EUROPEAN PARLIAMENT

Science and Technology Options Assessment

STOA

Implications of Global Trends in Eating Habits for Climate Change, Health and Natural Resources

Study

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SCIENCE AND TECHNOLOGY OPTIONS ASSESSMENT

Implications of Global Trends in Eating Habits for Climate Change, Health and Natural Resources

STUDY

Abstract

The study outlines the contribution of livestock production to climate change and health risks associated with high meat consumption. The natural resources required to produce animal-based and plant-based protein are contrasted and diets with different levels of both types of protein compared. Using world population projections, three scenarios based on different theoretical alternative consumption patterns are created to show possible requirements and greenhouse gas emissions for animal and plant protein production: "minimal" scenario (assumes consumption of animal protein only via milk and eggs); "optimal" scenario (assuming diets with a low meat intake) and "maximum" (baseline) scenario (current level of meat consumption extended to developing countries). Comments are made on alternative protein sources. Policy options are suggested.

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EXECUTIVE SUMMARY

The study was commissioned at the request of Science and Technology Options Assessment (STOA) Panel of the European Parliament (EP). It takes an interdisciplinary approach to review the effects of potential changes in global food consumption patterns on consumer health and the environment. The study was undertaken by Agra CEAS Consulting in the period January to April 2009 and comprises three parts reflecting the methodology used: (1) a literature review of the effects on health and the environment of present and future food consumption patterns; (2) a model to assess the effects of different scenarios for the development of consumption patterns; and (3) potential policy options for changing meat-intensive consumption patterns or mitigating the effects of these. A draft version of the report was presented at a conference organised by the STOA in the European Parliament on 30th March 2009[1].

Currently there are considerable differences in developed and developing world consumption patterns. Most notably, with annual per capita consumption of 80kg, an average developed world citizen consumes 2.5 times as much meat as a developing world citizen. Based on nutritional requirements, the scientific consensus strongly indicates that the developed world appears to be overconsuming meat products.

Going forward, based on current indications of a shift in diets, developing countries are expected to slowly adopt western consumption patterns. Increases in income and urbanisation are expected to drive rising per capita demand for meat in the developing world. Meanwhile, in the developed world meat consumption is expected to remain stable. The increase in per capita meat consumption in the developing world is a cause for concern particularly as almost all the projected global population increase of 40% (to 9.2 bln people) for the period 2005-2050 is attributable to the developing world. Overall therefore, world demand for meat is expected to grow substantially in the future.

The increased demand for meat will potentially place a great strain on the environment. This is due to the fact that the production of animal-derived food generally requires more resources than that of plant derived food. This is partly a result of the large amount of feed required to produce animal derived-food; for example, 7- 10kg of cereal feed are required to produce a single kilogram of beef. Among different types of livestock, ruminants generally place more stress on the environment due to relatively higher feed, water and fossil fuel requirements; they also create higher greenhouse gas (GHG) emissions than monogastrics although it is noted that if properly managed, grass-fed ruminants can have positive environmental effects through carbon sequestration. Overall therefore, a more plant-based diet is more environmentally friendly than a diet heavy in animal derived products.

[1] "Food for Thought: implications of global trends in eating habits for climate change, health and resource usage". 30th March 2009 10:30 – 12:30.

The consumption of meat products, in particular red meat is also associated with various negative health effects and associated public health and other costs. The health effects include an increased risk of heart disease, cancer, diabetes and obesity. On the other hand, underconsumption of animal-derived products is closely associated with malnutrition in poorer areas of the world where access to plant derived food is also very limited.

To assess some of the potential impact of shifts in consumption patterns, Agra CEAS set up a model to examine the effects of three different consumption scenarios for meat as defined by STOA; a maximum or baseline scenario (which assumes the spread of western consumption patterns), an optimal scenario (which assumes world meat consumption moves to what would be considered a healthy level) and a minimum scenario (which assumes a lacto-vegetarian diet). The results from the model suggest that, if western consumption patterns were to spread, global meat demand could more than double from the 2005 level of 251 mln tonnes to 563 mln tonnes by 2050. Assuming production methods and yield trends remain stable going forward and assuming the stock of suitable agricultural land available were to remain constant, production of this quantity of meat would potentially require 33% of global arable land for feed production, 58% of the world's surface as pastureland and up to the equivalent of 18% of 2050 oil production. GHG emissions from meat production would more than double from 2005 levels. Furthermore, an increase in the occurrence of cancer and cardiovascular disease and the health costs associated with these conditions would also be expected. As would be expected, results from the optimal and minimum meat consumption scenarios generate more moderate impacts both in terms of environmental and human health effects. It is important to note that the above figures should be read as providing a range of the orders of magnitude involved under the various possible scenarios, as one moves from a maximum (baseline) meat consumption scenario to an optimal and then to a minimum meat consumption scenario.

The report therefore highlights the point that the continuation and expansion of current meat intensive consumption patterns appear unsustainable. Furthermore, the wider substitution at worldwide level of meat with alternative animal derived products is currently unrealistic: fishing and aquaculture are not considered viable options for addressing the protein gap as seafood resources are already overexploited; and further research is required to make algae and in-vitro meat mass production viable. In view of this, the challenge is to reduce meat consumption and thereby approach the model's optimal scenario or to at least mitigate the adverse effects associated with meat production. Potential policy options to achieve this include: extending current legislation; using taxes and subsidies; mitigation through, for example, biogas production; increasing consumer awareness through meat-free days; and reducing demand through, for example, the increased substitution of meat in processed products.

1. INTRODUCTION

1.1. Background

Following on from previous projects, the Science and Technology Options Assessment (STOA) Panel of the European Parliament (EP) identified the need for an interdisciplinary approach linking the various implications for health and the environment of the eating habits of European consumers. Such an approach is considered to provide an essential overarching perspective to support EU policy-making in this area.

The implications of eating habits combine, on the one hand, the impact of demand for food on the use of natural resources with further environmental and energy use implications and, on the other hand, the potential health effects of different consumption patterns.

1.2. Aims and objectives

The aim of this research is to briefly address the potential impact of intensive livestock production on climate change and the potential health and environmental benefits from adopting a diet low in meat intake.

Accordingly, the detailed requirements of this study are to:

1. present information on needs for animal-derived vis-à-vis plant-derived food;
2. present information on requirements for land, water, feed and energy in different livestock production systems;
3. present information on the health risks linked to high meat consumption;
4. present information on the feasibility of cloned meat and other alternatives to animal protein;
5. calculate, where possible, the feed, water and energy requirements; socio-economic effects and greenhouse gas emission from livestock in three scenarios: "minimal", "optimal" and "maximum" level of animal protein consumption; and,
6. present policy suggestions which involve tackling greenhouse gas emissions from livestock and promotion of diets low in meat consumption.

1.3. Methodology and team

Our methodological approach to this study consisted of a desk based combination of a review of the relevant academic literature and data collection for the production of the various scenarios on animal protein consumption patterns. The Agra CEAS team conducting this work consisted of Mr. C. Caspari, Dr. Maria Christodoulou, Mr. John Nganga and Ms. Mariana Ricci and the work was undertaken in the period January-April 2009. The interim report was presented at a STOA seminar at the European Parliament on 30 March 2009 and this final report incorporates revisions made in the light of this meeting.

1.4. Report structure

In Section 2, in order to provide the context and background for the study we provide a succinct overview of the issues affecting the following key study elements:

- human nutrition;
- meat consumption trends;
- population and food demand projections;
- meat production systems;
- natural resources required and greenhouse gas emissions for both plant and meat production; and,
- health costs and risks linked to diets with a high meat intake .

Using this as a background we then present estimates of the required natural resources, socio-economic effects, GHG emissions and food requirements for each of the three animal protein consumption scenarios in Section 3. Possible areas for policy action designed to stimulate debate are put forward in Section 4. These are outlined under the headings of existing legislation, taxes and grants, mitigation techniques, and awareness and climate change.

2. DISCUSSION OF KEY FACTORS

2.1. Nutrition

2.1.1. Current consumption patterns

A review of international data indicates that there is a clear gap in food consumption patterns between developed and developing countries. Developed countries consume approximately 50% more food[2] by volume than developing countries, and a comparison of developed countries with least developed countries (LDCs) yields an even greater gap of more than 100% (Table 1). However, more noticeable than the difference in the overall consumption of food itself is the marked difference in the consumption of meat. With annual meat consumption per capita of 80kg, developed countries consume almost 10 times as much meat per capita as LDCs, where annual per capita meat consumption averages 9kg. The difference between developed and developing countries (28kg per capita per year) is smaller but there is still a multiple of 2.5. Ratios are similar if one compares milk consumption of developed countries with that of developing countries and LDCs. In contrast, differences between developed countries and developing countries/LDCs in the consumption of plant derived food are relatively small; developed country consumption is 414kg per capita per year compared with 404kg in developing countries, and 306kg in LDCs.

This difference in meat consumption (and in many cases also milk consumption) between developed and developing countries, is however expected to narrow. Economic growth fuels demand for meat in developing countries, while health concerns curb meat consumption in some developed countries. Data from the period 1990-2003 provides examples of this trend. In 1990 Japan consumed an average of 37kg of meat per capita. Growth in meat consumption over the period was slow, and Japanese meat consumption levelled off at 43kg per capita in 2000, remaining at this level to 2003. During the same period, Chinese meat consumption more than doubled from 25kg per capita in 1990 to 54kg per capita in 2003.

