



Contents lists available at ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha



Food choices, health and environment: Effects of cutting Europe's meat and dairy intake

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ARTICLE INFO

Article history:

Received 3 April 2013

Received in revised form 6 February 2014

Accepted 7 February 2014

Keywords:

Human diet

Dietary change

Livestock

Reactive nitrogen

Land use

Greenhouse gas emissions

ABSTRACT

Western diets are characterised by a high intake of meat, dairy products and eggs, causing an intake of saturated fat and red meat in quantities that exceed dietary recommendations. The associated livestock production requires large areas of land and lead to high nitrogen and greenhouse gas emission levels. Although several studies have examined the potential impact of dietary changes on greenhouse gas emissions and land use, those on health, the agricultural system and other environmental aspects (such as nitrogen emissions) have only been studied to a limited extent. By using biophysical models and methods, we examined the large-scale consequences in the European Union of replacing 25–50% of animal-derived foods with plant-based foods on a dietary energy basis, assuming corresponding changes in production. We tested the effects of these alternative diets and found that halving the consumption of meat, dairy products and eggs in the European Union would achieve a 40% reduction in nitrogen emissions, 25–40% reduction in greenhouse gas emissions and 23% per capita less use of cropland for food production. In addition, the dietary changes would also lower health risks. The European Union would become a net exporter of cereals, while the use of soymeal would be reduced by 75%. The nitrogen use efficiency (NUE) of the food system would increase from the current 18% to between 41% and 47%, depending on choices made regarding land use. As agriculture is the major source of nitrogen pollution, this is expected to result in a significant improvement in both air and water quality in the EU. The resulting 40% reduction in the intake of saturated fat would lead to a reduction in cardiovascular mortality. These diet-led changes in food production patterns would have a large economic impact on livestock farmers and associated supply-chain actors, such as the feed industry and meat-processing sector.

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1. Introduction

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 dietary recommendations (Linseisen et al., 2009; Ocké et al., 2009; Pan et al., 2012). The consumption of meat, dairy and eggs is increasing, worldwide (FAO, 2006; Kearney, 2010), and

this will aggravate the environmental impact related to livestock production (Bouwman et al., 2013; Godfray et al., 2010; Steinfeld et al., 2006; Thornton, 2010). Concerns about animal welfare, reactive nitrogen and greenhouse gas emissions have stimulated public debate in Europe about eating less meat and dairy products (Deckers, 2010a,b; Deemer and Lobao, 2011; Freibauer et al., 2011; Garnett, 2011; Krystallis et al., 2012). This debate draws on a growing consensus in the scientific community about changing 'western' diets possibly having a positive outcome for both human health and the environment (Friel et al., 2009; Godfray et al., 2010; Hawkesworth et al., 2010). There have been numerous life-cycle

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<http://dx.doi.org/10.1016/j.gloenvcha.2014.02.004>

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analyses (de Vries and de Boer, 2010; Nijdam et al., 2012; Weiss and Leip, 2012; Leip et al., 2013), input–output analyses (Tukker et al., 2011) and global assessments (Popp et al., 2010; Stehfest et al., 2013, 2009) of the environmental impact related to meat and dairy consumption and dietary changes. However, these studies do not address the implications for the structure of regional agriculture, even though the expected resource use and environmental impacts of change will manifest themselves the most on that scale. Against this background, the central question being addressed in this article is that of what the consequences would be for the environment and human health if consumers in an affluent world region were to replace part of their consumption of meat, dairy produce and eggs with plant-based foods? This question was explored with a focus on the 27 EU Member States (EU27), a region with a high per-capita intake of animal protein, compared with many other parts of the world.

2. Method and data

2.1. Overview

For this study, a large number of calculation steps were taken to arrive at the final estimates (Fig. S1). To investigate the consequences of dietary change based on reductions in the consumption of meat, dairy and eggs, we developed six alternative diets for the EU27. These diets consist of a 25% or 50% reduction in the consumption of beef, dairy, pig meat, poultry and eggs, which is being compensated by a higher intake of cereals (Table 1, S1). This article only presents the results for the alternative diets with a 50% reduction; those for the 25% reduction option are presented in the supplementary material. We assumed that a reduction in the consumption of meat, dairy and eggs would have a proportional effect on EU livestock production. Fewer livestock would mean a lower demand for feed, including forage (mostly grass and forage maize). The alternative diets therefore would result in opportunities to change the use of some of the land that is currently needed for feeding animals. We explored two scenarios for land that would be affected by such production changes: a greening world and a high prices world. We assessed the effects on greenhouse gas and reactive nitrogen emissions, land use, the use of mineral fertilisers and manure, and on N deposition in Europe. We did not apply a specific time period in the implementation of the alternative diets and land-use scenarios. Furthermore, we only used biophysical models and data to quantify the environmental effects, and only assessed the direct environmental effects on agriculture within the EU. Effects in other regions or other parts of the food chain (e.g. processing, transport, production of mineral fertilisers) were not quantified.

2.2. Alternative diets

We used statistics as compiled by the Food and Agriculture Organization of the United Nations to determine the quantity of commodities used by each EU Member State's food system in 2007

(FAO, 2010). These data represent the national supply. The commodities were aggregated into 12 major commodity groups. However, not all food is consumed, as certain parts are not edible (e.g. bones, peelings) and losses occur during processing, and in retail and preparation (FAO, 2010). Information about these food commodity losses were obtained from the literature (Kantor et al., 1997; Quested and Johnson, 2009). In an alternative approach to determining food losses, we compared FAO supply data with results from national studies that monitor actual food intake (Elmadfa, 2009). The two approaches yielded similar estimates on the relationship between supply and intake. This study is based on data on food commodities as they enter the post-farm food chain. These commodities are consumed both in their basic form (such as eggs or sugar), as well as in processed foods (for example, in bakery products). A 50% reduction diet would cause both forms of consumption to decrease.

