenarios.

Agricultural area released	High Prices Scenario	Greening Scenario
Fodder on arable land (including temporary grasslands)	Cereal production	Biomass production
Fodder maize	Cereal production	Biomass production
Grassland (permanent)	Cereal production	Extensification[1]

[1]no permanent grassland area is reduced in the 'greening extensification sub-scenario'

5.2.4 Emissions of nitrogen and greenhouse gases

We used the MITERRA-Europe model to assess the environmental effects (emissions of GHGs and reactive nitrogen) of changes in livestock and crop production. MITERRA-Europe is an environmental impact assessment model, which calculates emissions of N as N_2O, NH_3, NO_x and NO_3^-, and different greenhouse gases (CO_2, CH_4 and N_2O) on a deterministic and annual basis using emission and leaching factors (Lesschen et al., 2009; Velthof et al., 2009). MITERRA-Europe is partly based on data from the models CAPRI (Britz and Witzke, 2012) and GAINS (Klimont and Brink, 2004). The model includes modules for N leaching, soil carbon and for mitigation measures. Input data include activity data (e.g., livestock numbers, crop areas), spatial environmental data (e.g., soil and climate data) and emission factors (IPCC and GAINS). The model also includes simple descriptions of measures to mitigate GHG and ammonia emissions and nitrate leaching from agriculture. The application of such mitigation measures were not included in the present scenarios beyond those included in the baseline estimates, since the intention of the scenarios was to explore the specific effects of dietary change. It would however be a suitable task for future work to explore how different mixes of dietary and agricultural practice changes would further reduce the emissions of reactive nitrogen and greenhouse gases.

All statistical input data are based on three year averages of the period 2003-2005. The main input data for MITERRA-Europe are crop areas, animal numbers and feed use at the NUTS-2 (county or provincial) level. Data on crop areas and feed use are taken directly from CAPRI which is based on Eurostat statistics. Data on animal populations are from GAINS. The livestock population was distributed over the NUTS-2 regions according to CAPRI livestock data. Data on annual N fertilizer consumption were collected from FAOSTAT. Country specific N excretion rates of livestock were also derived from the GAINS model (Klimont and Brink, 2004).

The total manure N production was calculated at the NUTS-2 level from the number of animals and the N excretion per animal and then corrected for N losses in housings and storage. Manure is distributed over arable crops and grasslands according to Velthof et al., 2009, taking account of the maximum manure application of 170 kg N/ha or higher in the case of a derogation for the Nitrates Directive. Mineral N fertilizer was distributed over crops relative to crop nitrogen demand, while correcting for the amount of nutrients as present in applied manure and grazing manure (Velthof et al., 2009). The crop nitrogen demand was calculated as the total N content of the crop (harvested part + crop residue) times a crop specific uptake factor, which was set at 1.0 for grass and perennial bioenergy crops and 1.1 and 1.25 for cereals and other arable crops respectively (Velthof et al., 2009). A higher factor indicates a higher nitrogen surplus, thus higher risk of nitrogen losses.

Ammonia (NH_3) emissions from livestock manures occur during housing, during storage of manure, after application to the soil, and from grazed land. Country specific emission factors and removal efficiencies of ammonia abatement measures were adapted from the GAINS model (Klimont and Brink, 2004). Emissions of nitrous oxide (N_2O) from agriculture consist of emissions from manure management and the direct and indirect emissions from agricultural soils. These consist of i) direct soil emissions from the application of mineral fertilizer and animal manure, crop residues and the cultivation of organic soils, ii) urine and dung produced during grazing, and iii) indirect emissions from N leaching and runoff, and from volatilised and re-deposited N. All N_2O emissions were calculated using emission factors from the IPCC 2006 guidelines. The emission factor for NO_x was set at 0.3% of the N input (van Ittersum and Rabbinge, 1997).

Nitrogen leaching (mainly in the form of nitrate) was calculated by multiplying the soil N surplus by a region specific leaching fraction, which is based on soil texture, land use, precipitation surplus, soil organic carbon content, temperature and rooting depth. Surface runoff fractions are calculated based on slope, land use, precipitation surplus, soil texture and soil depth (Velthof et al., 2009).

For assessment of the alternative diets, balanced N fertilisation (BF) was assumed for mineral fertilizer (Oenema et al., 2007; Velthof et al., 2009). This means that N fertilisation is equal to uptake of the plant during growth, corrected by the crop specific uptake factor. This approach was justified as input from animal manure is reduced for the alternative diets and in order to sustain arable production an increase in mineral fertilizer might be needed. Further N inputs include biological N fixation, which is estimated as a function of land use and crop type (legumes) and N deposition for the reference situation that is derived at NUTS-2 level from the European Monitoring and Evaluation Programme (EMEP) (see Section 5.2.5.).

Livestock is the major source of CH_4 emissions in agriculture through enteric fermentation in ruminants and anaerobic digestion of manure during storage. CH_4 emissions in MITERRA-Europe were derived from European regional livestock densities and linear correlations with the IPCC (2006) emission factors (Lesschen et al., 2011). Changes in land use and land management influence soil organic carbon (SOC) stocks. Following the IPCC (2006) approach the amount of SOC in mineral soils is calculated by multiplying a default reference value by relative stock change factors for land use, soil management and carbon inputs. The reference soil carbon stock is a function of soil type and climate region for the upper 30 cm. IPCC assumes a period of 20 years to reach a new equilibrium for soil carbon stocks. For each crop activity relative stock change factors were assigned (van Ittersum and Rabbinge 1997). Changes in soil carbon stocks caused by changes in cropping shares were calculated and divided by 20 years to obtain annual CO_2 emissions. All GHG emissions are expressed in CO_2 equivalents, based on the following estimates of the potential 100-year global warming values relative to carbon dioxide (CO_2: 1, CH_4: 25 and N_2O: 298) (IPCC, 2007).

5.2.5 Nitrogen deposition

The effect of reduced ammonia emissions from agriculture related to the different diets on N deposition was assessed by the GAINS-model. GAINS describes the interrelations between these multiple effects and the pollutants (SO_2, NO_x, PM, NMVOC, NH_3, CO_2, CH_4, N_2O, F-gases) that contribute to these effects at the European scale (Amann et al., 2011). The scenario selected as a starting point was Goth_Nat_March2011. The activity data in the selected scenario are provided by national experts, therefore improving the quality of the national input, whilst other parameters like emission factors and rates of abatement technologies are taken from the European scenario GOTH_PRIMES2009. Input data for the activity change in the proposed scenarios are from the MITERRA-Europe model, as described above. The oxidized N deposition and averaged area critical loads exceedance are based on outcomes of the GAINS model.

5.2.6 Nitrogen fluxes, NUE and cereal balances

Outcomes of the MITERRA-Europe model were used to construct a complete picture of nitrogen flows in the EU agricultural and food system in the reference situation and for the alternative diets. Using data from Chapters 3 and 4, nitrogen intake resulting from human consumption was calculated. Based on the flow schemes the nitrogen use efficiency (NUE) of the EU agricultural system was also calculated. The NUE is defined as the N output in crop and livestock products as a percentage of the total N input (Oenema et al., 2009). According to the approach we used, N in feed crops were not included as part of the N output as these are an internal flow considering the chain from N inputs to N products consumed by humans.

The cereal export in the reference was derived from EU data (EC, 2009). It was assumed that 5.7% of the additional cereal production is needed for seeds, or is lost and that it is not available for export.

5.2.7 Bio-energy crops

In the Greening Scenario it is assumed that land previously used for production of fodder (e.g. forage maize) and temporary grassland will be converted to perennial bioenergy crops, i.e. Canary Reed, Switchgrass, Miscanthus, Poplar or Willow, depending on the location. Data on production, fertilizer use and other characteristics were based on MITERRA-Europe.

5.3 Results

5.3.1 EU meat and dairy production

Before looking into the effects of the changes in EU livestock production, we first analyse these changes themselves. The EU production of dairy and the various meat types in the reference situation and the alternative diets is presented in Table 5.3. This shows that meat consumption is dominated by pig meat, which accounts for more than 50% of EU meat production. Sheep and goat meat are excluded from this table, but these account for less than 3% of EU meat production.

Given the different nature of the products, milk and meat production are hard to compare. When expressed in protein, the result is that dairy accounts for ~45% of EU livestock production, and all the meats combined for ~55%. This is in line with the findings of Chapters 3 and 4, which also showed the high share of dairy products in protein consumption. This also implies that the alternative diets '-25% beef and dairy' and '-25% pig and poultry' do not have the same effect on overall protein production: in the '-25% beef and dairy' alternative diet, total European protein production is reduced by 14% compared with the baseline, whereas in the diet '-25% pig and poultry' this reduction is lower, being only 11% (Table 5.3). The -50% diets yield similar results. The large reduction in protein production for the 'beef and dairy' dietary scenarios compared with the 'pig and poultry' dietary scenarios is reflected in the results presented in the following sections. The difference between nitrogen footprints of beef meat from dairy cows compared to meat from dedicated beef cattle is not accounted for in the present study.

Table 5.3 Total EU meat and dairy production in the reference and in the alternative diets, (in million tonnes, meat in carcass weight).

	Cow milk	Beef	Pig meat	Poultry meat	Eggs	Protein production compared with reference
Reference	149.3	8.5	22.0	11.0	6.7	
-25% beef and dairy	112.0	6.4	22.0	11.0	6.7	86%
-25% pig and poultry	149.3	8.5	16.5	8.2	5.0	89%
-25% all meat and dairy	112.0	6.4	16.5	8.2	5.0	75%
-50% beef and dairy	74.7	4.2	22.0	11.0	6.7	72%
-50% pig and poultry	149.3	8.5	11.0	5.5	3.3	78%
-50% all meat and dairy	74.7	4.2	11.0	5.5	3.3	50%

5.3.2 Effects of alternative diets on livestock feed requirements

In the reference situation, grass is the feed item with the highest quantity used followed by cereals (Figure 5.2). A large share of the cereals are fed to pigs, but dairy cows also consume considerable amounts of cereals. A substantial amount of fodder from arable land, as well as fodder maize, is fed to beef cattle and dairy cows. Protein-rich feed, either domestically produced or imported as soy bean meal, is also important, whereas other feed and straw, energy-rich feed, fodder roots and by-products from the dairy industry play a minor role in animal feeding in Europe. The total amount of feed used in EU-27 is around 500 million tonnes per year.