2.1.2. General nutritional requirements

As is highlighted by the extensive literature on the subject, the issue of nutritional guidelines is complex. Cultural traditions, lifestyles, genetic make-up and differences in requirements by age are some of the factors which make the adoption of uniform global nutritional guidelines unrealistic. As a result, nutritional recommendations, if provided at all, vary from country to country. Indeed, nutritional requirements can greatly differ even within a region. Thus for example, the European Food Safety Agency (EFSA) takes the view that EU wide dietary guidelines are not feasible due to the aforementioned differences. Aggregating nutritional requirements at an international level is therefore even more of a challenge.

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[2] Defined as meat, milk, eggs, fish, cereals, fruits, oilseeds, pulses, starchy roots and vegetables.

Furthermore, the guidelines which do exist for certain regions have been established on the basis of different methodological approaches and objectives, for example to define maximum safe intake limits of protein or an ideal balanced diet.

This said, the World Health Organisation (WHO) has published some guidance on nutritional requirements, described in the form of safe intakes. The precise safe intakes vary based on age, weight, and the characteristics of the food consumed (e.g. nutrient quality). Table 2 presents the WHO safe level of protein intake for adults (men and women), with the safe intake range varying between 33 and 66 grams per day depending on body weight. From these global safe intakes, WHO has developed food-based (rather than nutrient-based) dietary guidance for some specific regions of the world.

In the USA and Canada, nutritional requirements are outlined in a system of recommendations called “Dietary Reference Intakes” (DRI). These DRIs are generated by the Institute of Medicine of the US National Academy of Sciences (NAS). In the absence of relatively simple international nutritional guidelines, the DRIs provide the most reliable information which is readily available on nutritional requirements. Table 3 presents the macronutrient requirements listed in the DRIs.

According to the DRI, intake of dietary cholesterol, trans-fatty acids and saturated fatty acids should be kept as low as possible, while at the same time maintaining a nutritionally adequate and balanced diet. Broadly speaking, the recommended protein intake of the DRI is more or less in line with the WHO safe intake limits.

The DRIs are set to cover the requirements of 97-98% of American/Canadian population by age and gender group. In this context, there is no differentiation between the different lifestyles that people lead and the macronutrients that they require. The only difference in nutritional requirement caused by lifestyle is with more active people, taller people and people with higher Body Mass Indices (BMIs) having higher energy requirements. Furthermore, the DRIs do not differentiate between the levels of macronutrients required by people of different ethnic origins.

In a similar fashion to WHO with its regional dietary based guidelines, the USDA also provides food-based dietary guidance through a scheme called “My Pyramid”. This scheme splits foods into different groups, and provides recommended daily intakes for each group. For example, it is recommended that men consume between 156-184 g and women between 142-156 g of protein rich food per day. It is noted, however, the definition of protein-rich is not limited to meat; it includes other high protein foods such as eggs, nuts and beans.

2.1.3. The need for meat

One of the key roles of meat in the diet is to provide protein. Meat also helps in providing B vitamins including vitamin B12, iron and zinc and other micronutrients. While it is generally considered that meat assists in ensuring a good diet, it is not essential. Despite this, it is worth noting the advantages that meat has as a source of protein over plants. First proteins from meat products are 95-100% digestible, while proteins from plants are often less digestible; soybean and wholegrain cereal protein is generally 80-90% digestible, and beans and breakfast cereal protein may be only 50-80% digestible. Second, the range of amino acids in plant food is more limiting; more specifically, the amino acid lysine is often lacking in plant based protein.

Finally, the concentration of protein in animal derived products is generally (though not always) greater than the concentration in plant derived products. Table 4 shows meat, beans and nuts to be high in protein, for example chicken breast provides 29.8 grams of protein for every 100 grams consumed. In contrast, most non-bean and nut plant derived products are relatively low in protein. In summary, protein in meat is more easily extractable. Fish and aquaculture products also provide a good source of high quality protein (see section 2.6.1). That said, various authors[3] conclude that plant-based diets can provide sufficient protein both in terms of quantity and range of amino acids if properly managed.

Due to the link between protein and meat, protein intake may therefore provide an indication as to a reasonable level of meat consumption. The previous sub-section showed the WHO estimates for protein requirements to be in the range of 33-66g per day. Table 5 shows current levels of protein intake along with their sources as calculated by FAO Stat. It is worth noting that the method used by FAO Stat in calculating food consumption and protein intake may lead to some inaccuracy in estimates of protein consumption. In spite of this it is clear that, with an average protein intake of 92 grams per person per day, developed countries are exceeding the protein requirements set out by the WHO and the US DRIs. Indeed protein intake from animal derived products alone (53 grams per person per day) is near the upper limit of total protein requirements. The position with respect to developing countries and regions depends on the region. While in Latin America total protein intake is relatively high (76% of the developed country average), in Asia and Africa it is lower (68% and 58% respectively), and even lower in the LDCs (51%). Furthermore, the intake of protein from meat is considerably lower in developing countries, reaching only a minor fraction of the levels in developed countries (Table 5).

A preliminary range for 'optimal' meat consumption can be derived from a combination of the protein requirements identified above and the current protein intake patterns outlined in Table 5. On a world level, 19% of protein consumed comes from meat. In the developed world, this percentage is higher at 29% (with a further 28% coming from other animal products).

[3] For example, Young and Pellet (1994).

Taking an average of 25% protein from meat sources, and applying this to the protein requirements of 33-66 grams protein a day implies that between 8.25 and 16.5 grams of protein consumed would come from meat. This translates into meat consumption of between 60 and 120 grams per day (carcass weight) or 22 – 44kg per year.

A further indication of what might constitute an optimal meat consumption level comes from health research. While the medical profession commonly recommends that the western world should reduce the quantity of meat consumed because it is too high (confirmed by data on current protein intake in Table 5) there is very little by way of strict guidelines on the consumption levels which people should target. The absence of guidelines may well be due to the issue of attributing direct causality. Nonetheless, indications based on negative health effects reinforce the scientific consensus that the developed world consumes too much meat. For example, in 2007 the World Cancer Research Fund recommended that red meat (beef, pork and lamb) consumption be limited to 500g (cooked weight) per person per week in order to significantly reduce the risk of cancer. This is the equivalent of 725g raw meat per week, or 100g per day / 37.8kg per year. However, this recommendation does not include poultry consumption. The American Heart Association recommends an upper limit of 62.6kg of lean meat per year. Finally, McMichael et al. propose a global target of 90 grams per person per day, below the current global consumption level of 100 grams per person. Of this, no more than 50 grams should come from red meat products. This target is primarily based more on the environmental effects of meat consumption rather than nutritional needs, though health benefits from the global 90g target are also identified.

Examining optimal meat consumption from the perspective of under-consumption and malnutrition can provide further indicators as to the minimum level of meat which should be consumed to maintain a basic healthy diet, especially where the availability of other foods is limited such as in the developing world. According to the FAO, 20 g of animal protein per person per day is required to effectively combat malnutrition. This equates to an annual consumption of either: 33kg of lean meat (roughly 60kg carcass weight); or 45kg fish; or 60kg eggs; or 230kg milk. Assuming 50% of animal protein comes from meat (as is the current world picture), this would imply meat consumption of approximately 80 grams per person per day. At the very extreme of under-consumption, per capita consumption of less than 10kg of meat per year often leads to malnutrition in developing countries according to the FAO. The most likely reason for this is the inability to obtain the full range of amino acids from the limited range of plant products available.

To summarise, while indications point to the over-consumption of meat in the developed world, it is difficult to arrive at a single figure for optimal meat consumption. This is further complicated by the heterogeneity of regions in terms of both dietary habits and needs. Taking into account nutritional requirements and some of the health and environmental arguments put forward, McMichael's average global target of around 90 grams meat per person per day would appear to constitute a widely applicable 'optimal' level of consumption.

2.2. Global food demand and demographics

2.2.1. World population growth

One of the challenges that world agriculture, and meat production in particular will face is to address the continued growth of the world population. According to the UN Population Division, world population is expected to keep growing until 2070, when it will peak at around 9.5bn. This represents nearly a 50% increase on the 2005 population of 6.5bn. Table 6 provides an overview of the predicted development of world population. While the population of the developed world is expected to stay relatively stable, the population of the developing world is forecast to grow very rapidly from 5.3bn in 2005 to 8bn in 2050. The rapid increase in developing world population will have significant effects on the demand for meat, as will be discussed below.

2.2.2. Developing world trends: urbanization and increased wealth

The increase in population is only one of the factors which will lead to increased demand for meat from the developing world. There are two other key factors which will lead to higher demand; these are increased income and increased urbanisation.