The alternative diets that were examined showed contrasting effects of ruminant and monogastric livestock production on resource use and the environment. The production of pig meat, poultry meat and eggs is based almost entirely on cereals and soybean meal, while Europe's grasslands are a major source of feed in the production of beef and dairy. In addition, the literature on life-cycle assessments of food products consistently shows that monogastric meats have smaller carbon and nitrogen footprints than beef (Leip et al., 2013; Lesschen et al., 2011; Weiss and Leip, 2012). The 50% level of reduction was chosen for two reasons. It was expected that, under a 50% reduction in livestock production, most permanent grasslands and domestic by-products would still be used in the agricultural system. With regard to dietary composition, we expect that a 50% reduction in the consumption of livestock products would stay reasonably well within public health guidelines on the intake of proteins, micro-nutrients and vitamins. Maintaining a 50% share of livestock products in the human diet would accommodate a variation in diets among the population, as currently not all individual diets are well-balanced. If the average intake 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., 2013). These considerations, however, certainly do not imply that larger reductions would not be possible.

We assumed that the reduced intake of meat, dairy and eggs would be compensated by an increase in cereals, on the basis of food calorie intake. If the protein intake would drop below the recommended level, pulses (which are high in protein) were added to the scenario diet. The calculations were carried out for each EU Member State and aggregated to the EU27 level. Reductions in consumption were not uniformly applied, but varied per country. In countries with currently low rates of meat and dairy consumption, a lower reduction was assumed, with higher reduction rates for other countries. Consumption levels of sheep and goat meat were maintained at current levels in our alternative diets, because of their role in conserving extensive grasslands in their present state, as these often have both a high biodiversity and

Table 1

Evaluated alternative human diets and corresponding livestock production.

Alternative diet	Human consumption	Livestock production
Reference	Present situation	Present situation
Reference–BF ^a	Present situation	Present situation
–50% beef and dairy ^b	Reduction of 50% in beef and dairy consumption	Reduction of 50% in cattle (in the number of animals)
–50% pig and poultry	Reduction of 50% in pig meat, poultry and egg consumption	Reduction of 50% in pig and poultry production (in the number of animals)
–50% all meat and dairy	Reduction of 50% in all meat, dairy and egg consumption	Reduction of 50% in cattle, pig and poultry production (in the number of animals)

^a BF = balanced (nitrogen) fertilisation: fertilisation according to crop requirements/recommendation.

^b The supplementary material also includes the results for three variants of a 25% reduction in consumption: beef and dairy; pig and poultry; and all meats and dairy.

cultural value (Paracchini et al., 2008). Sheep and goats depend on these extensive grasslands to a relatively larger degree than do beef and dairy cows (Lesschen et al., 2011). Furthermore, also fish consumption was assumed to remain on current levels. FAO data on consumption were also used for quantifying the intake of saturated fats, calories and proteins (Westhoek et al., 2011).

2.3. Livestock production, feed use and land use

The assumption was made that a reduction in the EU consumption of meat, dairy and eggs would have a proportional effect on EU livestock production, as fewer livestock require less feed. Data on current feed use were derived from the CAPRI model (Lesschen et al., 2011; Weiss and Leip, 2012; Leip et al., 2013). Calculations were done on a country level and subsequently aggregated to EU27 level (Lesschen et al., 2011). A proportional reduction was applied over the four main feed components (protein-rich feeds, energy-rich cereals, roughage, and forage maize). These reductions were based on the energy content of the different feeds and adjusted, where needed, to compensate for either too high or too low N (protein) content in total feed. All calculations were done per animal category and per country. The amounts in domestic by-products used as feed from, for example, oil and beer production, were kept at a current level. Thus, imports (such as soybean meal) were reduced more than proportionally. For the 'roughage' component, production was assumed to primarily take place on permanent grassland, therefore reducing the need for arable land or temporary grassland for this purpose.

2.4. 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 the European food system, thus opening up opportunities for land to be used for other purposes. We examined the effects of an alternative use of this land, according to two contrasting land-use scenarios: *high prices* and *greening*. The *high prices* scenario assumes a high global demand for food and an agricultural sector that is geared to produce (and export) as much cereal as possible. This means that cropland that is presently used for forage (e.g. maize), temporary grassland and some fertilised permanent grassland, but which would no longer be needed for feed production, could be converted into arable land for cereal production. The *greening* scenario assumes that arable land previously used in the production of animal feed (e.g. wheat and maize) and temporary grassland is converted to perennial bio-energy crops, such as canary reed grass, switchgrass, miscanthus, and poplar or willow, depending on the location. All permanent grassland is assumed to be maintained and N fertilisation to be reduced to a level commensurate with the lower required production level, in turn resulting in lower N emission levels and an increase in biodiversity.

2.5. Nitrogen cycle and greenhouse gas emissions

The changes in livestock numbers, feed and land use were fed into the MITERRA-Europe model. MITERRA-Europe is an environmental impact assessment model that calculates emissions of N, such as N₂O, NH₃, NO_x and NO₃, and greenhouse gases, such as carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O), 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 CAPRI (Common Agricultural Policy Regionalised Impact) (Britz and Witzke, 2012) and GAINS (GHG-Air pollution Interaction and Synergies) (Klimont and Brink, 2004) models, supplemented with an N

leaching module, a soil carbon module and a module on mitigation measures. Input data consist of activity data (e.g. on livestock numbers, crop areas), spatial environmental data (e.g. on soil and climate) and emission factors (IPCC and GAINS). The model includes measures to mitigate greenhouse gas and NH₃ emissions, as well as NO₃ leaching.