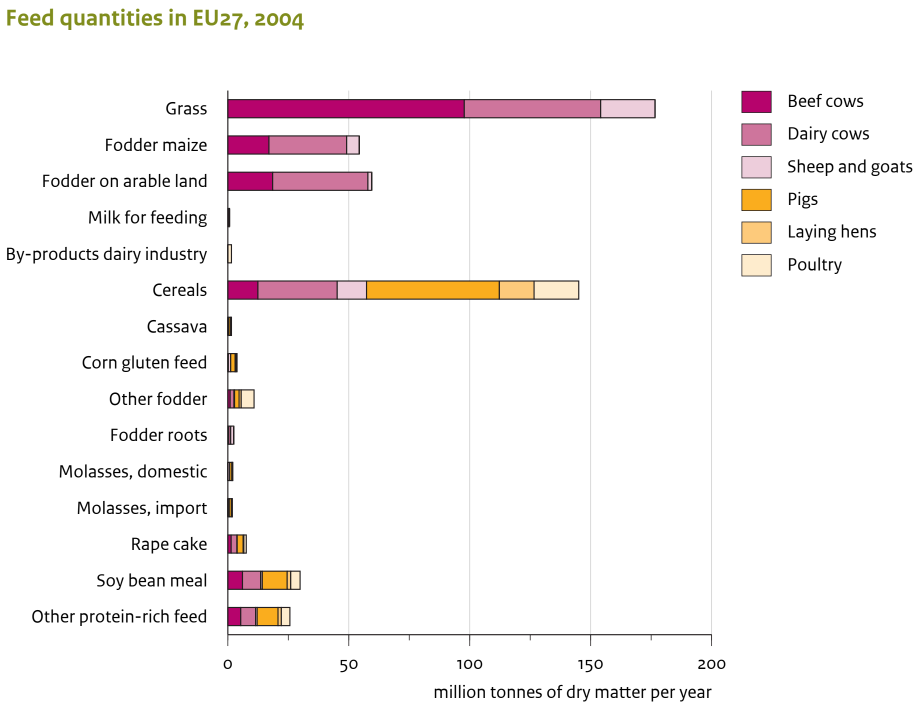

Figure 5.2 Feed quantities used in EU-27 in the reference situation (in million tonnes dry matter, calculation based on data from the MITERRA-Europe and CAPRI models.

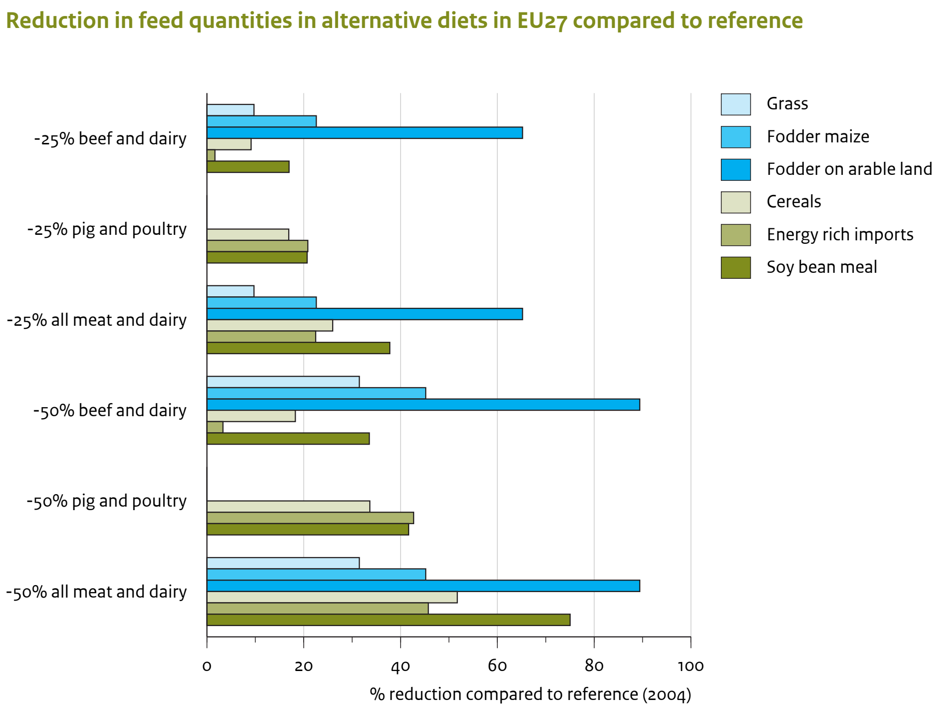

Figure 5.3 Calculated reduction in feed quantities for the main feed types as a consequence of the alternative diets as compared with the reference situation.

Figure 5.3 shows the percentage reductions resulting from the alternative diets compared with the reference situation. As a result of the choices made (see Methodology) fodder produced on arable land is reduced much more than grass consumption. In the 50% beef and dairy reduction diet, up to 89% less fodder is used compared with the reference, while grassland consumption is only reduced by 31%.

It should be noted that the feed calculations have been performed on a country basis, implying that in some countries fodder on arable land is still produced, whereas in other countries this production was reduced to zero, so grassland production had to be reduced. Also the use of energy rich products and of imported protein-rich feed (mainly soy beans or soy bean meal) is reduced more than proportionally, again in accordance with the choices made.

5.3.3 Scenario effects on land use

The alternative diets have implications for a number of land use categories. Following the assumptions made, the natural grassland areas (21.3 million hectares) and other arable crops (43.7 million hectares) were kept the same (Figure 5.4).

In the High Prices Scenario, the lower demand for forage by beef cattle and dairy cows results in a reduction in permanent grassland and fodder on arable land (including fodder maize area). In the alternative diets with a 25% reduction in beef and dairy, 2.6 million hectares of permanent grassland and 10.3 million hectares (55%) of arable land used for fodder production (including fodder maize) become available. In the alternative diets with a 50% reduction in beef and dairy, 9.2 million hectares (21%) of permanent grassland and 14.5 million hectares (77%) of fodder on arable land are released. It is assumed that these areas are cultivated with cereals, leading to an increase in cereal area from 55.9 to 72.8 million hectares in diets with a 25% reduction in beef and dairy and to a cereal area 83.6 million hectares in case of diets with a 50% reduction in beef and dairy.

The percentage reductions in managed grassland area are lower than the percentage reductions in grass quantity (-10% and -31%, respectively; see above), because the reductions mainly occurred in intensive grassland areas with higher yields as the focus was on reducing mainly fodder production on arable land. In the 25% reduction scenarios in some Member States total fodder on arable land area was already converted into cereal production. Hence, in the 50% reduction scenarios, additional reductions in grass production were mainly achieved by a decline in managed permanent grassland.

In the Greening Scenario, managed grassland area is maintained at 44.2 million hectares, and the lower demand for forage leads to an extensification of managed grassland areas and hence lower grassland yields (Figure 5.4). The changes in fodder area on arable land are similar to the High Prices Scenario. In this scenario, the released areas (of 10.3 and 14.5 million hectare respectively) are used to grow energy crops.

Figure 5.4 Changes in land use according to the High Prices and Greening Scenarios.

5.3.4 Scenario effects on nitrogen use, emissions and deposition

Figure 5.5 illustrates the nitrogen balance in the EU-27, which consists of the nitrogen applied to the land from fertilizer and manure, from grazing animals, nitrogen deposition and biological nitrogen fixation as well as the nitrogen removed by the crops. A positive value of the nitrogen balance indicates surplus nitrogen availability and a likelihood of nitrogen pollution problems. In all scenarios, nitrogen input is higher than crop removal, with a nitrogen surplus of 11.3 million tonnes in the reference scenario. This implies a nitrogen pollution risk, which is reduced in the dietary scenarios.

The results show that when balanced N fertilization is applied, both the mineral nitrogen fertilizer input as well as the N surplus are being reduced by 1 million tonnes. In the case of the alternative diets where all meat and dairy consumption is

Nitrogen balance in alternative diets in EU27

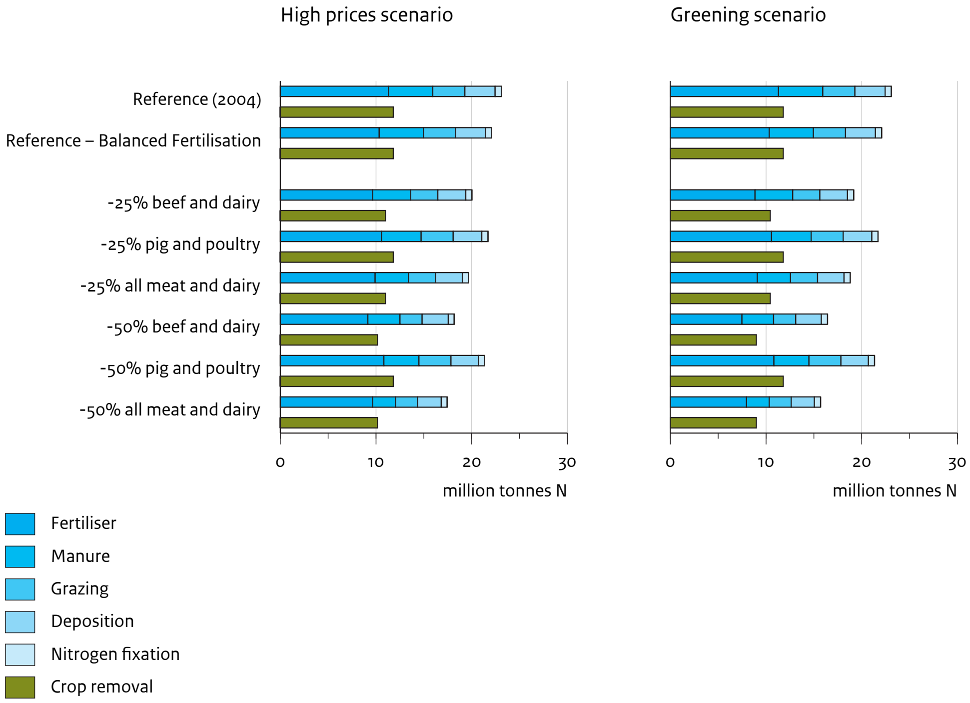

Figure 5.5 Nitrogen balance in the EU-27 (million tonnes nitrogen) in the reference and the alternative diets for the two land use scenarios.

reduced by 50%, the N surplus decreases to 7.3 million tonnes N (for the High Prices Scenario) and to 6.7 million tonnes N (for the Greening Scenario), as compared with the reference N surplus of 11.3 million tonnes. This amounts to a decrease in the N surplus of 35% and 41%, respectively. The lower N surplus in both cases is due to the lower N input from grazing and manure application, besides the N deposition decreases due to less NH_3 and NO_x emissions from livestock. The Greening Scenario has a lower N surplus than the High Prices Scenario because of the introduction of perennial energy crops, which are more efficient in their nutrient use than grain crops.

According to the reference situation total N emissions from agriculture for the EU-27 amount to 2.73 million tonnes as ammonia (NH_3), 0.08 million tonnes as nitrogen oxides (NO_x), 0.36 million tonnes as nitrous oxide (N_2O), 6.7 million tonnes as di-nitrogen (N_2), and the 3.03 million tonnes as N leaching and runoff.

All scenarios lead to a reduction in ammonia and nitrous oxide emissions to air and nitrogen leaching and run-off (Figure 5.6). Emission reductions are larger in scenarios involving reductions in beef and dairy production, as these sectors contribute more to the total N emissions.

In the Greening Scenario, reductions achieved range from about 8% for ammonia, 2% for nitrous oxide and 4% for nitrogen leaching and run-off in the 25% pigs and poultry reduction scenario to a reduction of 43% for ammonia, 31% for nitrous oxide and 35% for nitrogen leaching and run-off in the dietary scenario where all meat and dairy intake is reduced by 50%. Under this 50% dietary scenario total losses of N_r reduced by 42%.