The link between income and meat consumption is well documented. In simple terms, increased income per capita leads to higher meat consumption. Figure 1 shows the recent relationship between gross national income (GNI) and meat consumption on a global level. The curving trend line in Figure 1 demonstrates a further feature of the relationship between income and meat consumption: an increase in income in poorer country will have a stronger impact on meat demand than the same increase in a richer country. Two studies corroborate this relationship through income elasticities. The first of these studies, by Schroder et al. (1995) indicates that the elasticity of demand for meat is very high at low income levels, and decreases as income increases. This means, for example, that for a 1% change in income at the level of $1,725, demand for lamb will increase by 3.8%, for beef by 2.75%, for poultry by 1.8% and for pork by 1%. At the income level of $12, 075, the changes in demand will be lower, e.g. around 0.5% for poultry and pork, while demand for lamb will shrink by 0.4% (Table 7). A second study from the Economic Research Service of the USDA (1996) provides income elasticity estimates by country. While the elasticities quoted are lower than Schroeder’s, the trend is the same, that is to say demand for meat is more elastic at lower income levels than at higher income levels. For example, the average weighted income elasticity for meat in African countries is 0.78. This compares to 0.13 in developed North American countries. This identified relationship between income and meat consumption will be a major driver of demand for meat, as developing countries wealth increases and the developing country middle-class grows.

The effects of the income-meat consumption relationship will be further intensified by the expected faster rate of GDP growth in developing countries. Projections from the OECD (Table 8) show that US GDP per capita (PPP) is expected to grow at 1.6% per year between 2006 and 2025, with the EU-27 and EFTA growth expected to be a little higher at 2.3%.

During the same period, India's PPP GDP per capita is projected to grow by 6.3% per year, China's by 6.1%, Russia's by 4%, Brazil's by 3% and the rest of the non-OPEC developing world's by 3.3%[4]. Given the relationship between income and demand for meat identified above, the expected high increase in developing world GDP, if realised, will lead to considerably higher demand for meat.

As is indicated by several authors, the established economic relationship between income and meat consumption is reinforced by the rapidly growing urbanisation currently occurring in the developing world. While most of the factors cited relate directly to income (e.g. higher workforce participation in urban areas, smaller family sizes and more childless professional couples leading to higher per capita income), there is also an identified linkage between urban lifestyles and meat consumption as noted by Smil (2002), WHO (2003) and the FAO (2006). Thus urban lifestyles lead to the consumption of more convenience meals (meals eaten away from home, ready meal preparations etc.) due to perceived time constraints, and such convenience meals tend to contain meat. In addition, the better infrastructure of urban areas is seen as facilitating trade in perishable goods, leading to a more diversified diet than in rural areas (including more meat consumption). Finally, urban societies are those which are the first to be exposed to foreign products and intercultural exchange thus leading to the adoption of new consumption patterns.

Not only does overall meat consumption increases with urbanisation, but the importance of different meats also changes. IFPRI (Delgado et al, 1999) calculated urbanisation elasticities (% increase in consumption for a 1% increase in urbanisation) in relation to total meat consumption for different animal products in developing regions for the period 1970-95 (Table 9). The conclusion was pork, mutton and chicken become more important with increased urbanisation, while beef and milk become responsible for a lower share of total animal derived product consumption.

While urbanisation in developed countries is already advanced, a strong increase is expected in developing countries. During the period 2005-50, the developing country urbanisation rate is forecast to rise from 42.7% to 67%. The rate of urbanisation is even more marked in LDCs where the share of the population living in urban areas is expected to more than double from 27% in 2005 to 55% by 2050 (Table 10). In contrast, the developed world urbanisation rate stood at 74% in 2005, and is predicted to increase slightly to 86% by 2050. In summary, almost all of the projected growth of the developing world population is expected to take place in urban areas.

[4] OECD GDP forecasts date from just before the financial crisis and so do not incorporate the developments of the last 6 months.

2.2.3. Developed world trends

In developed countries, the level of urbanisation and income will not be key factors in driving meat demand. Indeed, in the developed world, changes in per capita demand for meat will depend on opposing factors. On the one hand, health concerns relating to the over-consumption of meat will place downwards pressure on per capita consumption. On the other hand, with more people adopting convenience lifestyles which encourage meat consumption, and the shift in age structure of the developed world population towards a slightly older population[5], there will also be upward pressure on per capita consumption.

Over the medium to long term, developed world per capita meat consumption is expected to be relatively flat. Indeed, Figure 2, which shows per capita meat consumption in developed regions points towards a levelling off in meat consumption. However, over the short term, per capita meat consumption may slightly rise; for example, the FAO and OECD predicted a 13% increase in per capita meat consumption over the period 2007-17.

To add to a relatively stable expected level of per capita meat consumption, the stable and eventually falling developed world population will ensure that total developed world meat consumption will remain at approximately the current level.

2.3. Meat production

The following sub-sections will examine the systems used to produce meat and their requirements in terms of land.

2.3.1. Animal production systems

FAO identify three main animal production systems:

The first is the **industrial** system, where the animals are separate from the land base for food and waste disposal; the characteristic of this system is that animals are grain-fed. There is considerable environmental risk from this system as large amounts of animal waste are generated, potentially causing water and air pollution. Furthermore, the heavy use of cereal as a feedstock also has considerable potential knock-on effects on the environment, given the ratio of cereal input to meat output (Table 11). The bulk of global poultry and pork is produced using this system, in addition to about 10% of global beef and a small amount of mutton (Figure 3).

The second system is the **grazing or grassland-based** system. As the name suggests, animals are primarily fed through grazing. Grazing systems vary on across the world, with different regions facing different issues; for example, in areas where fodder availability varies with the season, animals may undergo large weight changes during the year.

[5] From the section on nutritional requirements, it has already been seen that different age groups have different needs; with over 60s both needing and tending to consume more animal protein than children, therefore leading to higher per capita meat consumption on average.

Feed quality is often considered a constraint on animal productivity under the grassland-based system, and is causing the decline of grazing systems in areas where the final product competes with products from other systems. Environmental issues with the grassland-based system include: deforestation; the burning of savannah pastures in order for the animals to graze the young re-growth; and the degradation of temperate highlands. Grazing systems produce less than 10% of global meat.

The third is the **mixed** system, where crop and livestock production co-exist on the same farm. There are two sub-categories of this system; mixed irrigated and mixed rainfed systems. Mixed rainfed systems are predominantly found in the developed world and the CIS. Mixed irrigated systems are mainly found in Asia. With several sub-systems in these two groupings, there is considerable variation in the range of feed used, however common feeds include different types of forage, crop by-products, straw, pasture and some feed concentrate. Problems with mixed systems depend largely on the intensity of the system, and can therefore include the issues mentioned for landless or grassland systems. Mixed systems account for the majority of beef and mutton production, plus a large volume of pigmeat and poultry production (Figure 3).

2.3.2. Land requirements

2.3.2.1. Arable land: feed requirements, cropping patterns, yields

Opposing factors have affected the demand for feed over the last few decades. With the increasing intensity of systems, the use of cereal for feed has become more popular. However, this extra demand has been more than offset by improvements in feed conversion efficiency and the increased popularity of monogastrics. As a result, the rate of increase in demand for meat has been higher than that for cereal feed since 1980.
According to the most recent figures from FAO, 681m tonnes of cereal were used for feed in 2003 (Table 12). Cereal based feed is the main food input for intensive production systems, while under mixed production systems its use for feed varies. The type of cereal used as feed varies between regions, but on a global level, maize accounts for the majority (around 60%) of feedstock, followed by barley and wheat. The production of this 681m tonnes of cereal was estimated to require 222.38 million hectares of land; approximately one-third of all land used for cereal production in 2003. While cereals are the main cultivated feedstuff used, starchy roots also play a role, with some 147m tonnes used for feed in 2003. Oil crops, vegetables, pulses and sugar crops were less important, with between 10 and 30m tonnes of each used for feed.

Several authors have completed estimations as to the quantity of feed required to produce 1kg of meat, and these are shown in Table 11. The general consensus is that poultry has the lowest feed requirements for 1kg meat, with between 2 and 4kg required. Pig meat is next with between 2.64 and 5.9kg of feed required for each kg of meat. Beef is considered the least efficient with 7 to 13kg of feed required for each kg of meat. Data on mutton feed requirements is very limited. Examining FAO data, the 681 mln tonnes of feed used in 2003 equate to 2.64kg feed per 1kg meat[6]. This figure reflects the production of different meat types, and the fact that the aforementioned systems use cereal feed in different intensities.

Looking forwards, two factors point to an increase in demand for cereal as animal feed, most likely above the rate of increase of meat production. Firstly, the FAO predicts that the trend towards higher relative consumption of meat from monogastrics will continue, albeit at a slower pace. Secondly, the use of cereal feed is expected to increase in popularity in developing countries. A key question therefore is where the extra cereal required for animal feed will come from; the options are either at the expense of other uses (e.g. food and biofuels), from higher yields, or from an increase in the arable land area.

None of the three aforementioned options for increased cereal production are without problems. First, the share of total cereal production used for animal feed already stands at 33%, but may well have to increase. Second, while it is believed that crop yields can be increased in some areas, there are doubts as to whether the increase in yields alone will be sufficient to address rising demand. The rate of yield increase for arable crops in most regions has tended to slow down in the last two decades as the relatively easy gains in productivity from application of improved farm management techniques and higher application of inputs have no longer been so readily available in many regions. Going forwards, the FAO and OECD estimate a 15% increase in global wheat and coarse grain yields over the period 2007-2017; world population is expected to grow at a similar rate in this period. Third, there is little scope for the expansion of the arable land area unless forested areas are cleared. There are, therefore, potential future issues with land degradation caused by the need for ever more intensive production systems, and potential deforestation caused by the demand for extra land. On the other hand, feed conversion ratios may improve leading to less grain required to produce a kg of meat, slightly counterbalancing the increase in cereal demand expected from increased meat consumption; where there is a shift for meat from high (less efficient) feed conversion species (ruminants) to lower (more efficient) feed conversion species such as poultry and pigs, such as has proved to be the case with urbanisation in some developing countries, this factor may also have a moderating effect on demand for feed.