The reference year is 2004, which is the base year currently used by the CAPRI model. All the statistical input data are based on three-year averages over the 2003–2005 period. The main input data for the MITERRA-Europe model are on crop areas, animal numbers and feed use, on NUTS-2 (county or provincial) level. Data on crop areas and feed use were taken directly from the CAPRI model and are based on Eurostat statistics. Data on animal populations relate to countries and were obtained from the GAINS model. Livestock populations were distributed over the NUTS-2 regions according to CAPRI livestock data. Data on annual N fertiliser consumption were collected from statistical data from the Food and Agriculture Organization (FAO, 2010).

2.6. N flows

Country-specific N livestock excretion rates were obtained from the GAINS model (Klimont and Brink, 2004). The total manure N production was calculated on the NUTS 2 level, using the number of animals and the N excretion per animal, then correcting for N losses in housing and storage. Manure was distributed over arable crop fields and grasslands according to Velthof et al. (2009), taking into account the maximum manure application of 170 kg N ha⁻¹ from the Nitrates Directive, or a higher application for countries that had been granted a derogation. Mineral N fertiliser was distributed over crops relative to their N demand, taking account of the amount of applied manure and grazing manure and their respective fertiliser equivalents (Velthof et al., 2009). The N demand was calculated as the total N content of the crop (harvested part plus crop residue), multiplied by a crop-specific uptake factor, set at 1.0 for grass and perennial bio-energy crops and 1.1 and 1.25 for cereals and other arable crops, respectively (Velthof et al., 2009). The quantities of mineral fertiliser needed under the alternative diet scenarios were not only compared to the present use, but also to the quantities that would be needed under a balanced N fertilisation (BF) scenario (Oenema et al., 2007; Velthof et al., 2009). Balanced N fertilisation means that N fertilisation equals the uptake by the plant during growth, corrected by the crop-specific uptake factor. This approach was justified as the input of animal manure was reduced under the alternative diets. In order to sustain arable production, an increase in mineral fertiliser may therefore be needed. Further N input includes biological N fixation, which was estimated as a function of land use and crop type (legumes), and N deposition that was derived on NUTS 2 level, from the European Monitoring and Evaluation Programme (EMEP).

NH₃ emissions from livestock manure occur during housing, manure storage, after application to the soil, and from pastures. Country-specific emission factors and estimates of the efficiency of ammonia abatement measures were taken from the GAINS model (Klimont and Brink, 2004). N₂O emissions from agriculture consist of emissions from manure storage and agricultural soils. The latter consist of (i) direct soil emissions after the application of mineral fertiliser and animal manure, and indirect emissions from crop residues, (ii) emissions from urine and dung excreted during grazing, and (iii) indirect emissions from nitrogen that is lost through leaching and run-off, and from volatilised and re-deposited N. All N₂O emissions were calculated using emission factors from the IPCC, 2006 guidelines. The emission factor for NO_x was derived from van Ittersum and Rabbinge (1997) and was set at 0.3% of the N input.

N leaching was calculated by multiplying soil N surplus by a region-specific leaching fraction, based on soil texture, land use, precipitation surplus, soil organic carbon content, temperature and rooting depth. Surface run-off fractions were calculated on the basis of slope, land use, precipitation surplus, soil texture and soil depth (Velthof et al., 2009).

The effect of reduced ammonia emissions from agriculture on N deposition was assessed using the GAINS model. The GAINS model describes the interrelations between these multiple effects and pollutants (sulphur dioxide (SO₂), nitrogen oxide (NO_x), particulate matter (PM), volatile organic compounds (NMVOC), NH₃, CO₂, CH₄, N₂O, and F-gases) that contribute to these effects on a European scale (Amann et al., 2011). The activity data for the selected scenario were provided by national experts; thus improving the quality of the national input, while other parameters, such as emission factors and abatement technology implementation rates, were taken from the European scenario. Input data for the activity change in the proposed scenarios were obtained from the MITERRA-Europe model, as described above. The level of oxidised N deposition and averaged area critical load exceedances were based on outcomes of the GAINS model.

2.7. Greenhouse gas emissions

Data on methane (CH₄) emissions used in the MITERRA-Europe model were derived from European regional livestock numbers and IPCC (2006) emission factors. Changes in land use and land management will influence soil organic carbon (SOC) stocks. Following the IPCC (IPCC, 2006) approach, the amount of SOC in mineral soils was calculated by multiplying a default reference value by relative stock change factors for land use, soil management and carbon input. The reference soil carbon stock is a function of soil type and climate region for the upper 30 cm of soil. IPCC assumes a period of 20 years for soil carbon stocks to reach a new equilibrium. Relative stock change factors were assigned for each crop activity (Nemecek et al., 2005). Changes in soil carbon stocks caused by changes in cropping shares were calculated and divided by 20 years to obtain annual CO₂ emissions. All greenhouse gas emissions are expressed in CO₂ equivalents, based on estimates of the potential 100-year global warming values relative to carbon dioxide (CO₂: 1, CH₄: 25 and N₂O: 298) (IPCC, 2006).