The results for the High Prices Scenario show a similar pattern, but emission reductions are lower, since the cereals require more N inputs, with its related emissions, compared to the perennial energy crops. For the dietary scenario with 50% reduction in all meat and dairy intake, total N_r losses were reduced by 37%, with reductions of 40% for ammonia, 24% for nitrous oxide, and 29% for nitrogen leaching and runoff.

The changes in nitrogen fluxes are also demonstrated in a complete picture of nitrogen flows in the EU agricultural and food sector (Figure 5.7). Nitrogen in feed and manure are especially reduced, leading to lower losses to air and water. The nitrogen output of the agricultural system is even higher in the -50% meat and dairy diet, as more crops are exported from the agricultural sector. Nitrogen input is also significantly reduced, especially for nitrogen fertilizer and imported feed.

These changes also lead to a marked improvement of the nitrogen use efficiency (NUE). For the -50% dietary scenario reducing all meat and dairy, the NUE of the EU food system increases from 22% in the reference situation to 41% under the Greening Scenario (Figure 5.7) and to 47% under the High Prices Scenario.

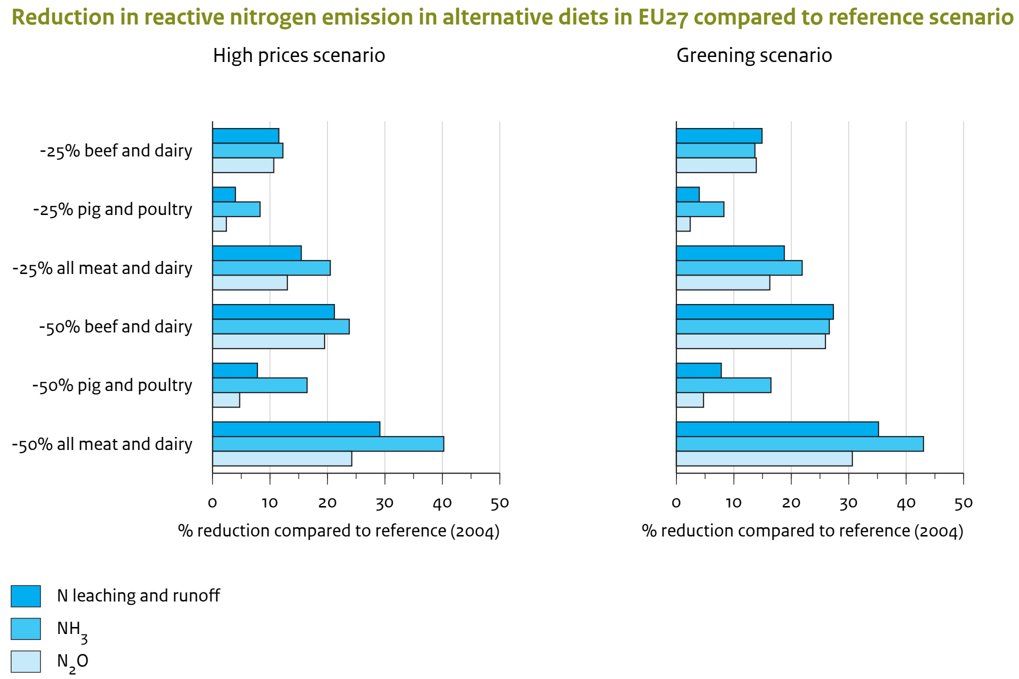

Figure 5.6 Percentage reduction in reactive nitrogen emissions in EU-27 from the alternative dietary scenarios compared to the reference with balanced fertilization, for the high prices and greening sub-scenarios.

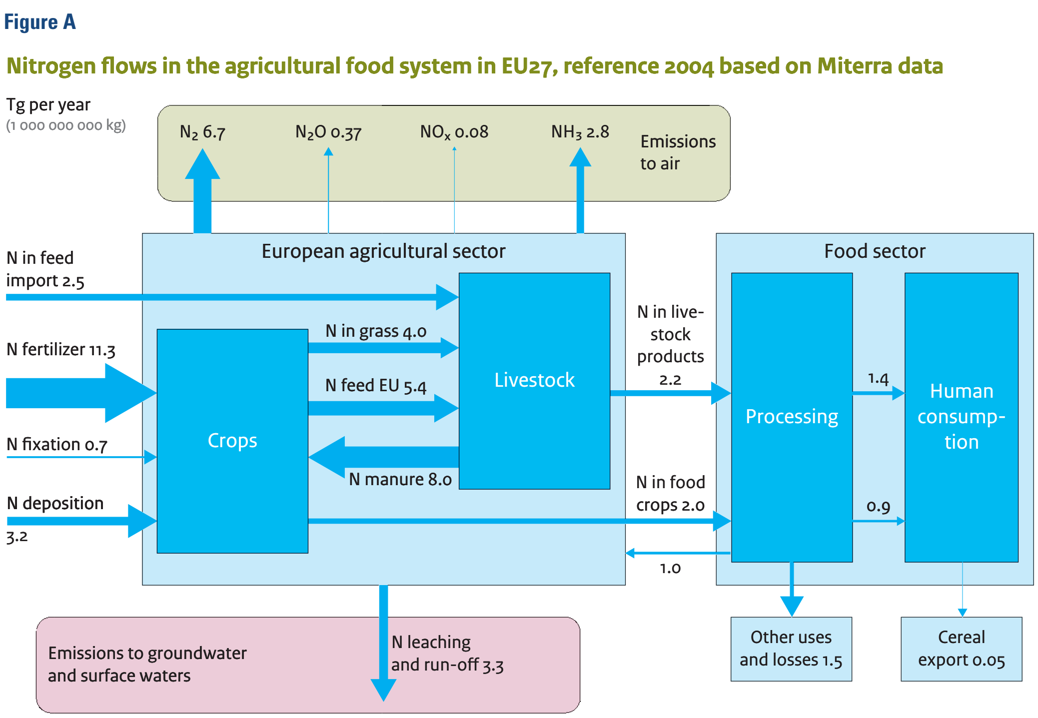

Figure 5.7 (A) Nitrogen flows in the EU agricultural and food sector in the reference situation **(A)** and in the alternative diets with -50% all meat and dairy in the Greening Scenario **(B, see next page)** and High Prices Scenario **(C, see next page)**.

Figure B

Nitrogen flows in the agricultural food system in EU27, -50% all meat and dairy Greening scenario

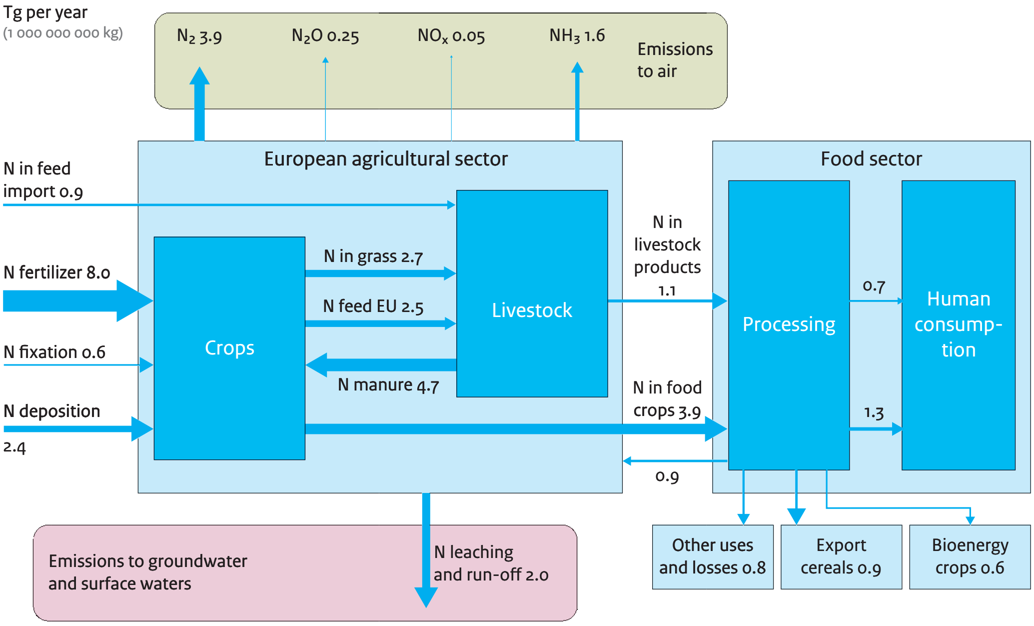

Figure C

Nitrogen flows in the agricultural food system in EU27, -50% all meat and dairy High prices scenario

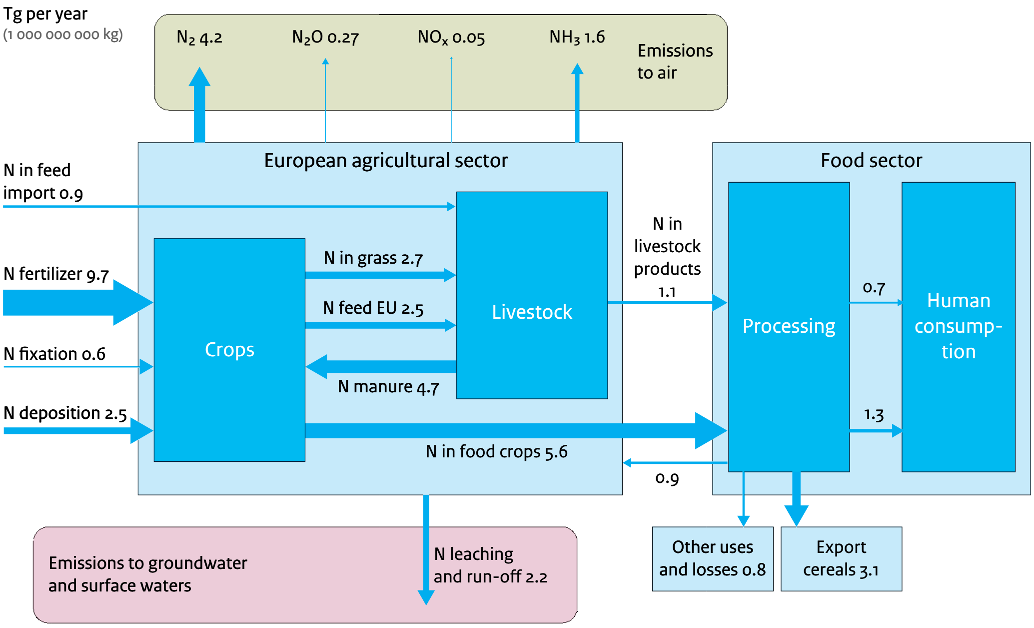

Figure 5.7 continued (B and C) Nitrogen flows in the EU agricultural and food sector in the alternative diets with -50% all meat and dairy in the Greening Scenario **(B)** and High Prices Scenario **(C)**.