[6] This average assumes all feed was used in meat production and ignores feed used in milk and egg production.

2.3.2.2. Pasture

According to the FAO, global land used for pasture amounts to 34.8 mln km^2. This is equivalent to 26% of the world's ice-free surface. Asner (2004) concluded that the expansion of grazing areas into marginal areas is nearing its limit, the implication being that new grazing land can only appear at the expense of arable land or forest. The use of arable land for pasture is unlikely, therefore the expected result is that pasture land is likely to come at the expense of further deforestation. Estimations from Tilman (2001) predict a further increase of 5.4 mln km^2 by 2050, with most of this extra land coming from Latin America – the implication being further deforestation.

Future increased demand for pastureland will not come from the growth in animal numbers alone; further factors are at play. Pastureland itself can disappear as the land may degrade or pastureland may be consumed by urban areas. Furthermore, grassland may be ploughed up to create arable land.

The Food Climate Research Network (FCRN) identifies conversion to arable land as a particular issue in Latin America; forested land may first be turned into grassland for grazing, and later into arable land for feed production. Finally, it should be noted that forage yields could potentially fall due to global warming, creating further pressure for additional grassland.

2.4. Meat and the environment

The following section examines the environmental requirements of meat production, both in terms of inputs required (water, fossil fuel) and outputs generated (greenhouse gases). Land requirements were examined in Section 2.3.2. Data identified in this section will be used for calculating potential environmental effects in section 3.

It should be noted that the quantities of inputs required and outputs generated per kg product depend on the farming systems used. The data quoted in this section generally relate to studies performed in developed countries, and hence are representative of the systems used in these countries (i.e. there will tend to be a bias towards industrial meat production systems).

2.4.1. Life cycle analysis (LCA)

In measuring environmental impacts, life cycle analysis (LCA) is most commonly used. LCA takes into account all the stages of production of the final product. In the case of food production, such stages may include: agricultural inputs (e.g. feed, fertiliser); agriculture itself; food processing/manufacturing; packaging (including packaging inputs); distribution and retail; storage; consumption; and land use change arising from agricultural production.

The contribution of different stages to the total environmental impact depends on the product, the methods used, and the impact measured (e.g. emissions, water requirements, etc). Data from FCRN on UK greenhouse gas emissions from food provides an example of how impacts may be spread over different stages of the production. According to this data, 40% of food related emissions come from agriculture; 5% from fertiliser production; 12% from food manufacturing; 5% from packaging; 13% from transport; 5% from retail; 11% from consumer homes; and 8% from catering.

Figures on environmental impacts per kg product which are quoted in this report generally use the LCA method. It should, however, be noted that the figures quoted may not take into account all the aforementioned stages (for example, land use change). Furthermore, figures quoted only take into account the processing connected to the commodity and not to the final product unless otherwise stated. For example, LCA figures for milk take into account the processing applied to raw milk, but not the further processing required to make milk derived products (e.g. cheese, cream, etc).

2.4.2. Water and agricultural production

The UN identifies agriculture as the major user of freshwater, with over 70% of freshwater withdrawals due to irrigation. Livestock plays a significant part in this. For example, estimates indicate that around 1,000 litres of water are needed to grow 1kg of feed.[7] If one assumes that 1,000 litres of water are needed to produce 1kg of feedstock, and 7kg of concentrated feed are needed to produce 1kg of beef, then 7 tonnes of water are needed to create the feed required for 1kg of meat (although it should be noted that such water is not actually 'lost' as it, in part at least, will return to the aquifer it is drawn from). The actual water requirements for livestock production are considerably higher, as drinking water alone accounts for 65% of the animals' body weight. Indeed, estimations by various authors place water requirements for 1kg of beef at around 15,000 litres (Table 13). Among all meats, poultry emerges as the least water intensive, with between 2,390 and 3,900 litres of embedded water in each kg food. The embedded water in plant based food is significantly lower, with between 100 and 5,000 litres in each kg of product.

While the effects of water overuse are not as tangible as those of greenhouse gas pollution or fossil fuel overuse, negative effects exist nonetheless. The third UN World Water report estimated that, if the current trend continues, 47% of the world's population will live in areas of water stress by 2030. A further issue is that of water pollution. The pesticides, fertilisers, manure and waste used in and created by meat production all contribute to water pollution, partly contributing to "dead zones" in oceans and seas where plant and animal life cannot exist.

[7] This requirement will vary enormously depending on climate conditions, rainfall patterns, crop and soil type and on whether the crop is rain-fed or irrigated.

2.4.3. Greenhouse gas effects of food production

The agricultural sector is considered to be a very significant contributor to global greenhouse gas (GHG) emissions and is estimated to be responsible for 17%-32% of the total current emissions (Food Climate Research). The main polluting gases generated by agricultural production are nitrous oxide, methane and carbon dioxide. While carbon dioxide is the most well known greenhouse gas, nitrous oxide and methane present a much higher risk for the environment. Compared to carbon dioxide's global warming potential (GWP) [8] of 1, methane has a GWP of 21 and nitrous oxide a GWP of 310. While CO_2 in livestock and crop production comes from agricultural inputs, methane arises from direct livestock emissions and nitrous oxide is one of the components for the production of fertilisers.

According to McMichael *et al*, within the livestock related food chain there are many activities which contribute to climate change: from deforestation for grazing and feedstock production; soil contamination and carbon loss; transport; processing; production of fertilisers; animals' direct emissions; and enteric fermentation. McMichael's estimates, based on these activities, place livestock's share of total emissions from agriculture at 80% with cattle, sheep and pig production being the main contributors (Table 14). Estimations from other sources which ignore land use change estimate livestock's share of GHG emissions to be around 50%.

The direct greenhouse gas emissions resulting from the production of 1kg of different meats are displayed in Table 15. Cattle and sheep are clearly identified as the heaviest polluters due to rumination, with between 7 and 37kg CO2 equivalent created by the production of 1kg of meat. Poultry creates the lowest level of emissions, with between 1.1 and 4.6kg CO2 equivalent per 1kg meat.

The emissions created by pastoral and intensive systems vary. According to data from the FAO, pastoral livestock systems are more polluting than intensive systems in terms of direct GHG emissions from ruminant's enteric fermentation, as shown in Figure 4. Under intensive systems, emissions from manure can be controlled by animal waste management schemes (AWMS) such as biodigestors, which avoid soil and atmospheric contamination caused by manure, while the direct emissions from pastoral systems are also more difficult to control. Furthermore intensive production generates lower direct emissions due to the use of additives and other feedstock components which optimise protein absorption from livestock. On the other hand, livestock produced in intensive systems has higher feed consumption than pastoral systems and the emissions from this feedstock use needs to be considered; these emissions are due to the use of agricultural inputs such as nitrogen applied in the form of synthetic nitrogen fertiliser (and are not taken into account in Figure 4). Additionally, with proper grazing management, pastoral systems have the benefit of assisting carbon sequestration; for example, rotational grazing keeps plants in a growing state, hence increasing the amount of carbon sequestered.

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[8] Global warming potential (GWP) was a measure created to compare the impact of different greenhouse gases in the atmosphere. It evaluates the capacity of greenhouse gas molecules to absorb (or trap) heat and the time the molecules remain in the atmosphere. The estimates are based in the GWP of carbon dioxide (1). Methane and nitrous oxide, even having a much higher GWP are currently less dangerous than carbon dioxide, due to their lower concentration in the atmosphere.

As with meat production, emissions from plant based food production varies with the system used. Large-scale producers of grains and vegetables tend to use more fertiliser, pesticides and mechanical equipment than small farms, thus generating more emissions from all these sources. The use of fertiliser per hectare of grain is also higher than vegetable crops, hence the higher emission rates of grain crops, with 50% of the total emissions of cereals coming from N_2O (half of it resulting from the use of fertilisers).

GHG emissions from milk, egg and fish production fall into the range of between 0.4-5.5kg CO2 per kg product are therefore generally lower than those of beef, lamb and pork production. However, it should be noted that emissions from these products can increase significantly with processing. For example, according to Wallen et al, milk produces around 400g CO2 per kg product while cheese produces an estimated 8kg; based on the fact that 10kg milk are required for 1kg cheese, half of these GHG emissions can be attributed to the milk used and half to the processing. Similarly, raw fish produces around 2kg CO2 per kg product, while frozen fish produces 6kg. Therefore, with fish and dairy products there is a noticeable difference between the emissions produced by agricultural production, and the emissions connected to the final processed product.

In conclusion, the sum of both direct and indirect[9] GHG emissions arising from livestock production are higher than those for crops, as would be expected given the often intensive use of grain for livestock feeding (Table 15). For both crop production and livestock production, lower emissions can be achieved via mitigation measures such as improved management of fertiliser, feed use and biodigestors.