3. Results

3.1. Dietary changes and effects on human health

We calculated that in diets with a lower consumption of meat, dairy and eggs, the average consumption of cereals increases by 10–49% (Table 2, S2). The protein intake in the alternative diet is up to about 10% lower than under the reference scenario (Fig. 1a, S2a). Nevertheless, the mean protein intake is still at least 50% higher than the dietary requirements set out by the World Health Organization (WHO) (WHO, 2007). Additional pulses to provide a sufficient supply of proteins were needed under only one

alternative diet in one country (Hungary). Under the alternative diets, the intake of saturated fats is reduced by up to 40% (Fig. 1b, S2b). This proportion is close to the recommended maximum dietary intake (RMDI) proposed by the World Health Organization (WHO, 2003, 2008a, 2011), corresponding to an RMDI for saturated fats of 25.5 g per day, in Europe (WHO, 2003). These dietary changes reduce average red meat consumption from the current 89 g per person per day to 46 g (Fig. S3) under a 50% reduction in all meats and dairy foods. This brings diets in line with intake levels advised by the World Cancer Research Fund (a maximum of about 70 g per person, per day) This maximum is equivalent to a population average of 43 g of red meat per person, per day (WCRF and AICR, 2007).

Significant health benefits are expected to result from a lower intake of saturated fats and red meat, as diets rich in saturated fats are associated with an increased risk of cardiovascular diseases (CVD) and stroke. In the World Health Organization European region, currently, around 25% of total mortality can be attributed to CVD and 15% to stroke, in total about 3.8 million deaths, annually (WHO, 2008b). In terms of disease burden, these attributable fractions are around a respective 11% and 6.5% of total annual loss of disability-adjusted life years (DALYs, an aggregate of years of life lost and years spent in reduced health) (WHO, 2008b). There are also indications that the intake of red meat is associated with an increased risk of colorectal cancer (CRC) (Norat et al., 2002; Chan et al., 2011, Pan et al., 2012). Mortality and the disease burden of CRC in the World Health Organization European region are substantially lower than the CVD burden (250,000 annual deaths; 2.5% of total mortality; 1.4% of total annual DALYs). The reduction in livestock production and subsequent reduction in emissions may also have indirect health benefits, related to a lower use of antibiotics (Marshall and Levy, 2011) and improved water quality (nitrates) (Powlson et al., 2008) and air quality (related to the role of NH_x in particulate matter formation) (Moldanová et al., 2011).

3.2. Effects on feed demand and land use

The reduction in livestock production will lead to a reduced demand for feed. The total demand for feed will be reduced from the baseline use of ~520 to ~285 million tonnes, under a 50% reduction in all meat and dairy production (Table S3). The need for forage grown on arable land will be reduced by 90% – which constitutes the greatest reduction. This is a result of the assumptions that favour forage from grassland over forage from arable land. The 50% meat and dairy reduction diet gives a 75% reduction in soymeal use, a 46% reduction in energy-rich feed imports and a 52% reduction in feed cereal use. Under the diets in which only pig and poultry production is reduced, the use of grass, fodder maize and other fodder grown on arable land is similar to that under the baseline scenario. The reduction in cereal use is larger under alternative diets with a reduction in pig and poultry consumption than those with a reduced level of beef and dairy consumption.

Table 2

Average per-capita consumption of selected^a food commodity groups under the reference diet and the three alternative diets (g person⁻¹ day⁻¹).

	Reference	–50% beef and dairy	–50% pig and poultry	–50% all meat and dairy
Cereals	256	326	311	382
Pulses	4	4	4	4
Dairy (expressed as milk)	554	277	554	277
Beef	23	12	23	12
Poultry	32	32	16	16
Pig meat	62	62	31	31
Sheep and goat meat	3	3	3	3
Eggs	28	28	14	14

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

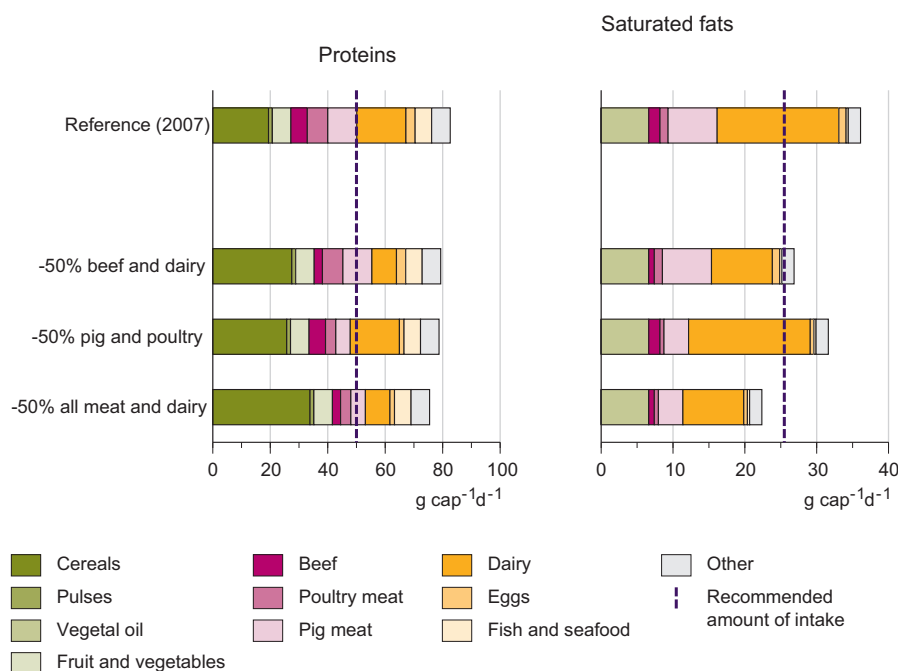


Fig. 1. Effects of dietary changes on the average daily per-capita intake of proteins and saturated fats. (a) Population average daily protein intake in the EU27, in g day^{-1} , for the various food commodity groups, under the reference (2007) scenario and in case of the six alternative diets in which meat and dairy consumption is reduced step by step. (b) Idem, for saturated fats.