5.3.5 Nitrogen deposition and exceedance of critical loads

Based on the GAINS model, grid averaged atmospheric N_r deposition currently reaches values of up to 47 kg per ha per year, of which around 21 kg per ha is in the form of reduced nitrogen (ammonia and ammonium, NH_x). As ammonia emissions are lowered in the scenarios, this also leads to a reduction of nitrogen deposition (Figure 5.8).

Both in absolute and relative terms, the reduction is the strongest in regions with high livestock density. The maps show that the reduction in deposition is larger for the dietary scenarios with reduction of beef and dairy than in the comparable diets with reduction of pig and poultry meat. The maps also show that the beneficial effects of reducing EU livestock production in terms of atmospheric nitrogen deposition can be seen beyond the EU territory: this is especially visible in the alternative diets with a reduction of 50% all meat and dairy.

The lower nitrogen deposition rates also result in less exceedance of critical loads (Figure 5.9). Critical loads represent the amount of atmospheric deposition below which effects on ecosystem do not occur, according to present knowledge. A

Figure 5.8 Reduction in nitrogen deposition (in %) compared to the reference for the range of alternative diets, based on analysis using the GAINS model.

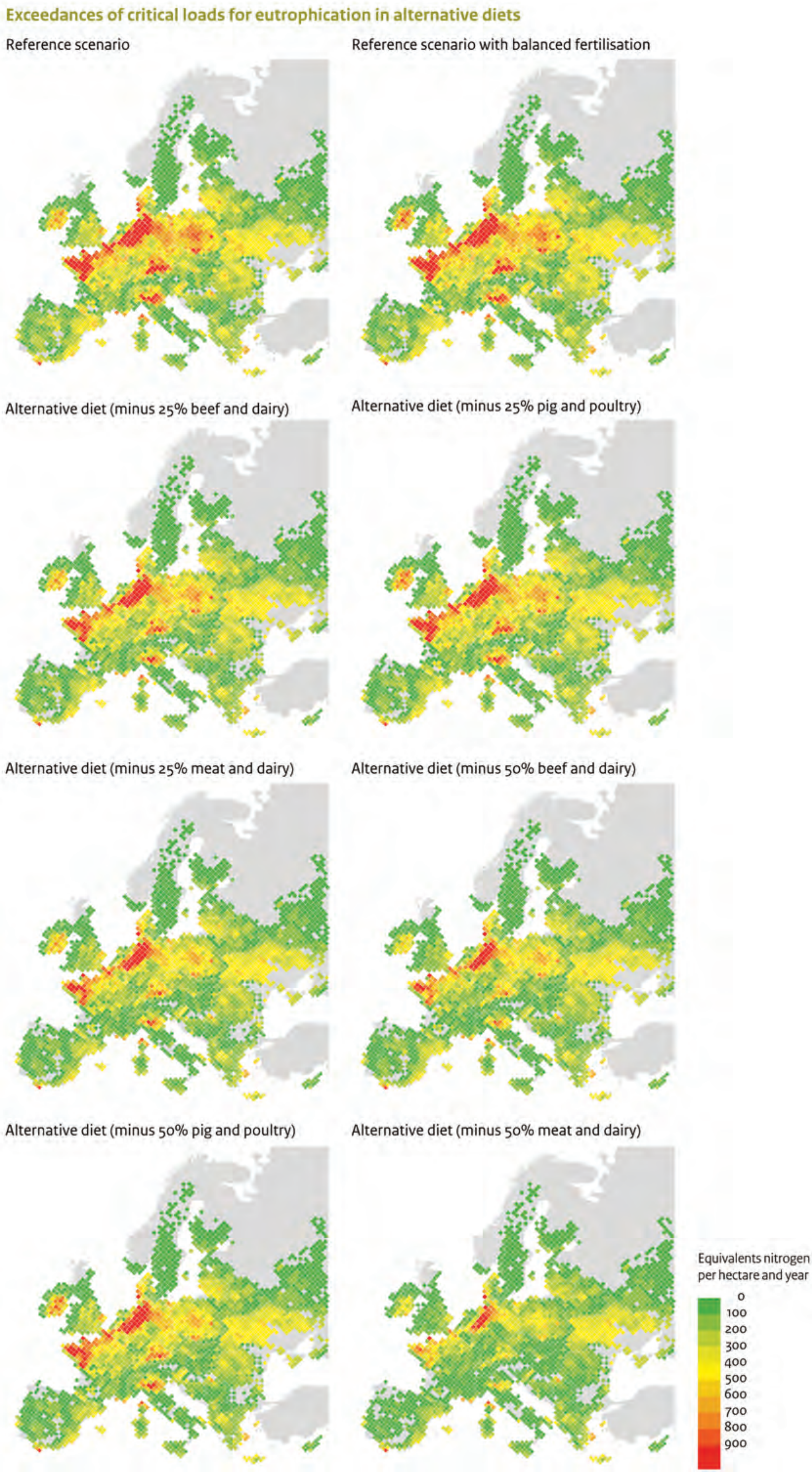

Figure 5.9 Average annual exceedance of critical load for the reference and alternative diets, as calculated with GAINS for N deposition in kg nitrogen per ha for natural ecosystems.

reduction in critical load exceedance can therefore be interpreted as reducing the level of risk to ecosystems and associated biodiversity that is associated with excess nitrogen deposition. The consequences of the alternative diet scenarios are especially large in areas with intensive livestock production such as Brittany, the Netherlands, the western part of Germany and the Po valley in Italy. These reductions in critical load exceedance would result in a decrease in the eutrophication of vulnerable ecosystems, potentially leading to a regeneration of original biodiversity.

The lower ammonia concentrations in the air also lowers the human health risks, as ammonia contributes to particulate matter formation with consequences for respiratory and other illnesses. Further analysis of the present results would be necessary to quantify the impact of the alternative diets on particulate matter levels and human health risk.

5.3.6 Bio-energy production

In the Greening Scenario it is assumed that land which is no longer needed for the production of forage maize, temporary grassland and other fodder on arable land will be used for bio-energy production (see Figure 5.4). It has been assumed that this would be in the form of grassy or woody biomass crops, which could be used for either the generation of electricity, for heating or could be converted to biofuels (second or third generation biofuels).

The area of arable land which could be converted is 10.3 million hectares in the case of a reduction of 25% beef and dairy scenario and 14.5 million hectares for the reduction of 50% beef and dairy. The scenarios envisage replacement crops of Canary Reed Grass, Switchgrass, Miscanthus, Poplar or Willow, depending on the location. The total energy production would be 1600-2300 PJ (Table 5.4). According to the National Renewable Energy Action Plans (NREAPs) the final energy consumption from biomass in EU-27 by 2020 is estimated at 5700 PJ (Beurskens et al. 2011). This means that the perennial biomass crops could fulfil 29% and 40% of this total demand, for the 25% and 50% reduction of beef and dairy scenarios respectively.

Table 5.4 Production of biomass for bio-energy in different alternative diets, according to the Greening Scenario, where released land is used for bio-energy production. NREAPs are the National Renewable Energy Action Plans for the EU-27.

Scenario	Area (million hectare)	Crude production (million tonnes)	Energy production (PJ)	% contribution to NREAPs bio-energy projection for 2020
Minus 25% beef and dairy (Greening Scenario)	10.3	91.6	1645	29%
Minus 50% beef and dairy (Greening Scenario)	14.5	126.1	2263	40%

5.3.7 Effect on GHG emissions

Introduction of the alternative diets and related land use scenarios would have a significant effect on greenhouse gas emissions from the EU agricultural sector. The GHG emissions would be from 3% to 42% lower compared to the reference-BF, depending on the scenario (Figure 5.10). The lowest emission occurs in the -50% all meat and dairy diets, in combination with the Greening Scenario in which the total GHG emissions from agriculture are around 268 million tonnes CO_2-eq, being 42% lower than in the reference BF situation (with 464 million tonnes CO_2-eq). In the same diet in combination with the High Prices Scenario, the GHG emissions are 378 million tonnes CO_2-eq, being 19% lower than in the reference situation. (Figure 5.10). The differences between the two land use scenarios (high prices vs greening) are mainly caused by differences in carbon flows, as will be explained below.

In the reference, methane is responsible for almost 50% of the direct GHG emissions from EU agriculture. As methane emissions are mainly related to the number of ruminants, these emissions are therefore the lowest in the human diets with reduced beef and dairy consumption. As the number of sheep and goats, which are ruminants as well, remains constant over the scenarios the reduction of methane emission is not completely halved in the -50% all meat and dairy alternative diet.

The nitrous oxide emissions are reduced to a lesser extent (Figure 5.10). These emissions are mainly related to the use of nitrogen in general, whether in the form of manure or fertilizer. As reduction in fertilizer use is much less than that for manure, the nitrous oxide emissions do not decrease so much. This is especially the case in the High Prices Scenario, where increased arable area is associated with significant nitrous oxide emissions that compensate the reduction in soil nitrous oxide associated with livestock reduction. The reductions of nitrous oxide emissions are larger in the greening sub-scenarios, though still not as large in relative terms as the reductions in other nitrogen losses. When compared with the reference, the nitrous oxide emissions in the various scenarios are from 4 to over 50 million tonnes CO_2-eq lower. The latter value corresponds to emissions that are 30% lower than compared to the reference in the Greening Scenario with -50% of all meat and dairy. Most of this effect is achieved by reductions in beef and dairy production. By contrast, the smallest reduction is in the -25% pig and poultry alternative diet, under the High Prices Scenario.

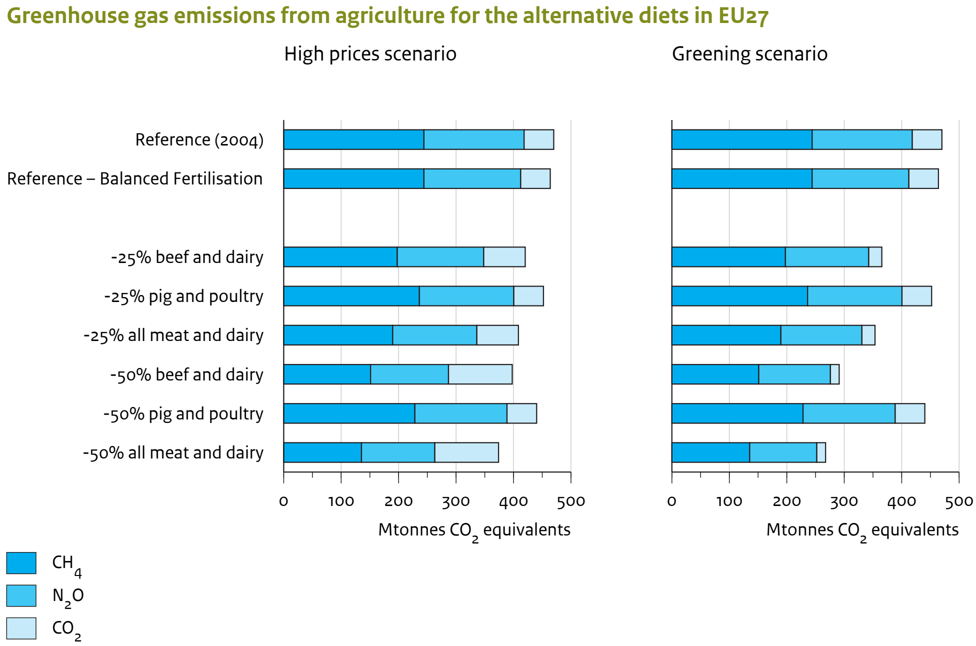

Figure 5.10 Direct effects on the greenhouse gas emissions from EU agriculture in the alternative diets and two land use scenarios.