2.4.4. Fossil fuel requirements of meat and plant production and implications for GHG emissions

Calculations of the amount of fossil fuel required to produce a unit of crop or livestock output are fraught with difficulties. There are difficulties in measuring and attributing the amount of fossil fuel used in the production chain specifically to a single output. Additionally, the final figure of fossil fuel per kg product depends on a number of assumptions (notably for livestock, on the coefficient used for feed conversion efficiency).

Fossil fuel requirement estimates completed by different authors are presented in Table 16 (megajoules of fossil fuel per kg product). This data suggests that meat production requires considerably more fossil fuel per kg product than plant based food production. This is corroborated by estimations by Pimentel and Pimentel (Table 17), which identify beef and sheep production as particularly fossil fuel intensive.

[9] 'Indirect' is defined as emissions arising from land use change.

It should be noted that, in general terms, a key component of agricultural production for both crops and pasture, and thereby directly and indirectly for livestock, is fertiliser. Not only does the application of fertilisers directly result in GHG emissions; FAO estimates fertiliser derived CO^2 emissions at 41 million tonnes per year and farm emissions at 90 million tonnes; but fertilisers currently also require a significant amount of fossil fuel in production. Inorganic nitrogen fertilisers, for example, are made using fossil fuels such as coal and natural gas which are limited. Furthermore, significant energy is required for the production process itself.

2.5. Meat and consumer health

This section reviews existing research on various health problems commonly associated with higher red meat consumption, and conversely various health benefits associated with the higher consumption of vegetables and other plant-derived products. Some of the data identified will be used for assessing the health impacts of different consumption patterns in section 3.

It is important to note two points. Firstly, the reviewed research does not call into question the value of meat as a source of vitamins and minerals, but highlights the importance of a balanced diet, in which animal protein and saturated fat from livestock foods play a lesser role.

Secondly, the medical conditions outlined in this section are not solely attributable to an excess/deficit of meat; a variety of other factors such as lifestyle and genetic makeup contribute to these effects. Attributing causality is a notable problem with health issues, and this explains the lack of hard data on the medical effects of different levels of meat consumption.

In order to balance the discussion in this report on diet and health, at the other end of the spectrum, malnutrition issues as they currently affect a very significant part of the world population are also presented.

2.5.1. Heart disease

The risk of heart disease caused by high intakes of saturated fat is the most common condition associated with high meat consumption. Studies of Australian aborigine populations demonstrated that meat intake has positive nutritional effects[10] if low in saturated fat content (i.e. game meat) (Mann, 2000). The American Heart Association recommends a maximum consumption of 62.6kg of lean meat per year, while the average American diet reaches 100.7kg (total meat)[11]. In the USA 67% of the protein intake is derived from meat (Walker *et al*, 2005).

[10] Higher intakes of iron, retinol, zinc and vitamin B12 than vegetarian diets.

[11] It is estimate the average amount of saturated fat in the American diet is 15% of the total calories intake. The American Heart Association recommends a saturated fat intake to be less than 7%. (Berglund *et al in* German and Dillard, 2004).

Research by Sinha et al (2009) concluded that men consuming over 140g red meat per day had a 27% higher chance of death by heart disease than those that consume less than 30 grams per day. Women consuming over 140g had a 50% higher chance than those consuming no or little red meat (Table 18).
The American Stroke Association conducted research in 2004 to identify dietary patterns which could raise the risk of stroke in women. By comparing data from patients who followed a healthier diet (high intake of fruit, vegetables and grains) and those following a Western diet (high intake of red meat, refined grains and sugars), it concluded a diet high in red and processed meat increased the risk of hemorrhagic and ischemic stroke by 125%[12] (Fung *et al*, 2004).

The optimum diet to prevent coronary heart diseases (poor cardiac rhythm, high blood pressure, thromboses, etc) according to the American Medical Association is moderate (15% of total energy) protein intake (from varied sources) and increased intake of soybeans, legumes, nuts, fish and poultry (to decrease the amount of saturated fat).

2.5.2. Obesity

The correlation between obesity and meat intake has been extensively discussed. Research based on measurement of the body mass index (BMI) concludes that meat-eaters have a higher BMI than vegetarians (Table 19).

Although most of the meat and non-meat eaters participating in this research had a BMI between kg/m^2 20 and 25 (normal), there were considerably more non-meat eaters in the <20.0 BMI category and more meat eaters with a BMI of between 25 and 30 and >30 (clinically obese).

Other studies indicate that meat-eaters have a higher intake of protein, energy, saturated fat and monounsaturated fat, all of which are associated with a higher risk of cancer and coronary disease (Table 20).

The American Cancer Society estimates there are 90,000 more deaths per year in the USA due to cancer caused by obesity (Calle *et al*, 2003). Medical researchers therefore advise a diet with increased plant foods to help prevent excess overweight and obesity (Spencer *et al*, 2003).

2.5.3. Cancer

The association of high meat consumption and certain types of cancer has long been suggested by medical research[13]. Studies using extensive samples of men and women of different ages and races have so far given results which underpin this link, thus confirming the co-relation between high meat consumption and a higher incidence of cancer. For example, Sinha et al identified a 22% higher chance of death by cancer for men consuming over 140 grams red meat per day, and 20% higher chance for women, when compared with people eating under 30 grams per day (Table 18).

[12] Prudent diets presented an average risk rate of 0.69 while western diets a risk rate of 1.57.

[13] To mention a few: Norat *et al.* Meat, fish and colorectal cancer risk: the European prospective investigation into cancer and nutrition, 2005.

Research conducted by the European Prospective Investigation into Cancer and Nutrition (EPIC) group, using men and women between 21 and 83 years old from 10 European countries concluded there are higher chances of **colorectal cancer** in people who have diets with high consumption of red meat. The results showed at the age of 50, those who have a high level of red meat consumption have a 1.71% chance of developing colorectal cancer, against 1.28% for people with the lowest red meat intake. Among all categories, those who consumed processed meat are estimated to be at more risk. The research also considered fish consumption, which showed the opposite result. The participants with the highest consumption of fish had a 1.28% chance of developing colorectal cancer at the age of 50 compared to 1.86% from those with the lowest fish consumption.

Gastric cancer was also associated with high intake of meat, especially among those with cancer in their family history. Research conducted in Italy concluded that increased consumption of fresh fruits and vegetables could help decrease the risk of gastric cancer (Palli *et al*, 2001).
Another study including mixed race men also pointed out there was a higher risk of **prostate cancer** in men who had a high intake of processed meat – especially cooked meat such as bacon and sausages (Rodriguez *et al*, 2006).

Studies on other types of cancer also concluded that high levels of meat consumption increase the risk of cancer. Regarding **breast cancer**, the preparation of meat may also be of high influence, with well-done and fried red meat in particular being implicated. According to Zheng *et al*, women with high red meat intake have a 78% higher chance of developing breast cancer, especially fried meat as it forms heterocyclic amines and polycyclic hydrocarbons when exposed to high temperatures, which are associated with cancer. Research with premenopausal women also found high fat intake of is linked to higher risks of breast cancer in general, with animal fat from red meat and dairy products considerably increasing the risk (Cho *et al*, 2003).

In addition to the increased risk from meat consumption, lifestyle factors expose heavy meat eaters to a greater risk of cancer. Meat eaters are more likely to consume larger quantities of other unhealthy products such as chips and high fat dairy products. Meat intake is therefore usually correlated with higher energy intake, and hence obesity (section 2.5.2); obesity is in turn correlated with a higher risk of cancer. A study published by the Massachusetts Medical Society analysed the risk of cancer in men and women with different BMI. Men above 35.0 BMI and women above 40.0 BMI had a considerably higher risk of developing all types of cancers.

Palli *et al*. Red meat, family history, and increased risk of gastric cancer with microsatellite instability, 2001.

Rodriguez *et al*. Meat consumption among black and white men and risk of prostate cancer in the cancer prevention study II nutrition cohort, 2006.

Zheng et al. Well-done meat intake and the risk of breast cancer, 1998.

Cho et al. Premenopausal fat intake and risk of breast cancer, 2003.

2.5.4. Diabetes

Diabetes type 1 and diabetes type 2 are both associated (among other things) with total saturated fat, which is strongly present in red meat, especially in processed products. A 12-year study conducted by the Department of Nutrition from the Harvard School of Public Health concluded that high intakes of processed meat increased the chance of diabetes type 2 among men, with those consuming processed meat between 2 and 4 times a week having a 0.33% higher chance of developing diabetes than those consuming it less than once a month (0.18%) (Table 21).
The ingestion of nitrites and nitrosamines (which can be formed by the interaction of nitrites with amines present in meat), both commonly found in processed meat, are also associated with high risk of diabetes type 1 (Virtanen *et al*, 1994 *in* van Dam, 2002).

2.5.5. Undernutrition

Malnutrition is still a reality for 13% of the world population (850 million persons), and is most prevalent in southeast Asia and Africa (McMichael *et al*, 2007). Meat can play an important role in combating malnutrition. Research from the FAO concludes that meat intake of under 10kg per year may lead to malnutrition, while an animal protein intake of 20g per day will assist in effectively combating the condition. It is noted in this context that current world food production would be sufficient to feed the current world population (6.3 billion), if it were more equally distributed and contained a relatively small amount of animal protein (Walker *et al*, 2005).