As the demand for animal feed declines, land currently used in feed production will become available for alternative purposes. In the *high prices* land-use scenario, with a 50% reduction in all meat and dairy production, 9.2 million hectares of mainly intensively managed permanent grassland and 14.5 million hectares of arable land are no longer required for feeding European livestock (Table 3, S4, Fig. S4). This land, instead, will be used for additional cereal production, leading to an increase in EU cereal acreage from 60 to 84 million hectares and in the net export of cereals from 3 to 174 million tonnes (Fig. S5). In the *greening* land-use scenario, around 14.5 million hectares are used in the cultivation of perennial energy crops.

The demand for food cereals will increase when the consumption of meat and dairy is reduced. Feed demand, however, would decrease by more (Fig. 2). In combination with the increased availability of land, domestic cereal production would become much larger than domestic demand, leading to an increase in cereal exports. As a consequence of the dietary changes, the average amount of cropland used within the EU for domestic food production would be reduced from 0.23 to 0.17 hectares per EU citizen.

3.3. Effects on reactive nitrogen emissions

A reduction in livestock production would lead to a significant decrease in the reactive nitrogen input and losses across Europe

(Fig. 3, Table S5). In the *greening* scenario, under a 50% reduction in all meat and dairy consumption, fertiliser input is reduced from 11.3 to 8.0 million tonnes N yr^{-1} , while emissions of nitrates to groundwater and surface water and ammonia (NH_3) to air both are reduced by 40%, compared with the reference situation. The level of nitrogen use efficiency in the EU food system as a whole would improve, from 22% in the reference situation to 41% under the *greening* scenario and to 47% under the *high prices* scenario. The nitrogen use efficiency here is defined as the N output in food crops and livestock products as a percentage of total N input (Oenema et al., 2009).

Results indicate that at the current level of livestock production, changes in the emission of reactive nitrogen from European agriculture on an EU scale closely relate to relative changes in the magnitude of livestock production. Reducing N emissions through dietary change would lead to a cascade of positive effects (Galloway et al., 2008). Reductions in nitrate leaching and ammonia emissions and deposition would be the highest in regions with intensive livestock production. Under the 50% reduction diet, average NH_3 emissions and NH_x deposition in the EU would be reduced by about 40%, resulting in a reduction in the exceedance of critical load thresholds for adverse reactive nitrogen effects on ecosystems (Fig. 4). Reduced nitrogen emissions will lead to an improvement in water quality and to lower risks of eutrophication. The total N load to rivers and seas for the EU27 in 2005 was estimated at 4.6 million tonnes, 55% of which

Table 3
Agricultural land use in the EU under the different alternative diets and land-use scenarios (in million ha).

	Land-use types for which the area remains constant under both <i>Greening</i> scenario scenarios			<i>High prices</i> scenario				
	Semi-natural grassland	Other arable crops	Fodder on arable land	Managed grassland	Cereals	Energy crops	Managed grassland	Cereals
Reference	21.3	43.7	18.9	44.2	59.9	0.0	44.2	59.9
-50% beef and dairy	21.3	43.7	4.3	44.2	59.9	14.5	35.0	83.6
-50% pig and poultry	21.3	43.7	18.9	44.2	59.9	0.0	44.2	59.9
-50% all meat and dairy	21.3	43.7	4.3	44.2	59.9	14.5	35.0	83.6

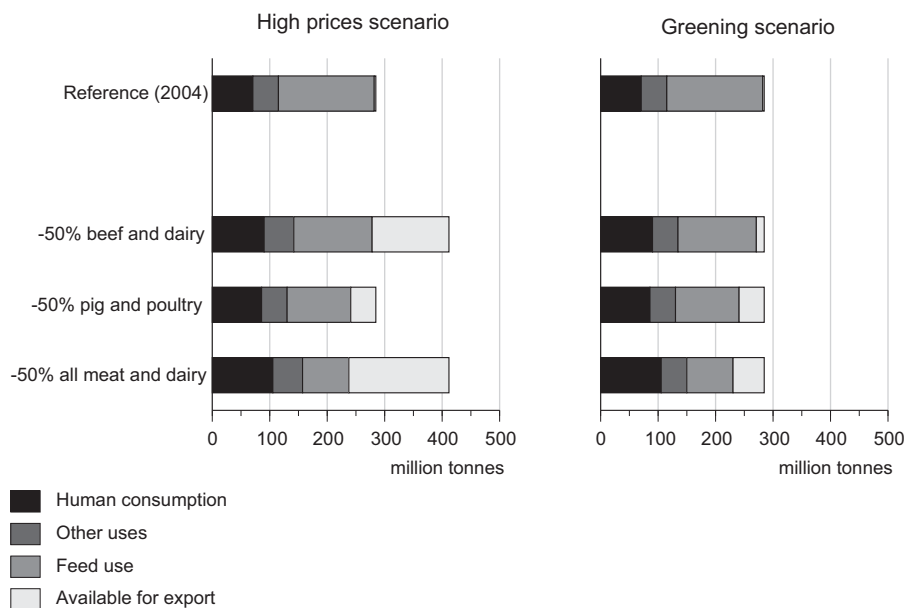


Fig. 2. Cereal demand in the EU as affected by the alternative diets under two land-use scenarios.

from agricultural sources (Grizzetti et al., 2012). Due to human activities, nitrate concentrations in major European rivers have increased by as much as a factor of 10, during the 20th century. Although improvements have been made in recent decades, the eutrophication threshold value for nitrate in fresh water and marine systems is commonly exceeded. Similarly, the World Health Organization nitrate standard for drinking water (50 mg/L) is commonly exceeded in shallow phreatic groundwater (van Grinsven et al., 2012).