The effect of land use changes within the EU on CO_2-emissions are significant, and opposite in the two types of land use scenario. In the High Prices Scenario, grasslands are converted into arable land, leading to additional CO_2-emissions. When these CO_2-emissions are averaged over a period of 20 years, this amounts to up to 59 million tonnes CO_2 year^{-1} in the diet with -50% all meat and dairy (as well as in the -50% beef and dairy diet). CO_2-emissions related to organic soils and liming, amount to 51 million tonnes CO_2 in the reference, and these emissions remain largely constant in the alternative diets and land use scenarios. This means that the total net CO_2-emissions from land use and land use change amount to 110 tonnes CO_2 in the diet with -50% all meat and dairy.

In the Greening Scenario carbon sequestration occurs as a result of the conversion of arable land into perennial biomass crops. These perennial biomass crops have dense rooting systems and ploughing is absent, which increases the soil organic carbon stocks. For the greening sub-scenarios with conversion of arable land into perennial biomass crops, carbon emissions would be at a level of 36 million tonnes CO_2 year^{-1} for the -50% all meat and dairy scenario. In combination with the CO_2-emissions related to organic soils and liming (51 million tonnes) this means that even in the Greening Scenario, for minus 50% all meat and dairy diet, there are still net CO_2-emissions, in spite of the carbon sequestration due to land use changes.

The above mentioned data refer to direct GHG emissions from EU agriculture. There would also be a number of other effects, both within and outside the EU, which are more difficult to quantify, and which are partly independent from changed diets. These include the following aspects (not an exhaustive list):

- In the Greening Scenario the use of nitrogen fertilizer would be up to 23% lower compared to the reference. This would lead to lower CO_2 and N_2O emissions related to the production of nitrogen fertilizer, which is not accounted for in the present analysis.
- The scenarios would lead to major changes in the import and export balances for food commodities (see also paragraph 5.3.8). The import of soybean and soybean meal would be drastically reduced in both the high prices and greening scenarios. In addition, the export of cereals would increase, especially in the High Prices Scenario. Both these developments would reduce the need for land conversion and deforestation outside the EU, and thus lead to significant reduction of carbon emission (Stehfest et al., 2013; Stehfest et al., 2009; Westhoek et al., 2011). While not accounted for in the present calculations (which focus on GHG emissions from the territory of the EU-27), this effect could be even larger than the impact on direct GHG emissions from EU agriculture.
- In the High Prices Scenario, instead of exporting cereals, these could be used alternatively for the production of bio-ethanol production. The by-product of bio-ethanol production (DDGS) could be used as protein-rich feed, thus replacing a soy bean meal or other protein sources.

5.3.8 Effect on import and export of agricultural commodities

The varying alternative diets and land use scenarios have an effect on the import or export of certain agricultural commodities. The main commodities affected are cereals and soy (and soy bean meal). In the case of cereals, three simultaneous changes are relevant:

1. The reduced need for feed cereals (See Chapter 4.3). This reduction is in fact slightly stronger than the reduction for the livestock sector itself. This is due to the assumption that the amount of by-products in feed is kept as much as possible the same level, meaning that the reduction is higher for products as cereals.
2. The increased cereal demand for human consumption to compensate for reduced consumption of livestock products, while maintaining the same calorific intake.
3. The additional production of cereals on 'liberated' land in the High Prices Scenario.

The total demand for cereals in the EU-27 for the different alternative diets and land use scenarios is shown in Figure 5.11. This figure makes a distinction between EU demand for cereals according to the scenarios and the amount available for export.

Considering firstly the trade-off between consumption of cereals by livestock and humans the alternative diets show that a reduced human consumption of livestock products leads to a net reduction of cereal consumption by humans and livestock. This is because the compensatory increase in cereal consumption by humans is less than the decrease in cereal consumption by livestock. This makes sense as it is well known that large losses (in terms of energy and nitrogen) occur in transforming feed into animal products. The total EU demand for cereals decreased by between 5 to 52 million tonnes, depending on the scenario. The latter figure amounts to a 52% reduction in EU cereal demand, which is equal to 100 kg of cereal per EU citizen per year.

In the Greening Scenario, cereal production is kept constant so as to allow extensification of grassland and the production of bioenergy other land. Nevertheless, the reduction in cereal demand in the scenarios allows for the additional amount of cereals available for export of between 5 to 52 million tonnes according to the different alternative diets scenarios. The cereal export in the reference situation is around 3 million tonnes, therefore the cereal export may increase to between 8 and 54 million tonnes according to the dietary scenarios.

In the High Prices Scenario, the reduced consumption by livestock allows the EU cereal production to increase to more than 400 million tonnes annually. Most of the additionally produced amount is also available for export. The scenario with the highest quantity available for export is the alternative diet with -50% all meats and dairy, where over 174 million tonnes would be available for export. These 174 million tonnes would currently amount to about 6% of the global cereal production.

The alternative diets also result in a reduction of the import of soy (or soy bean meal) and other feed products such as corn gluten feed. This effect is partly an effect of the choices made in the scenario design, where it was predetermined that imports were to be reduced first when feed requirements were reduced because of lower livestock production. The use of soy bean is lowered from around 34 million tonnes in the reference situation to 8 million tonnes in the diet with -50% all meats and dairy (for both the high prices and greening scenarios), which represents a 76% reduction in soy bean import. This would imply that the area of land currently required to produce this feed would be drastically reduced as well.

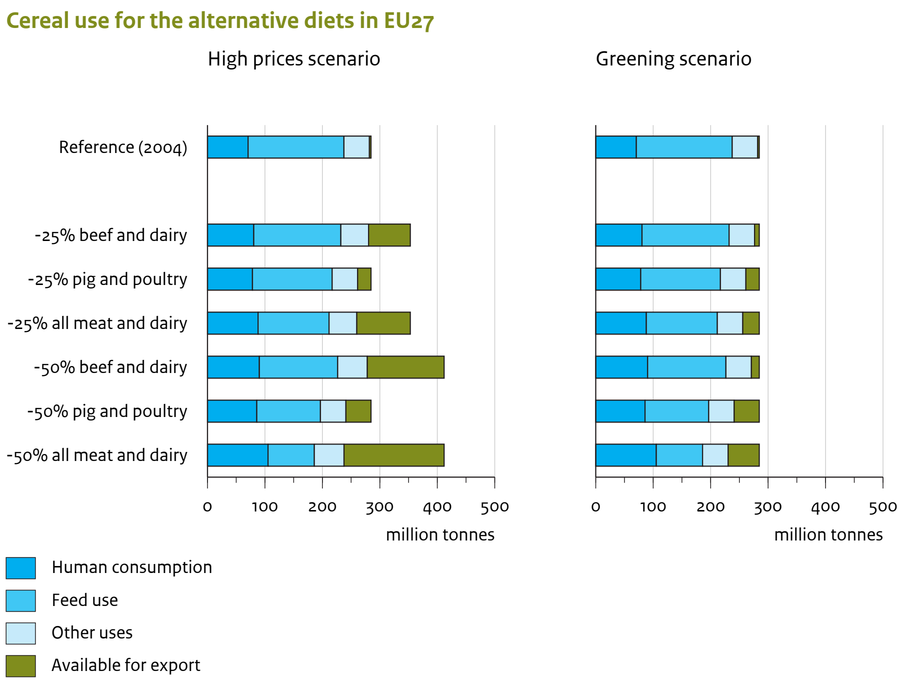

Figure 5.11 Cereal balance for the EU, with feed demand, demand for other (industrial) uses, direct food demand and the quantity available for export.

5.4 Discussion

By using a biophysical approach we quantified the consequences for the environment of replacing 25% to 50% of current meat, eggs and dairy consumption in the EU with plant-based foods.

To make the calculations we assumed a parallel reduction in production of livestock products in Europe. This is a very critical assumption. Instead of reducing production, EU farmers and the food industry could try to increase their exports to countries outside the EU. In this case, the environmental benefits of the consumption change would largely be outside the EU. This raises the question of what would happen in reality if European citizens reduced their consumption of livestock products. This is hard to predict, and would also depend on policies and on the capacity of farmers and the food industry to respond to new challenges. Currently, the production costs of many livestock products (perhaps except for dairy products) are generally higher in the EU than in other countries, such as in Brazil, Australia, the United States and Thailand. This makes it difficult for European livestock farmers to compete on the global market. European farmers could however try to either lower their production costs, or switch to a 'premium' segment with higher added value.

The potential for variant outcomes is also illustrated by the land use scenarios. Overall the high prices and greening scenarios both showed substantial benefits in terms of reduced nitrogen and greenhouse gas emissions and the associated health, environment and climate risks. The differences between the high prices and greening scenarios primarily reflect the available options of how to apportion the other benefits arising from reduced livestock consumption in the EU, including increased export of plant products, reduced reliance on feed imports, and headspace to develop European bioenergy production. With the evidence provided by the present scenarios, it then becomes a question for policymakers to consider how best to exploit these opportunities.

Within this study, we performed no explicit sensitivity analyses, although the combination of dietary and land-use scenarios could be regarded as a kind of sensitivity analysis. These alternatives show clear, plausible and largely linear outcomes for environmental effects. The most sensitive parameter for the reactive nitrogen and greenhouse gas emissions will be the assumed alternative land use. There is also an uncertainty in the absolute value of certain emissions, for example the quantity of nitrate leaching to ground water, as is clear from the difference in outcome for this parameter between MITERRA-Europe and CAPRI (Chapter 2).

5.5 Conclusions

By using biophysical models and methods, we examined the large-scale consequences in EU-27 of replacing 25% to 50% of meat, dairy and eggs with plant-based foods on a dietary energy basis (see Chapter 4), assuming corresponding changes in livestock production. We modelled the effects of these alternative diets and found that halving the consumption of meat, dairy products and eggs in the EU would achieve a 40% reduction in nitrogen emissions from agriculture. As agriculture is the major source of nitrogen pollution, this is expected to result in a substantial improvement in both air and water quality in the EU.

The maximum reduction achieved in ammonia emissions is 43%, leading to a significant reduction in nitrogen deposition within and even beyond the EU territory as well as to an improvement in air quality, reducing particulate matter concentrations and the associated human health risks. Greenhouse gas emissions from agriculture and land use within the EU would be reduced by 19% to 42%, depending on the land use scenario. Per capita 23% less cropland is needed for food production.