According to the FAO more than a quarter of children under five years of age in developing countries are malnourished. At the other end of the spectrum, the nutritional challenge of the developed world is to stop the rising trend of obesity among its population, particularly children. In European countries, the average rate of child obesity is between 15% (Denmark) and 36% (Italy).

To summarise, an increase in meat consumption in malnourished populations could play an important role in tackling iron-deficiency anaemia and improve overall energy intake, which are common health problems in low income countries. At the same time a reduction in meat consumption in developed economies would reduce obesity and other health risks.

2.5.6. Health and safety issues associated with meat production

Health problems related to meat are not only caused by meat consumption. In the US, it is reported that 30% of workers from intensive livestock producing farms suffer from occupational respiratory diseases – acute and chronic asthma (Walker *et al*, 2005). The excessive contact with manure, odours, chemicals, bacteria, toxins and dust are serious health hazards. Workers in large plant production farms are also exposed to risks related to the spraying of plant production products, and the application of inorganic fertilizers and other agro-chemicals.

Those living near intensive livestock production farms may be susceptible to a higher risk of health problems. Research from the University of Iowa suggests people living near large-scale pig farms have more headaches, eye irritation, nausea and respiratory conditions than people living near smaller farms (Walker *et al*, 2005).

2.5.7. Costs to the public administration of consumer health issues

Estimating the public administration costs of consumer health is a complex exercise, not least because lifestyle, family history and diet factors unrelated to meat consumption can also lead to the development of the aforementioned health conditions. If we consider the research which associates high BMI and high meat consumption to increased risk of cardiovascular diseases, data from the American Heart Association[14] gives an idea of the financial burden of diseases associated with the western diet. Table 22 shows the direct and indirect costs from several heart conditions in the USA in 2006. It is noted that these figures do not suggest what could be the potential costs of high meat consumption, but simply indicate the scale of costs associated with diseases which can *inter alia* be caused by excessive meat consumption. If data were available on the exact contribution of high meat diets to the incidence of these diseases, then more direct and specific extrapolations could be made on the associated health costs. For example, if the risk of stroke increases by 125% with high meat consumption (as discussed above), and we assume that a third of the population suffering strokes has this level of meat consumption, then it could be deduced that up to US$ 3.9 billion of the total costs to the health system from stroke in that year were due to high meat consumption[15].

Expenditure associated with the conditions of obesity and overweight reached US$117 billion in 2001 in the USA, of which US$8.8 billion were related to heart disease and US$ 98 billion to type 2 diabetes. In terms of indirect costs, US$ 3.9 billion were spent in lost productivity due to obesity. As concluded by much nutritional and medical there is a direct co-relation between obesity and high protein intake, and so a decrease in the consumption of meat would have a direct impact on obesity expenditure, especially indirect costs.

Barnard *et al* estimated that the US spent between US$28 and US$61 billion on direct medical costs related to beef and poultry consumption in 1992 (Barnard *et al*, 1995 *in* Fiala, 2006). The American Heart Association estimated that each year over US$33 billion in direct costs are spent on diseases and conditions related to diet. Over US$9 billion are spent in lost productivity related to heart disease, cancer, stroke and diabetes caused by unhealthy diets.

2.6. Alternative foodstuffs

2.6.1. Aquaculture

Fish is one of the most nutritional sources of animal protein with additional advantages such as lower fat content and beneficial fatty acids. In spite of this positive nutritional picture, however, the available research indicates that the use of seafood protein as an alternative for red meat in people's diet is a short-term and inefficient solution; it would not fully address the problem of GHG emissions, and would pose a threat to the sea and ocean biodiversity.

[14] Heart Disease and Stroke Statistics—2006 Update: A Report from the American Heart Association Statistics Committee and Stroke Statistics Subcommittee.

[15] This is a proxy on the basis of simple extrapolation only; more complex models would need to be used here for an accurate estimate.

The key limitation in the further use of fish is the strain it would put on ocean and water based resources. According to FAO, in 2005 1/3 of world's fish stocks were being fully exploited – catches were close their maximum sustainability limit – and 2/3 were overexploited, depleted or recovering from depletion – yielding less than the amounts needed to maintain stocks due to excess fishing pressure. The report's authors affirmed "This confirms earlier observations that the maximum wild capture fishery potential from the world's oceans has probably been reached and reinforces the calls for more cautious and effective fisheries management (…). In the case of inland fishery resources, there is widespread overfishing, arising from either intensive targeting of individual large-size species in major river systems or overexploitation of highly diverse species assemblages or ecosystems in the tropics". Various other studies corroborate this finding that resources are being over-fished; indeed Worm et al (2006) indicated that if current trends continue, the world will exhaust stocks of wild caught seafood by 2048.

According to Pimentel, Shanks and Rylander the fishing industry is therefore only able to supply 1% of world's food energy (protein). However this small percentage is high in nutritional value. An average of 80% of fish is lean meat and its protein is readily digestible. Around 10% of fish protein contains lysine and it is also a major source of fatty-acids, important for the development of brain and body.

For a further comparison an intake of 226 grams of fish or hamburger would cover 100% of an adult RDA in terms of protein, niacin, vitamin B12 and phosphorus, 25-50% of iron, zinc and copper; and 25% of thiamine, vitamin B6 and riboflavin. The most impressive difference is the fish serving is equal to an intake of 280 calories while the beef serving is estimated to contain 750 calories (Lovell, 1998).

Further considerations connected to the use of fish are the high fossil fuel requirements and GHG emissions arising from fishing. Figure 5 indicates that livestock production such as beef and pork need less fossil fuel input than shrimp production. It is noted that the fossil fuel input in fishing is related to the vessels used for seafood extraction, transport and other stages of the fishing industry.

Taking into account the limited resources and the use of fossil fuel by the fishing industry, a possible solution could be to increase the number of fish farms. However fish farming production derives part of its feed components (fish oil and fishmeal) from wild fish, therefore again drawing unsustainably on wild resources. In fact an average of 1.9kg of wild fish is required per kg of farmed fish produced (Table 23). Alternatives for the fish production are investing in technology to feed species with fishmeal and fish oil plant-based replacements; this strategy has succeeded using algae for the production of molluscs and shrimp, but this has not developed due to the excessively high costs of algae.

To conclude, the anticipated growth of world population, and consequent increased needs for animal protein, and the fact that the amount of protein which can be extracted from fish and seafood is much lower than from livestock products (although of high quality nutritionally), mean that aquaculture cannot provide a sustainable longer term alternative on a world scale to livestock production. The current outlook consensus for the sector remains focused particularly on exploitation of wild fish for particular niche markets (e.g. salmon, haddock, and tuna). Although farming fish is an alternative, it is not sufficiently environmentally friendly at present to consider as a sustainable option for meeting the nutritional requirements of a growing population.

2.6.2. In vitro meat

Another possible alternative to livestock production without the need to change people's animal protein consumption would be to produce in vitro meat. In vitro meat can be created by culturing animal cells which are suspended on plastic or silicon sheets. They are 'fed' with a nutrient-rich soup and stretched to give it texture. The idea was introduced to improve nutrition during space travel, but it has been further considered by the scientific community and supported by animal welfare groups. Other benefits of in vitro meat are the potential elimination of environmental impacts (direct and indirect) from the livestock sector, reduction of disease and contaminants within the food supply chain and the opportunity to enhance meat properties (add extra nutrients such as polyunsaturated fat and/or omega 3).

Studies have been undertaken and these concluded it is feasible to produce in vitro meat, but the necessary techniques and prospective impacts need to be much further developed before it is produced in enough quantity to be tested. Until now, the scientists have reportedly been able to produce a small quantity of 'fish' like meat, which was then cooked in order to evaluate the maintenance of meat characteristics after contact with heat; the result was apparently positive and it is estimated that in ten years, mince meat from cultured animal cells may become available on the market.

However, the current costs of research to produce in vitro meat are very high and the production of 250 grams of beef has been estimated to cost US$ 1 million. This therefore clearly limits market interest for in vitro meat. Despite some promise from the early stages of this research, another challenge would be to convince the food industry and in particular consumers that in vitro meat is a safe and good substitute to naturally produced animal protein.

Meat and milk from cloned cattle are claimed by scientists to be safe for human consumption (Yang *et al*, 2007; Yamaguchi *et al*, 2008), but there is still no commercial production of such cloned animals. In surveys, the European population have tended to come out strongly against the high use of biotechnology for production of foodstuff (Gaskell *et al*, 2000) and recently the European Parliament voted to prohibit the production, consumption and trade of cloned animals (and their material) in the EU.

2.6.3. Algae

Algae could also theoretically be useful to tackle climate change in two different ways: by capturing CO_2 from atmosphere as a natural process for mitigating carbon dioxide emissions and as an alternative complementary source of protein. Currently the main use of algae occurs as a substitute for synthetic compounds in foodstuffs, use by the pharmaceutical and cosmetic industry, the animal feed industry and nutraceutical companies for the fabrication of compounds, tablets and infant food. There is no use of algae as an animal protein substitute at the moment, only as a nutritional supplement.