3.4. Effects on greenhouse gas emissions

Net greenhouse gas emissions directly related to EU agricultural production (excluding pre-farm and post-farm emissions) will decrease by 42%, from 464 to 268 million tonnes CO₂ eq yr⁻¹ under a 50% reduction in all meat and dairy consumption, in combination with the *greening* scenario (Fig. 5, S6). Under the *high prices* scenario, net greenhouse gas emissions will decrease by 19%, to 374 million tonnes CO₂ eq yr⁻¹. Reductions in CH₄ emissions are similar under the two scenarios, as these are directly coupled to the number of ruminants, which form the largest component in the greenhouse gas emission reduction (108 million tonnes CO₂ eq yr⁻¹). N₂O emissions will be reduced to a lesser extent because they are mainly linked to turnover processes of reactive nitrogen in soils that are associated with both livestock and arable farming. Under the *high prices* scenario, tillable grassland in the EU is converted into arable land, leading to additional CO₂ emissions from decreasing soil carbon stocks. These emissions would contribute 59 million tonnes CO₂ yr⁻¹, when averaged over a period of 20 years. Under the *greening* scenario, soil carbon sequestration occurs as the perennial biomass crops increase levels of carbon in the plant–soil system that are equivalent to 36 million tonnes CO₂ yr⁻¹, again averaged over 20 years. Reductions in emissions outside the EU, related to the lower demand for soybean and the higher export of cereals, were not included in our calculations but would provide a substantial additional benefit (Stehfest et al., 2013). The annual amounts of biomass for energy produced under the *greening* scenario represents 2.3 EJ or 54.1 million tonnes oil equivalent, equal to roughly 3% of EU's current primary energy intake (Eurostat, 2011).

4. Discussion and conclusion

Our study explored the consequences for human health and the environment of replacing 25–50% of current meat, eggs and dairy consumption in the EU with plant-based foods, and assuming that consumption and production of livestock products in Europe remain tightly linked. Reducing livestock production by 50% will lead to large structural changes within the EU agricultural sector, resulting in a reduction in the emission of greenhouse gases (25–40%) and reactive nitrogen (around 40%). Due to reduced feed demand, the use of imported soybean meal would drop by 75% and the EU would become a large net exporter of basic food commodities. Given increasing global food demand, the beneficial environmental effects of dietary changes within the EU, therefore, would extend beyond its territory. The results reflect the large share of livestock production in the total environmental impact of EU agriculture, as was already revealed for greenhouse gas (Lesschen et al., 2011; Weiss and Leip, 2012; Leip et al., 2013).

This study was based on a number of important assumptions. The first assumption is on the lower meat, eggs and dairy intake being compensated by a higher cereal intake while maintaining total dietary energy intake. As far as health impacts are concerned, this is a relatively conservative approach. First of all, the current average per-capita energy intake is higher than needed. Full replacement of the calorific contents of livestock products, therefore, will not be necessary. Second, additional health benefits could be expected if this energy replacement were to be partly in the form of fruits and vegetables, since in most European countries the average intake of these is currently below the recommended level (Elmadfa, 2009). As far as environmental impacts are concerned, substituting wheat with other carbohydrate-rich commodities (e.g. potatoes) would yield similar effects, while the use of fruit and vegetables would lead to smaller environmental benefits. This is because, in general, the environmental effects (such as those of land use and greenhouse gas emissions per calorie) of fruits and vegetables are larger than those of cereals, but lower than those of dairy and meat (Garnett, 2013; Nemecek and Erzinger, 2005; Nemecek et al., 2005). We did not investigate the effects of the dietary changes on the intake of micro-nutrients. As the current intake of, for example, calcium and iron is already low