Due to reduced feed demand, the use of imported soybean meal would drop by 76% in the scenario where all meat and dairy consumption reduced by 50%, while the EU would simultaneously become a significant net exporter of basic food commodities. Depending on the land scenario, either a significant amount of bio-energy crops could be grown in combination with extensification of grassland use, or the EU could become a major exporter of cereals. For the full 50% scenario for all meat and dairy, this would equate to a 60 fold increase in cereal exports (from 3 to 174 million per year, High Prices Scenario) or allow grassland extensification while contributing 40% of the National Renewable Energy Action Plans (NREAPs) for the EU-27 for 2020 (2.3 EJ additional bioenergy, Greening Scenario).

The nitrogen use efficiency (NUE) of the food system would increase from the current 22% to between 41% and 47%, depending on choices made regarding land use. Substantial added benefits would arise from the reduced impacts outside the EU both from decreased soy import (76% reduction) and from less transboundary air pollution resulting from EU emissions.

6 GENERAL DISCUSSION AND OVERALL CONCLUSIONS

In Chapters 4 and 5 the alternative diets have been applied and analysed for their nutritional and environmental implications. Two aspects which remain to be discussed are the potential economic consequences for the European agriculture sector, and the question of how such changes in dietary patterns might be achieved. In this chapter we first discuss the assumptions made in the alternative diet and land use scenarios (Section 6.1). We then discuss the economic implications for agriculture (Section 6.2) and the possible ways that changes in dietary patterns might be achieved (Section 6.3). Finally, in section 6.4 we draw overall conclusions from the study.

6.1 Assumptions regarding alternative diets and land use scenarios

The central theme of this study is the effects of changes in diet and agricultural production on the fluxes of reactive nitrogen and other environmental impacts at the European level. This research uses hypothetical 'alternative diet' scenarios to examine the effect of potential changes. These dietary scenarios include 25% and 50% reductions in the consumption of different livestock products. As such they are neither predictions nor recommendations in themselves. They are tools to examine the effects of change in a particular direction. We also applied two land-use scenarios to examine the effects of two contrasting responses concerning the use of the resources released by a decreased European consumption of animal products. These are also neither predictions nor recommendations, but serve to illustrate the effects of particular 'directions of travel'.

In this study, we made the assumption that changes in the consumption of livestock products, which drive so much of human impact on the nitrogen cycle will be 100% balanced in terms of dietary energy by changes in the consumption of cereals. We chose to replace meat and dairy with cereals in the alternative diets for several practical reasons. In particular, cereal was chosen as a more or less 'neutral' replacement with regard to health benefits. It was not chosen to implement changes towards an 'optimal' diet. In this regard, the choice of these details in the scenarios certainly does not mean that this study advocates such a shift, or suggests it as optimal. Reducing total caloric intake and increasing the amount of fruits and vegetables in the current average European diet would of course be beneficial for human health, however these are seen as additional steps. The same applies for measures to improve farm management systems which can reduce nitrogen and other pollution. Examining the effects of a set of changes from the current system to an 'ideal' food system would involve modelling the effects of changes in a large number of parameters, after deciding what 'ideal' systems would be, from either an environmental or health viewpoint.

Rather, the purpose of the alternative diets as we constructed them for the present study was more limited. They allowed us to focus on what would be the implications of simply reducing the amount of livestock products in European diets while keeping calorific intake constant. The results show that such simple changes in dietary choice can have a major impact on environment and health. Such changes could then be seen as complementing strategies to improve farm management practices, reduce calorific intake and increase the amounts of fruits and vegetables in European diets.

The second reason for keeping the alternative diets and scenarios used in this study as simple as possible was to be as transparent as possible with regard to the associated assumptions. For example, altering crop areas we particularly focused on wheat, since the information from life-cycle assessments indicates that, on a dry-matter basis, cereals serves as a good surrogate for the estimation of emissions from a wide range of crops. For this reason we present the results as indicative of major shifts between livestock and crops in consequence of possible dietary change. Furthermore, it is known from food balance information that the fruit and vegetable component of our diet is responsible for a small proportion of energy intake and so compensating in energy terms for a reduction in the intake of livestock products will rely heavily on crops such as wheat (even if fruit and vegetable consumption was to increase substantially).

The two land use scenarios address the production side and are chosen to relate to a wide range of land use or production options. The High Prices Scenario broadly equates to a world in which resource allocation is left to freely exploit global market opportunities, while a Greening Scenario is broadly relevant to a wide range of intervening policy options, including support for extensification and the return of agricultural land to its natural vegetation cover (e.g. forest), which is simulated in terms of effects on the N and C cycles by the bioenergy option. In principle, other greening scenarios could also be envisaged that involve additional planting of forest, taking land out of agricultural production. Our focus on agricultural bioenergy production in the Greening Scenario is again a simplification that allows us to illustrate the potential for bioenergy production that could be achieved as a result of dietary change in Europe.

The High Prices Scenario sees Europe becoming a major exporter of crop produce, particularly cereals. The research did not have an explicit time dimension, but assuming that such a transition might take 10-20 years, the exported amount of cereals would be absorbed by expanding global markets that, due to increased population growth and indeed consumption shifts, are expected in all baseline scenarios. A reduction in pressure to convert land to agriculture elsewhere would be expected as a major consequence of increased cereal export under the reduced meat consumption - High Prices Scenarios (Stehfest et al., 2013; Westhoek et al., 2011).

6.2 Economic consequences for the European agricultural sector

This study did not include economic assessment of the economic impact of the alternative diets: neither on the agricultural sector, nor at the level of European society as a whole. However, given the large transformations of diets and the large impact of these on especially the livestock sector, it is relevant to reflect on the potential economic consequences.

It is expected that within the European agricultural sector, a reduction in livestock consumption matched by a proportionate decrease in livestock production would have adverse effects on income to the livestock sector, especially if consumer preferences were to change rapidly. The farm-level economic impact would depend on the type of new output found for the land released from livestock production. In this regard, it would be essential that any strategic planning to foster behavioural change to reduce livestock consumption in Europe would be accompanied by active measures to address new market opportunities. Examples may include further development of markets for bioenergy production, for high value 'premium' livestock products, and for other high value plant biotechnological options. Such strategic planning would naturally be incorporated into future reviews of the EU Common Agricultural Policy.

The risk that decreased livestock production would adversely affect incomes on farms has been highlighted by a study of the UK food system, using scenarios similar to those in this study. Audsley et al. (2010) showed that a hypothetical reduction in the UK farm gate value of livestock from dietary change was not fully compensated by an increase in the value of crops for direct human consumption. Their study highlighted strong regional effects, with gains in areas with high quality arable land and losses of income on less suitable land, particularly in Scotland and Wales. This finding, that the increase in the value of crops that are consumed directly does not fully compensate for the loss of value of livestock, is also supported by results from Rutten et al. (2013), who examined the economic effects of a 'healthy diet'. By contrast, if attitudes toward food were to change within society and consumers opted for products with a higher added value, such as meat and dairy produced in systems with a higher level of animal welfare and environmental performance, with a stronger market focus on such benefits, the economic effects on the livestock sector could be less severe. A stronger focus on these issues could potentially compensate for the disadvantage to marginal upland areas, so long as the animal welfare, environmental and product quality advantages can be demonstrated.

Other ways in which farm income can be maintained under patterns of decreasing livestock consumption in Europe need to be further investigated. For example, if the price of bioenergy were to increase, with higher prices paid to farmers for bioenergy crop produce, this would help compensate for loss of farm income. Other options that could increase value could include further development of plant biotechnological products.

Fewer animals slaughtered also means that less by-products, such as leather and pet food would be generated. In the case of leather for example, more synthetic fabrics might be needed, leading to additional GHG emissions. These effects would have to be quantified in new studies.

The effects above should be assessed against the current value of livestock production. The annual added value of the EU livestock sector amounts to more than 143 billion euro, which is around 60% of the total added value of EU agriculture. The added value of beef and dairy combined amounts to around 79 billion euro and for the pig sector 31 billion. The combined annual added value of the poultry and egg sector is almost 23 billion euro. In addition to this value added by the production of livestock, milk and eggs, the processing industry adds further value. A reduction of the consumption of livestock products would therefore affect the whole food industry. The effect on the food industry may partly offset if consumers choose highly processed and expensive meat replacements or other high-value plant based products.

Certain policy responses could be formulated to compensate the livestock sector for the loss in revenues. Policies could range from support to the sector to become more competitive (by lowering production or by aiming at higher added value) or buy-out schemes for farmers who voluntarily want to reduce their production capacity. Market-based solutions are however also possible. In the Netherlands, for example, a large scheme has been set-up by the major retailers in which pig farmers reduce the number of pigs per unit floor area by 25% in order to improve animal welfare. Farmers are compensated for the additional costs and loss of production. Hundreds of pig farmers already participate in this scheme. In the end, for farmers in this scheme, it appears that it is not the size of physical production which counts, but the net profit and continuity of their farms (van Grinsven et al., 2015).

The conclusion is that diet-led changes in food production patterns would probably have a large economic impact on livestock farmers and associated supply-chain actors, such as the feed industry and meat-processing sector. The overall effects at farm and food business level are difficult to assess, and depend on the response of farmers, markets for products from alternative land uses, farm support policies and consumer decisions.

Lastly, it may be noted that such a decrease in livestock consumption in Europe should be seen against current trends in increasing consumption in other parts of the world. These provide the opportunity for increased export of European farm products. In this regard, a European trend over the next 10 to 20 years to reduce per capita consumption of livestock may be seen as part of a wider transformation of aspirations associated with a growing middle class in fast developing economies. Such a transformation could include a growing appreciation of the health and environmental benefits of avoiding excess meat and dairy consumption, which would help avoid what would otherwise be an even larger rate of increase in global livestock population.

6.3 Policies and possible pathways to dietary change

Options to foster change

Our study shows that a change towards diets with a lower consumption of livestock products has clear environmental and health benefits. But this still leaves the question of whether such a change in consumption behaviour would be realistic in the short or longer term. There might be various pathways leading to such change (Westhoek et al., 2014):

1) Changes in consumer preferences may evolve due to environmental or health concerns, or simply because eating meat and dairy would become less 'normal' or fashionable for various reasons, a process that is already happening (Dagevos and Voordouw, 2013). A shift towards lower meat and dairy consumption could also be actively influenced by governments, food manufacturers, retailers, restaurants and foodservice businesses (such as catering firms). Retailers in particular have a large influence on consumers' choices. Corporate responsibility schemes are already supporting reductions in the intensity of livestock production for animal welfare and environmental reasons. This trend could continue and extend to other drivers, including a shift towards lower levels of consumption linked to higher process quality. Governments could also initiate or 'nudge' changes through public procurement policies.

2) A more direct policy intervention would be to increase the price of meat and dairy products, either by direct taxation (e.g. Deckers, 2010; Vinnari and Tapio, 2012), or by taxing the environmental effects (e.g. greenhouse gas emissions or nutrient use) caused by their production (e.g. Wirsenius et al., 2011). As meat and dairy have larger environmental footprints than plant-based alternatives, the price of animal products would over time increase faster than plant-based products. Higher meat and dairy prices (relative to alternatives) would very probably lead to lower meat and dairy consumption (Helming et al., 2014).