Algae have a high nutritional value (Table 24) and are an important source of nutrition for many types of fish in their early stages. It is also used by in infant formulae products as some of its properties (DHA) are important for children at their first stages of development (brain and eyes) and are found in only few types of food (e.g. breast milk, but not cow milk).

Despite the fact that algae (like meat) is a good potential source of vitamins, the cost of production is currently its biggest disadvantage. To farm algae in mass production, either a huge amount of land is required (most of current production is in open ponds) or a photo bioreactor is required in order to optimize its growth, but this equipment is expensive. Neither type of production is currently competitive. Algae needs light and grows at a relative slow rate; also not all types of algae can be grown heterotrophically.

As a conclusion, high investment in biotechnology to create more efficient algae varieties, together with marketing and pricing strategies to convince the food sector and achieve consensus concerning quality and value as an animal protein substitute on a larger scale, are issues that must be taken into account by decision-makers and prospective producers before this alternative can be considered further.

2.6.4. Amino acid supplementation/fortification

As mentioned in section 2.1.3, plant based protein has several limitations when compared with protein from animal sources. Among these limitations is the absence of essential amino acids, particularly lysine. As a result, while lysine is abundant in livestock product intensive diets, it can be absent from plant product diets particularly the typical cereal based diets of parts of the developing world (e.g. cassava in Africa). The WHO/FAO report on protein requirements (2007) has acknowledged that protein and amino acids are a fundamental part of a human diet, especially for growing children in the developing world where a long-term lack of lysine and other essential amino acids has affected growth and capacities of the whole populations for decades.

It has been suggested that the supplementation of grain based food could be one method of addressing the absence of lysine. For example, Bressani et al in the 1970s concluded that lysine supplementation had positive effects when the supplementation improved the balance of lysine among other amino acids. However, more thorough and up to date research is needed in this area – along the lines of that conducted in the case of fortification with vitamins and mineral supplements to demonstrate the benefits of fortification - before comprehensive conclusions can be drawn in relation to this issue.

2.7. Other socio-economic effects of meat production

As meat production contributes significantly to the increase of total GHG emissions, it seems important to discuss the prospective socio-economic challenges caused by climate change (some of which, in their turn, have implications for food production). Its effects can already be seen with the rise in global average temperatures and sea levels, desertification and the increase of other adverse natural phenomena such as floods, droughts, storms and tornados.

Food scarcity caused by climate change is a major concern. The possible decrease in crop yields, soil-erosion, intensive rainfall and longer dry-periods are likely to affect food production. The expected changes in temperature may also contribute to the spread of pests and livestock diseases (Rosegrant and Cline, 2003).

With respect to health, negative effects from climate change are also expected, such as an increase in air pollution and changes in the patterns of transmission of infectious diseases (McMichael *et al*, 2007). The increase in drug resistance has already been researched[16] by the World Health Organisation as a possible result of climate change (WHO, 2003). Diseases such as malaria and dengue (typically from tropical climates) could also be more widely spread by the creation of new habitats to their transmitters.

Another aspect to consider longer term is the potential adverse geo-political effects which may be caused by the potential increases in deforestation, water and land scarcity. In an extreme scenario, these issues could trigger conflicts among regions and nations for the use and appropriation of natural resources (which have declined in the last two centuries), which could re-emerge as an increasing threat for the next generations (Schwartz and Randall, 2003).

[16] Patz, J.A.; Lindsay, S.W. New challenges, new tools: the impact of climate change on infectious diseases, 1999.

3. EVALUATING THE EFFECTS OF MEAT CONSUMPTION

In order to further investigate the effects of future meat consumption scenarios and obtain some indication of the effects of different consumption patterns, a static model has been used to generate estimates of the impact of these scenarios. This model examines three possible scenarios, which were chosen and named by STOA. These scenarios are as follows:

Scenario 1- Maximum or Baseline scenario: Current consumption patterns continue in developed countries, while developing country meat consumption increases as these countries adopt western eating habits;

Scenario 2 -Optimal scenario: Developed world meat consumption is reduced to only the amount necessary for a healthy diet, while developing world meat consumption continues to increase up to this level;

Scenario 3 -Minimum scenario: Global demand is based on a lacto-vegetarian diet. To understand the potential evolution of meat consumption, the model uses the year 2005 as a base year[17] and then makes estimations at five year intervals between 2010 and 2050.

It should be noted that the issues discussed are complex, and that any number of possible scenarios of future development could be postulated. The choice of scenarios is not intended to be prescriptive in terms of how what might be termed a better balanced diet might be achievable. Instead the aim has been to provide the full range of impacts that may be expected between the two extremes (minimum and maximum scenarios). It should also be noted that alternative foodstuffs (as discussed in section 2.6) may have a role to play in a healthier and more environmentally friendly diet; however, the use of such alternative foodstuffs is not considered within the three scenarios.

3.1. Methodology overview

The model divides the world into regions chosen to be representative and on the basis of suitable data availability. The following regional groupings were used:

- Europe (excluding Russian Federation, Ukraine and Belarus)
- Russia, Ukraine and Belarus
- Developed North America
- Japan
- Latin America and the Caribbean
- Africa
- Developing Asia
- Oceania

[17] 2005 is the most recent year for which detailed population data is available. 2003 is the most recent year for which FAO data is available. 2005 is therefore used as the base year, with consumption estimated based on the 2003 FAO data.

Figure 6 displays the regional groupings on a map. It is worth noting that the availability of data varies; while population and income data is available for the whole world, data from FAO on meat consumption is not available for all countries. As a result, data on meat consumption from FAO is considered representative of the whole region, including countries for which no data is available.

As the model is static, it was developed in a series of progressive stages. First, per capita demand for different products was estimated for each of the aforementioned regions. Developed region per capita meat, dairy and fish demand have been held constant at 2005 levels, while developing region demand evolves with income. Second, global demand for different food products was estimated based on per capita demand and population evolution. Finally environmental and health effects were estimated for the global demand levels calculated. A more detailed methodology for each of these stages can be found in the corresponding section.

3.2. Global demand for meat

3.2.1. Methodology and issues

In the discussion of the methodology, the baseline Scenario 1 (Extension of current western consumption patterns) is considered first. Scenario 2 (Optimal) and Scenario 3 (Minimum) are then derived from this.

It should be noted that, as the model is static, it does not take into account the effects of a change in the price of meat itself on demand and vice-versa. One would expect that, as demand for meat increases and if supply is not sufficient to meet demand, the price of the product will increase, hence dampening some of the increase in demand. This factor is not accounted for in the model which has been primarily developed to highlight trends under different assumptions.

3.2.1.1. Demand for meat

The long term forecasts for global meat demand for meat are based on both the change in meat demand per capita, and the change in population.

A distinction has already been made between changes in demand in the developed and developing worlds. In the developed world, per capita meat consumption has been relatively stable since 1980, as Figure 2 shows. While there have been increases in meat consumption in some regions over this 23 year period, consumption appears to have generally leveled off during the last 5 years[18]. In addition, as has been noted in section 2.2.3 that opposing factors are expected to have the greatest effect on future per capita meat demand in developed countries. On one hand, health concerns are likely to lead to lower demand (or changes in meat consumption patterns).

[18] It is worth noting that the 1992 dip in European meat consumption was caused by the inclusion, for the first time, of data relating to the Russian Federation

On the other hand, shifts towards convenience lifestyles and an ageing population may lead to higher demand. Given the difficulty of accurately predicting how attitudes towards meat will change in the developed world both over the short and long term, it will be assumed that the opposing factors counterbalance each other. Going forwards, therefore, developed world per capita meat demand will be held constant at 2003 levels. The former European-USSR (Russia, Ukraine and Belarus) will be treated as a developing region.

For the developing world, it has already been seen that urbanization and income are two key factors in driving an increase in per capita meat demand. However, given the high degree of interdependence between these two factors in estimating future demand, only income is used in the model. As already mentioned, the relationship between real GDP and the consumption of meat was explored through elasticities (Section 2.2.2). To estimate future per capita demand for meat in developing countries, a combination of income elasticities by country from ERS and GDP projections based on OECD growth rates are used. However, as already mentioned in section 2.2.2, demand for additional meat decreases as income increases. This means that elasticities fall, as demonstrated in Figure 7. Therefore, with income rising over the period of the model, it was necessary to adjust the original ERS country elasticities in order that they fitted the new income level at each 5 year interval. The adjusted elasticities were capped at a minimum of 0, in other words, it was assumed that per capita meat demand would never decrease as a result of an increase in income.

While the method used provides a good indication of the evolution of meat demand, there are two main limitations. First, the ERS elasticities were calculated for all meat products, not for particular meats. It is possible that preferences for different meats will also vary with income, and it was already seen in section 2.2.2 that preferences for different meats vary with different levels of urbanisation. Changes in preferences towards different meats are not reflected in the model; current consumption preferences are simply projected into the future. Secondly, the cultural aspect of attitudes towards meat consumption is not fully included.

Using the demand estimations created for Scenario 1 (Extension of current western consumption patterns), demand estimations for the optimal scenario (Scenario 2) have been created by limiting all meat consumption per capita to the optimal amount. The reference amount used is 33kg per person per year, as indicated in Section 2.1.3. For simplification purposes, a single optimal amount is used on a global level as calculating optimal values for each region was not considered possible in the timeframe and budget of this study.