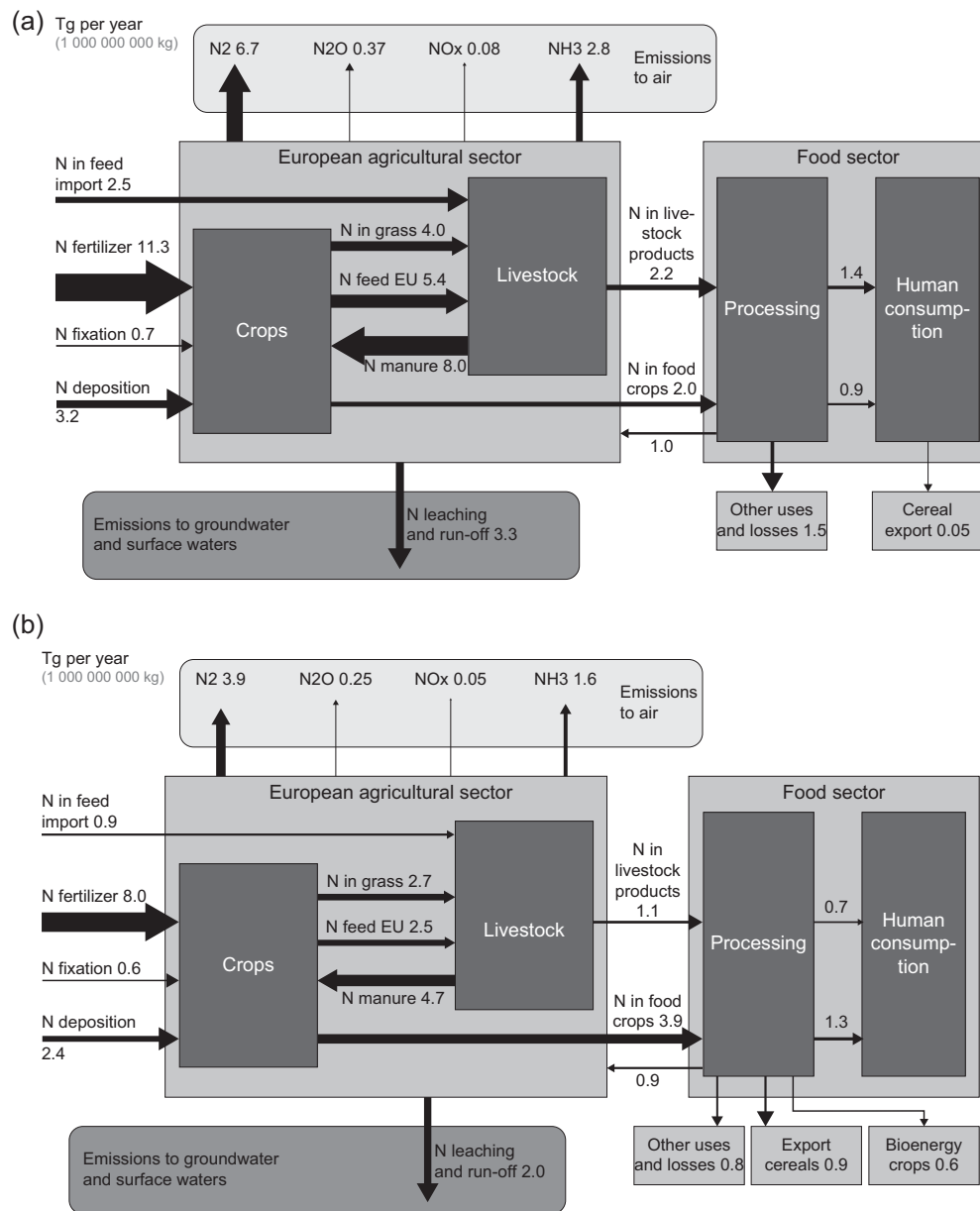


Fig. 3. Nitrogen flows (in Tg yr⁻¹) in the EU agricultural and food systems, under the reference scenario for 2004 (a) and in the case of the alternative diet with a 50% reduction in the consumption of meat, dairy and eggs, under the *Greening land-use* scenario (b).

in most EU countries (Elmadfa, 2009), this is certainly an aspect that requires further attention. In all diets, the average protein intake in the EU remains higher than required. Even with a 50% reduction in all animal products, the mean EU intake of proteins would still be more than 50% higher than would be required.

The second important assumption is on the reduction in meat, eggs and dairy consumption being followed by a parallel reduction in EU livestock production, meaning that the current tight link between production and consumption in Europe will be maintained. Instead of reducing production, EU farmers and the food industry could try to compensate for reduced domestic markets by increasing exports to other countries. If this happened, the environmental benefits of the consumption change would largely shift from within to outside the EU. As current production costs of many livestock products (except potentially for dairy products) are higher in the EU than in some other countries, such as in Brazil, Australia, the United States and Thailand, it is unlikely that the EU will become a significant net exporter of livestock products, as also

indicated by the assessment of similar scenarios by using economic models (Stehfest et al., 2013).

No explicit sensitivity analyses were performed, although the combination of dietary and land-use scenarios could be regarded as a sensitivity analysis. These alternatives show clear, plausible and largely linear outcomes for environmental effects. Previous research has shown that the uncertainty in absolute emission estimates as calculated by using the MITERRA-Europe model is relatively small on EU scale, due to cross-correlations and spatial aggregation (Kros et al., 2012). Uncertainty on the relative changes in emissions between the various alternative diets and scenarios will be even lower. The most sensitive parameter for the reactive nitrogen and greenhouse gas emissions will be the assumed alternative land use.

As stated in the methodology section, only biophysical models were used. Would the use of economic models have yielded different outcomes? And would it be possible to assess the economic effects on the agricultural sector and other economic

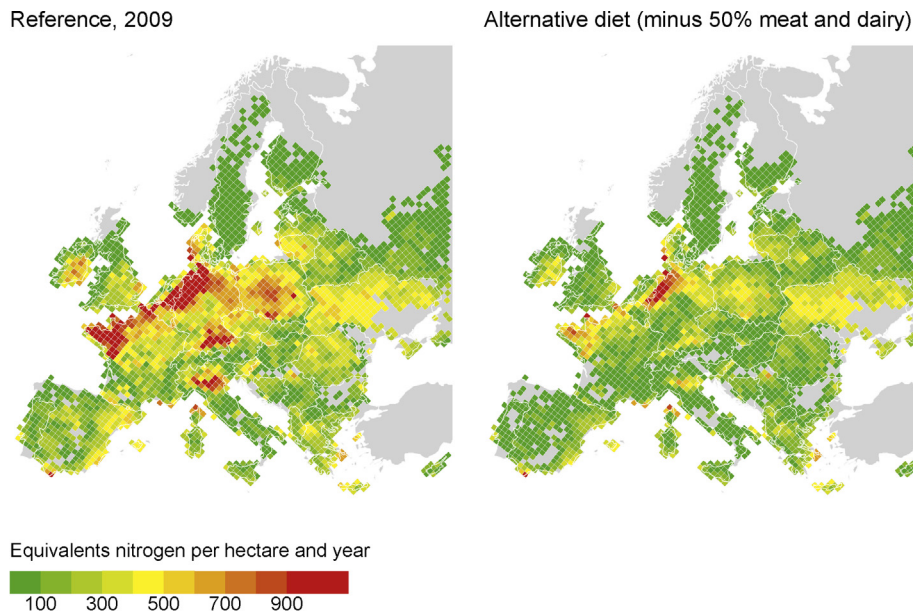


Fig. 4. Annual exceedance of the critical load for N deposition in $N\ ha^{-1}$ for natural ecosystems, under the reference scenario and the 50% less meat and dairy alternative diet under the *high prices* land-use scenario.