3) Indirect measures include fostering better public awareness about the links between the health effects and the environmental effects of excess consumption of animal products Public information on the links between these issues is at its infancy, and much more could be done to inform citizens, leading eventually to altered cultural aspirations, both in Europe and beyond.

Differences between livestock types

It should be noted that the dietary and land use scenarios in this study have examined the effects of decreasing different types of livestock product, contrasting pig and poultry reductions versus reductions in intake of beef and dairy products. The different responses in the scenarios terms of levels of nitrogen pollution and greenhouse gas emissions reflect the fact that there are significant differences in efficiencies between types of livestock products. For example, Sutton, et al. (2011a) showed that nitrogen use efficiency in feed conversion was lowest in beef and highest in poultry and egg production. Others such as Eshel et al. (2014) have seen in these differences the opportunity to argue against certain livestock (especially beef) in favour of other livestock products. It should be noted that beef from dairy cattle has in general a lower environmental footprint than pure beef cattle (Nijdam et al., 2012).

In particular there are several trade-offs between issues when comparing livestock types, which means that it becomes a question for policy makers to consider the priorities between issues. For example, more efficient poultry and pig meat production is associated with lower nitrogen and greenhouse gas emissions per unit product than less efficient beef and dairy production. However, pig and poultry also depend on arable land to produce livestock feeds, and in order to benefit from economies of scale tend to focus on intensive farm installations, which give large local point sources of pollution (e.g. contributing hot spots of ammonia emissions, making a locally intense threat to biodiversity). By comparison, according to the prevalent farming systems in Europe for beef and dairy production, part of the beef and dairy production is based on lower quality land which is more suited to grassland. Also the current structure of farms is generally associated with a smaller fraction of large point sources. Providing the evidence basis to analyse such trade-offs is a topic for future research.

The key point is that our analysis shows how European citizens are eating more livestock products than needed for a healthy diet. Current food consumption in Europe is contributing to both health and environmental threats, especially through alteration of the nitrogen cycle, but also through other means such as altered land-use and greenhouse gas emissions.

According to international dietary guidelines there is substantial headspace to reduce consumption of animal products in Europe. The dietary scenarios analysed here of -25% and -50% of certain livestock products, while retaining the same calorific intake, together with the land use scenarios demonstrate the strength of the relationships. For European citizens, eating less of all of these livestock categories would make a difference. However, there are a mix of efficiency, land use and pollution arguments when considering the differences between livestock products which should be recognized if considering any policy differentials between livestock types.

6.4 Overall conclusions

This study is one of the first to examine, in detail, the relationships between large scale diet-led changes in food production and continental-scale effects on land use, the N cycle, greenhouse gas emissions and the associated implications for human health. In this study we have evaluated the nitrogen emissions related to EU agriculture, and we have disaggregated these per commodity group (Chapter 2). This shows that currently the nitrogen losses from EU agriculture are highly correlated with the output of the livestock sectors, which are responsible (directly and indirectly) for over 80% of the nitrogen emissions to air (in the form of ammonia) and water (mainly as nitrates). We have also calculated the nitrogen losses per unit of protein consumed. This shows that plant-based commodities such as cereals have lower to much lower losses per unit of protein provided. The nitrogen losses per unit of protein from beef are 20 times those from cereals. The losses from poultry meat and eggs are about four times those of cereal-based foods.

There are therefore basically two ways to reduce nitrogen emissions from European agriculture:

i) reduce emissions per unit of product, with a special focus on animal production. This can be done by both management improvements at the farm level (for example shifting to more nitrogen efficient cropping systems, and implementation of new more nitrogen efficient production technologies), as well as in the food chain at large (for example reducing food wastes and implementing better recycling of N in manure and wastes) and/or
ii) reduce the consumption and production of livestock products.

As most of the attention over the last decades has been on the former route, this study focused on the latter route.

Based on this background, the historic and current consumption of livestock products was analysed (Chapter 3). This showed that average per capita EU consumption of livestock products has significantly increased in the period 1960-2005, especially that of dairy products, pig meat and poultry meat. As a result, the per capita consumption of protein and saturated fats has increased. The high intake of saturated fats leads to an increased risk of cardio-vascular diseases; the average intake currently is 42% higher than the maximum amount recommended by the WHO (Chapter 3). Also the consumption of red meat (beef, pig meat, sheep and goat meat) increased, with current consumption twice the amount compared with the World Cancer Research Fund WCRP guidelines. There are indications that this high intake of red meat is associated with an increased risk of colorectal cancer. In terms of protein, rates of EU consumption are 70% higher than WHO guidelines. Although this is not associated with direct health threats, high consumption of livestock products tends to be associated with high intake of saturated fats. Equally, this figure demonstrates that there is substantial potential to reduce European protein consumption.

The combination of expected lower health risk and lower environmental pressure motivated the exploration of alternative diets with lower intake of livestock products, and compensated by higher intakes of plant-based products (mainly cereals). It was therefore assumed that the reduction in consumption of meat, dairy and eggs would be followed by a corresponding reduction in livestock production. This is in line with the current situation, in which EU-27 is more or less self-sufficient in livestock production, with (compared to the domestic production and consumption) relatively low import and export rates.

The main quantitative findings of the study are:

With respect to the total loss of reactive nitrogen and losses per food commodity (Chapter 2):

- Total losses of reactive nitrogen amount to between 7.2 and 10.4 million tonnes of reactive nitrogen, depending on model assumptions. This means that food production is responsible for about half the emissions of reactive nitrogen in European countries.
- Livestock production chains are responsible for a high proportion of nitrogen losses. Over 80% of the ammonia emissions from agriculture to air and nitrogen emissions to water are related to livestock production. Beef and dairy products cause 56% of total direct N_r emissions from agriculture.
- There are large differences between food commodities in terms of nitrogen losses per unit of protein produced. The nitrogen losses per unit of protein from beef are 20 times those from cereals. Poultry meat, which has the lowest nitrogen emissions intensity from the animal product groups considered, still leads to up to twice as many emissions as fruits and vegetables for the same quantity of protein intake.

- There are also other differences which need to be considered when making comparisons between livestock groups, such as their ability to make use of marginal agricultural land, their requirement for livestock feed produced on good arable land and the size and spatial distribution of the emissions.

With respect to historic and present EU food consumption (Chapter 3):
- The consumption of meat and dairy products in EU-27 has increased considerably over the last 50 years. There is still significant difference between the 15 'old' member states and the 12 new member states, with the latter having generally lower consumption rates.
- Notably, the consumption of pig meat, poultry meat and dairy has increased most strongly.
- The current per capita intake of saturated fats in the EU-27 is 42% higher than the recommended maximum dietary intake of WHO. In some countries (France, Belgium, Austria, Finland and Germany) this is even higher.
- The current per capita intake of protein in the EU-27 is 70% higher than recommended by WHO, while current intake of red meat is roughly double the maximum recommended intake of the World Cancer Research Program. Current per capita energy intake as around 10% higher than recommended by WHO.

With respect to the effects of the alternative diets (Chapter 4):
- Replacing 25-50% of the current intake of meat, dairy and eggs by plant-based products (mainly cereals in our calculations) in the EU-27 would lead to diets with an average intake of proteins which still is 50% higher than recommended. In some EU member states, with currently low intake of proteins, the average intake would come close to the recommended level.
- In the dietary scenario with 50% reduction of all meat and dairy, including eggs, intake of saturated fats across the EU-27 would be reduced by up to 40%. This would bring saturated fat intake in line with the recommended maximum values. Such a reduction in saturated fat intake would be expected to reduce cardiovascular mortality.

With respect to the environmental effects of the alternative diets (Chapter 5):
- A 25-50% reduction in meat, dairy and egg consumption and parallel reduction in livestock numbers within the EU would result in lower nitrogen and greenhouse gas emissions from both livestock and crop production.
- The reduction in livestock production would have a large impact on feed demand, thus having a large impact on the structure of EU agriculture. In the case of a 50% reduction of all meat and dairy, imports of soy to the EU could reduce by 76%.
- Less land would be needed for feed production (grassland, cereals etc.), providing substantial headspace to develop other land uses. The land 'released' could, for example, be used for cereal production for export (as we examined in a High Prices Scenario) or for the production of bioenergy crops (including forestry) (as we examined in a Greening Scenario).
- In the case where all the released land is used for cereal production (High Prices Scenario with 50% reduction in all meat and dairy), cereal export from the EU-27 could increase from ~5 million tonnes currently up to ~170 million tonnes.
- In the case where the released land is used for bioenergy crops (Greening Scenario with 50% reduction of in all meat and dairy), an estimated additional 2.3 EJ per year of bioenergy could be produced, which would amount to 40% of the 2020 goals of EU National Renewable Energy Action Plans (NREAPs).
- In case of a 50% reduction of all meat, dairy and eggs consumption the nitrogen emissions (in the form of nitrates and ammonia) from EU agriculture would be reduced by about 40%. This would have considerable environmental benefits, particularly for human health (through particulate matter air pollution and water quality), as well as for aquatic and terrestrial biodiversity.
- Greenhouse gas emissions from EU agriculture would be reduced by 25-40%. This excludes potential additional reduction outside the EU, for example related to soy production or from prevented land use changes.

Our study demonstrates how dietary changes could produce a cascade of effects, through reduced production of livestock and manure, lower feed demand, resulting in lower N and greenhouse gas emissions, and freeing up agricultural land for other purposes. In Europe, the evidence of diet being an important factor in relation to environmental policy has already impacted the policy community. The Roadmap to a Resource-Efficient Europe (EC, 2011) highlights the food sector as a priority area for developing incentives for a healthier and more sustainable system for the production and consumption of food. Moving in this direction means paying attention to stimulating the changes required and checking for any unintended nutritional consequences. The biggest challenge for agricultural policy in Europe is that of how to achieve such a fundamental change in European agriculture and address the implications for farm incomes, farmed landscapes and planning, at a wide range of scales.

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Annex 1: Reference diets and relative changes in alternative diets

Reference diet (g per capita per day)	Austria	Belgium	Bulgaria	Cyprus	Czech R	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy
Cereals	260	238	304	167	282	245	260	230	224	250	285	247	290	294
Vegetable oil	44	45	33	35	39	12	17	21	40	34	52	38	38	55
Fruit & vegetables	358	297	190	363	200	305	229	233	349	265	554	293	299	435
Pulses	3	4	5	7	4	3	8	3	4	3	7	5	4	6
Potatoes & other starchy roots	73	88	41	56	80	96	149	81	76	81	93	61	132	46
Sugar	93	111	74	95	73	121	92	68	74	101	66	91	82	62
Dairy	543	553	379	361	451	672	543	824	607	573	713	399	564	585
Beef	24	26	7	10	11	36	19	25	36	18	25	6	32	33
Poultry	27	39	31	51	38	28	27	27	33	24	21	43	40	25
Pig	96	49	26	72	68	72	39	50	46	81	40	69	53	65
Sheep and goat	1	2	3	13	0	2	1	1	5	1	19	0	6	2
Eggs	32	30	28	23	21	44	24	19	33	27	20	36	15	26
Fish & other seafood	26	48	9	44	20	48	32	61	68	29	41	8	41	47
Others	239	222	192	138	291	217	243	195	115	230	137	180	300	99

Changes in consumption (in %) compared to reference diet

-25% beef & dairy	Austria	Belgium	Bulgaria	Cyprus	Czech R	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy
Cereals	108%	120%	100%	104%	106%	110%	111%	132%	132%	117%	118%	100%	117%	109%
Dairy	76%	72%	100%	100%	78%	67%	72%	56%	64%	67%	55%	100%	73%	89%
Beef	78%	80%	100%	100%	100%	62%	93%	73%	60%	100%	82%	100%	65%	63%

-25% pig & poultry & eggs	Austria	Belgium	Bulgaria	Cyprus	Czech R	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy
Cereals	119%	105%	105%	119%	107%	115%	102%	124%	115%	111%	100%	116%	104%	103%
Poultry	86%	71%	73%	51%	73%	84%	100%	89%	77%	98%	100%	58%	59%	95%
Pig	50%	100%	100%	76%	75%	69%	100%	96%	100%	61%	100%	100%	94%	77%
Eggs	68%	76%	76%	99%	100%	45%	95%	100%	64%	78%	100%	60%	100%	80%

-25% all meat and dairy	Austria	Belgium	Bulgaria	Cyprus	Czech R	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy
Cereals	127%	125%	105%	122%	113%	125%	113%	156%	148%	128%	118%	116%	121%	112%
Dairy	76%	72%	100%	100%	78%	67%	72%	56%	64%	67%	55%	100%	73%	89%
Beef	78%	80%	100%	100%	100%	62%	93%	73%	60%	100%	82%	100%	65%	63%
Poultry	86%	71%	73%	51%	73%	84%	100%	89%	77%	98%	100%	58%	59%	95%
Pig	50%	100%	100%	76%	75%	69%	100%	96%	100%	61%	100%	100%	94%	77%
Eggs	68%	76%	76%	99%	100%	45%	95%	100%	64%	78%	100%	60%	100%	80%

-50% beef and dairy	Austria	Belgium	Bulgaria	Cyprus	Czech R	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy
Cereals	122%	136%	106%	122%	117%	126%	125%	149%	151%	130%	131%	107%	132%	123%
Dairy	50%	48%	74%	68%	52%	44%	48%	37%	43%	45%	36%	66%	48%	59%
Beef	50%	51%	100%	100%	100%	36%	63%	46%	35%	72%	53%	100%	39%	37%

-50% pig&poultry	Austria	Belgium	Bulgaria	Cyprus	Czech R	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy
Cereals	131%	112%	108%	136%	117%	128%	106%	138%	129%	123%	103%	128%	111%	113%
Poultry	57%	47%	48%	34%	49%	56%	70%	59%	51%	65%	73%	39%	39%	63%
Pig	30%	73%	100%	49%	49%	44%	90%	64%	70%	38%	88%	51%	62%	50%
Eggs	45%	51%	50%	66%	71%	29%	63%	72%	42%	51%	71%	39%	91%	53%

-50% all meat and dairy	Austria	Belgium	Bulgaria	Cyprus	Czech R	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy
Cereals	153%	148%	114%	158%	134%	153%	131%	187%	179%	153%	133%	135%	143%	136%
Pulses	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	258%	100%	100%
Dairy	50%	48%	74%	68%	52%	44%	48%	37%	43%	45%	36%	66%	48%	59%
Beef	50%	51%	100%	100%	100%	36%	63%	46%	35%	72%	53%	100%	39%	37%
Poultry	57%	47%	48%	34%	49%	56%	70%	59%	51%	65%	73%	39%	39%	63%
Pig	30%	73%	100%	49%	49%	44%	90%	64%	70%	38%	88%	51%	62%	50%
Eggs	45%	51%	50%	66%	71%	29%	63%	72%	42%	51%	71%	39%	91%	53%

Reference diet (g per capita per day)	Latvia	Lithuania	Lux	Malta	NL	Poland	Portugal	Romania	Slovakia	Slovenia	Spain	Sweden	UK	EU-27
Cereals	231	306	261	339	175	308	253	363	275	288	210	203	242	256
Vegetable oil	30	20	26	15	35	22	35	26	26	25	55	31	35	38
Fruit & vegetables	216	236	433	427	327	227	431	300	211	269	357	279	301	319
Pulses	2	5	3	6	3	4	5	4	4	5	6	4	5	4
Potatoes & other starchy roots	115	113	63	73	108	144	96	115	77	75	86	71	125	90
Sugar	58	92	88	102	92	86	66	57	84	48	51	84	71	77
Dairy	475	622	602	428	730	458	508	602	312	563	403	810	552	554
Beef	11	10	59	29	25	6	25	10	8	29	21	33	30	23
Poultry	32	39	62	38	23	31	39	30	28	31	43	23	45	32
Pig	46	65	66	54	48	75	65	47	48	60	90	53	40	62
Sheep and goat	0	0	2	2	1	0	4	3	0	1	6	2	8	3
Eggs	35	25	20	35	41	26	22	29	26	20	34	25	23	28
Fish & other seafood	24	73	54	58	37	19	106	10	17	19	78	55	39	43
Others	185	213	235	135	163	201	150	168	207	205	172	143	184	175

Changes in consumption compared to reference diet

-25% beef &dairy	Latvia	Lithuania	Lux	Malta	NL	Poland	Portugal	Romania	Slovakia	Slovenia	Spain	Sweden	UK	EU-27
Cereals	105%	105%	134%	103%	139%	103%	109%	115%	100%	108%	100%	126%	115%	114%
Dairy	82%	62%	61%	84%	55%	100%	82%	60%	100%	72%	100%	55%	79%	75%
Beef	100%	100%	46%	72%	75%	100%	75%	100%	100%	71%	88%	66%	72%	75%

-25% pig&poultry&eggs	Latvia	Lithuania	Lux	Malta	NL	Poland	Portugal	Romania	Slovakia	Slovenia	Spain	Sweden	UK	EU-27
Cereals	105%	109%	128%	105%	106%	113%	108%	102%	102%	103%	122%	105%	116%	111%
Poultry	87%	71%	45%	62%	100%	76%	60%	79%	95%	87%	56%	99%	53%	75%
Pig	100%	71%	72%	94%	91%	58%	75%	100%	100%	79%	58%	77%	100%	75%
Eggs	65%	88%	100%	61%	53%	81%	97%	73%	88%	100%	63%	82%	91%	75%

-25% all meat and dairy	Latvia	Lithuania	Lux	Malta	NL	Poland	Portugal	Romania	Slovakia	Slovenia	Spain	Sweden	UK	EU-27
Cereals	100%	115%	163%	108%	145%	116%	116%	117%	100%	111%	122%	131%	132%	125%
Dairy	82%	62%	61%	84%	55%	100%	82%	60%	100%	72%	100%	55%	79%	75%
Beef	100%	100%	46%	72%	75%	100%	75%	100%	100%	71%	88%	66%	72%	75%
Poultry	87%	71%	45%	62%	100%	76%	60%	79%	95%	87%	56%	99%	53%	75%
Pig	100%	71%	72%	94%	91%	58%	75%	100%	100%	79%	58%	77%	100%	75%
Eggs	65%	88%	100%	61%	53%	81%	97%	73%	88%	100%	63%	82%	91%	75%

-50% beef &dairy	Latvia	Lithuania	Lux	Malta	NL	Poland	Portugal	Romania	Slovakia	Slovenia	Spain	Sweden	UK	EU-27
Cereals	120%	116%	154%	114%	163%	113%	124%	125%	100%	121%	113%	145%	131%	128%
Dairy	55%	41%	41%	56%	37%	68%	55%	40%	100%	48%	68%	37%	53%	50%
Beef	100%	100%	23%	44%	47%	100%	47%	100%	100%	44%	58%	39%	45%	50%

-50% pig&poultry&eggs	Latvia	Lithuania	Lux	Malta	NL	Poland	Portugal	Romania	Slovakia	Slovenia	Spain	Sweden	UK	EU-27
Cereals	114%	119%	141%	113%	119%	123%	119%	107%	110%	112%	137%	119%	129%	122%
Poultry	58%	47%	30%	41%	68%	51%	40%	52%	63%	58%	37%	66%	35%	50%
Pig	69%	45%	46%	62%	60%	36%	49%	69%	66%	52%	36%	50%	78%	50%
Eggs	43%	58%	78%	40%	35%	54%	65%	48%	59%	74%	42%	55%	61%	50%

-50% all meat and dairy	Latvia	Lithuania	Lux	Malta	NL	Poland	Portugal	Romania	Slovakia	Slovenia	Spain	Sweden	UK	EU-27
Cereals	134%	135%	195%	127%	182%	136%	143%	132%	110%	133%	150%	163%	160%	149%
Pulses	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Dairy	55%	41%	41%	56%	37%	68%	55%	40%	100%	48%	68%	37%	53%	50%
Beef	100%	100%	23%	44%	47%	100%	47%	100%	100%	44%	58%	39%	45%	50%
Poultry	58%	47%	30%	41%	68%	51%	40%	52%	63%	58%	37%	66%	35%	50%
Pig	69%	45%	46%	62%	60%	36%	49%	69%	66%	52%	36%	50%	78%	50%
Eggs	43%	58%	78%	40%	35%	54%	65%	48%	59%	74%	42%	55%	61%	50%

'Nitrogen on the Table' assesses the influence of food choices on nitrogen pollution, greenhouse gas emissions and land use in Europe.

The European Nitrogen Assessment (ENA) identified agriculture as a major source of nitrogen losses. The current total loss of reactive nitrogen from European Union agriculture amounts to an estimated 6.5 - 8 million tonnes per year, representing around 80 % of reactive nitrogen emissions to the EU environment. These nitrogen losses affect our air quality (through ammonia and its links to particulate matter), water quality (through nitrates), biodiversity and soil quality (through increased nitrogen deposition) and greenhouse gas balance (through the release of nitrous oxide).

The present ENA Special Report has been prepared by the Expert Panel on Nitrogen and Food of the UNECE Task Force on Reactive Nitrogen. It examines nitrogen and other pollution losses from the food system and assesses the potential impacts of alternative diets on emissions of nitrogen to air and water. It then considers the potential impacts on land-use change and associated greenhouse gas emissions.

The study finds that reductions in reactive nitrogen emissions associated with decreased intake of meat and dairy products would have substantial benefits, not only within the EU, but also at continental and global scales. The scenarios also match to consumption patterns that are better aligned with international dietary recommendations.

The Task Force on Reactive Nitrogen is a component body of the UNECE Convention on Long-Range Transboundary Air Pollution and has "*the long-term goal of developing technical and scientific information, and options which can be used for strategy development across the UNECE to encourage coordination of air pollution policies on nitrogen in the context of the nitrogen cycle and which may be used by other bodies outside the Convention in consideration of other control measures*" (www.clrtap-tfrn.org).