sectors of these dietary changes? Other studies (for example Stehfest et al., 2013; Lock et al., 2010) have assessed the environmental and economic impact of reduced meat and dairy consumption using economic models. It is clear from these studies that the use of economic models is not straightforward and is not as transparent as our approach, for two reasons. First, there is the effect of the choice of model to consider (Stehfest et al., 2013). Computable general equilibrium (CGE) models include all sectors, but usually in less detail, whereas partial equilibrium models (PE) only represent one sector (the agricultural sector) with everything having to be solved within this sector. PE models come up with different answers than CGE models, as within CGE models, labour and other production factors can move from one sector to another. Second, in order to force the models to simulate a reduced consumption of meat and dairy, consumption functions need to be altered. In the approach taken by Lock et al. (2010), who assessed

the effects for two countries, assumptions regarding the effect on trade had to be made. Stehfest et al. (2013) also showed that results largely would depend on how trade and trade policies are modelled.

The effects on the livestock sector will most likely be severe, especially if consumer preferences change rapidly. This is demonstrated by a study of the UK food system, using scenarios similar to ours. Audsley et al. (2010) showed that the reduction in the UK farm gate value of livestock from dietary change is not 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. However, if the attitude towards food were to change within society and people would opt for products with a higher added value, such as meat and dairy produced in systems with a higher level of animal

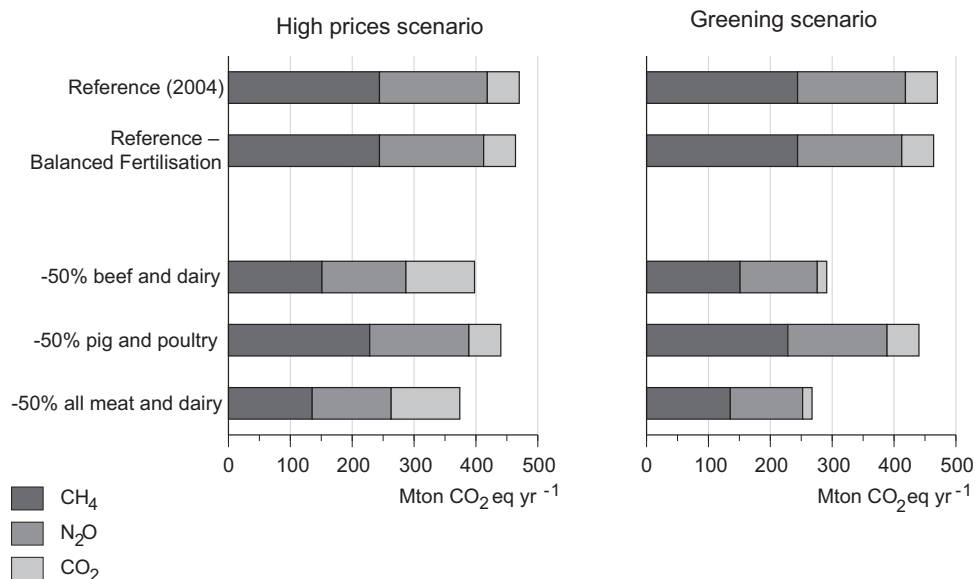


Fig. 5. Greenhouse gas emissions (in $Mton\ CO_2\ eq\ yr^{-1}$) from EU agriculture under the reference situation and the three alternative diets for the *high prices* scenario and the *greening* scenario. Balanced fertilisation is fertilisation according to crop requirements.

welfare, the economic effects on the livestock sector would be less severe. The farm-level economic impact of a change along these lines would crucially depend on the type of new output found for the land released from livestock production.

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. Consumer preferences may change 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 dietary shift could also be actively 'nudged' by governments, food manufacturers, retailers, restaurants and foodservice businesses (such as catering firms) when acting together to stimulate change. In addition, governments could also initiate changes through public procurement policies. Another policy approach could be to assess all policies in every policy field to determine which ones are promoting livestock production (including unintentional promotion) and subsequently to change those policies. A precondition for such an approach would be a sense of urgency among decision makers in wanting to reap the combined health and environmental benefits.

A more direct policy intervention could be that of making meat and dairy products more expensive, either by direct taxation (e.g. see Deckers, 2010a,b; Vinnari and Tapio, 2012), or by taxing the environmental effects (e.g. greenhouse gas emissions or nutrient use) caused by their production (e.g. see Wirsenius et al., 2011). Direct taxation could be motivated by either environmental or ethical (animal welfare) concerns. As meat and dairy have larger environmental footprints, the price of animal products would increase more strongly than that of plant-based products. Higher meat and dairy prices would very likely lead to lower consumption.

Meat and dairy prices may also increase within the EU as global demand increases further (FAO, 2006). These higher prices may lead to a lower consumption of meat and dairy within the EU. The same high prices, however, are also likely to work as a stimulus for expanding EU meat and dairy production, in turn resulting in higher export levels of meat and dairy products.

This study is one of the first to examine, in detail, the relationships between 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. It 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 (COM, 2011) highlights the food sector as a priority area for developing incentives for a healthier and more sustainable 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.

Acknowledgements

We thank the other members of the TFRN Expert Panel on Nitrogen and Food: C. Pallière, T. Garnett and J. Millward. We also thank G. de Hollander, D. Nijdam, L. Bouwman (all PBL) and S. Caldeira (JRC) for data, suggestions and support. We acknowledge

financial support through the UNECE Task Force on Reactive Nitrogen, including from the Netherlands Ministry (WOT-04-008-010) and the UK Department for Environment, Food and Rural Affairs, together with support from the European Commission for the NitroEurope IP, ÉCLAIRE, Legume Futures and AnimalChange projects.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.gloenvcha.2014.02.004.

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