3.2.1.2. Demand for milk, eggs and fish

Future demand for milk, eggs and fish has been estimated using the same method as was used for future meat demand; that is to say, developed country demand has been kept constant, while developing country demand evolves based on income. It should be noted that estimating future demand for milk, eggs and fish is particularly difficult as there tends to be a particularly strong cultural aspect to consumption of these products which is generally more significant than the cultural aspects of meat consumption. In view of this, the estimations provided must be seen as broad approximations.

3.2.1.3. Animal product wastage

It should be noted that the estimates provided are based on consumption demand for animal products. Historically, consumption demand is slightly below the level of production, as a small part of production is lost to wastage, or allocated to other uses. For example, 2003 consumption of meat products was 249.8 mln tones against production of 253.2 mln tones (hence a 1.4% difference). For eggs, milk and fish, the differences between production and consumption in 2003 were higher; 11.6%, 17.4% and 21.3% respectively.
It is therefore reasonable to expect that actual production in the three scenarios would be ahead of the demand figure quoted.

3.2.1.4. Demand for plant derived food

As seen in Section 2.1.1, the difference in consumption of plant derived food between developed and developing regions is relatively small. Indeed, in some cases, developing countries consume more plant derived food than developed countries.

Estimating the evolution of plant derived food is particularly difficult and not necessarily meaningful since this encompasses such a broad range of products with different characteristics. Elasticity estimates from ERS show that demand for these foodstuffs does increase with income but also that substitution of plant products with meat products takes place as income increases. Substitution even occurs among plant derived products, with products such as potatoes showing the characteristics of inferior goods[19] at high income levels. Furthermore, there is a cultural factor to take into account when examining consumption of plant derived food. As an example, Latin America has considerably lower consumption per capita of plant derived food than Africa (316kg per capita per year compared to 396kg), despite being the wealthier continent[20]. This could be attributed to cultural factors leading to higher meat consumption, and as a result, less plant derived food. To conclude, the relationship between plant derived consumption and income is not as straightforward as that between meat and income. In view of these complexities the simplifying assumption is made that demand per capita for plant derived food remains constant under the maximum (baseline) scenario.

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[19] Meaning demand for the good decreases as income decreases. This is due to substitution; with higher income levels, potatoes are more likely to be substituted by other plant products such as cereal derived pasta or bread.

[20] According to GDP PPP figures, with a per capita GDP of just over $4 000, Latin America is four times wealthier than Africa.

Under the optimal meat consumption and minimum meat consumption scenarios, meat has to be substituted for by other foodstuffs. Meat demand above the level of 33kg under the optimal scenario, and all meat demand under the minimum scenario is replaced with plant derived food, milk and eggs on a weight basis. Fish will not be used as a substitution product; demand for fish will increase during the period, and as indicated in section 2.6.1., fish resources are already near the upper limit of exploitation, therefore substitution of meat with fish would appear unrealistic. The consumption patterns for the corresponding periods are used to determine how much of each product group replaces meat.

3.2.2. Results: Scenario 1: Maximum (baseline) scenario

Under the maximum (baseline) scenario, per capita meat demand in Russia/Belarus/Ukraine is forecast to level off at 63kg in 2030. Latin American per capita meat demand will level off at 84kg per capita in 2040, above the demand level of Europe but below that of North America. Developing Asian per capita meat demand will reach 61kg per capita in 2045. African meat demand will increase during the whole period, reaching 32kg per capita in 2050 (Figure 8). Per capita demand for fish products in developing regions will increase and finish above the demand levels of all developed regions except Japan in 2050 (Figure 9). In 2050, developing Asia will lead the world in per capita egg demand (Figure 10). Milk consumption will change over the period, with European ex-USSR approaching the demand levels of North America and Europe in 2035. Per capita demand for milk in developing Asia, by contrast, will remain low and be overtaken by African per capita demand in 2050 (Figure 11).

With the increase in population and per capita demand for meat, global meat demand under the maximum (or baseline) scenario is forecast to more than double from 2005 levels of 251mln tones to 563 mln tones by 2050 (Figure 12). Demand for milk is projected to increase by a similar proportion rising from 561 mln tonnes in 2005 to 1,322 mln tonnes in 2050. Driven by higher per capita demand in Asia, global demand for eggs and fish is projected to triple during the period, starting from bases of 58 and 113 mln tonnes in 2005 and reaching 161 and 352 mln tonnes respectively in 2050.

3.2.3. Results Scenario 2: Optimal meat consumption

Under the optimal scenario, per capita meat demand in all developed countries, Latin America and Russia/Ukraine/Belarus is forecast to immediately revert to the optimal level. Asian per capita meat demand is expected to reach the optimal level by 2015. African per capita meat demand will finish at 32kg in 2050, just below the optimal level (Figure 13).

Due to the partial substitution of meat with eggs and milk, per capita demand for these products is slightly higher under the optimal scenario, though there are no major changes from the maximum (baseline) scenario (Figure 14). Global meat demand would start at 174 mln tones in 2005, and is forecast to reach the level of actual 2005 global meat demand around 2030. In 2050, global meat demand would stand at 307 mln tones. Global demand for plant based food will grow at a rate slightly above that of the population due to the substitution of meat with plant based food (Figure 15).

3.2.4. Results Scenario 3: No meat consumption

The partial substitution of meat with eggs and milk further increases per capita demand for these products under the minimum scenario. Under the minimum scenario, per capita demand for milk is 617 mln tonnes in 2005, rising to 1481 tonnes in 2050. This compares to 561mln tonnes under the maximum (baseline) scenario, rising to 1322 mln tonnes. For eggs, the situation is similar (Figures 16 and 17).

3.3. Environmental and socio-economic effects of consumption

While there is generally a range of studies on the environmental effects of meat production, studies on the environmental effects of fish, egg, dairy and plant based food production are more scarce, if available at all. Figures related to the environmental effects of production of these foods, where provided, may therefore be less accurate than those related to meat.

The environmental effects presented in this section are limited to those which can be expressed both quantitatively, and with a relative degree of accuracy within the framework of the model. In view of this, effects on factors such as biodiversity are not analysed, however potential effects can be inferred from the demand for land, emissions, etc.

3.3.1. The demand for land

3.3.1.1. Methodology and issues

As noted in section 2.3.2, the demand for land for animal production comes from both grazing areas and land used to grow feed crops. There are various difficulties in estimating the future demand for land. These include: predictions regarding the likely prevalence of the various animal production systems in future; future crop yields; the future trend in the usage of different crops as animal feedstuffs; developments in feed conversion ratios; and the consistency of data regarding land use.

Current trends in feed cropping, animal farming systems and crop yields will be used to make projections regarding the arable land required for animal feed production. These current trends will be projected forwards as there are no reliable forecasts for these factors. It will also be assumed that the global arable land area remains at the current level of 1.4bln hectares (1.6 bln hectares including permanent crops). This assumption is in line with the trends identified in Section 2.3.2.1.

With regards to feed conversion ratios, there are two issues. First, it is not known if feed conversion ratios will continue to improve in future. Second, the use of feed for milk and dairy production is difficult to estimate; data on feed conversion ratios for milk and eggs is not readily available, and on a global level it is not possible to differentiate between feed used for meat production and feed used for dairy production. Due to this uncertainty, feed requirements will be calculated for meat production only, based on the 2003 FAO average of 2.64kg feed per 1kg meat.

Finally with regard to data consistency, there are some gaps in data on current arable land use. According to FAOStat, oilcrops, cereals and sugarcrops were the largest users of arable land in 2003. The FAO food balance sheets identify the majority of oilcrop production as being used in food manufacture; however oilcrops used in food manufacture are not included in per capita food consumption figures for oilcrops. As a result, the proportion of global arable land used for food and feed production based on data from FAO Stat is relatively low (around 55%).

3.3.1.2. Land for feed

Under the maximum (baseline) scenario, 14.2% of the world's 2005 arable land area was dedicated to animal feedstuff production in 2005 and this percentage would increase to 32% by 2050 (Figure 18).[21] This equates to approximately 1/3 of food and feed cereal production in 2005, and almost 50% in 2050.

Under the optimal scenario, the percentage of the world's land used for feed would increase from 9.9% in 2005 to 17.4% in 2050 (Figure 18). [22]

3.3.1.3. Pastureland

According to the FAO, 26% of the world's ice free surface was used as pastureland in 2005. Under the maximum (or baseline) scenario, 58% of the world's ice free surface would potentially be required for grazing in 2050 if the prevalence the grazing production system and intensity of use of pastureland were to continue at current rates.

3.3.1.4. Overall arable land use

As would be expected, the differences in consumption patterns lead to different patterns in total arable land use for food production[23]. Under the maximum (baseline) scenario, 743 mln hectares of arable land were needed for food production in 2005, rising to 1,211 mln hectares by 2050 (an increase of 63%).

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[21] Adjusting for the inconsistencies on land use data described in section 3.3.1.1, the area used for feed corresponded to 27% of land used for arable food and feed production in 2005 and 37% in 2050.

[22] These figures correspond to 20% and 24% of all land used for food and feed production in 2005 and 2050 respectively.

[23] Food, in this case, is defined as meat, cereals, fruit, oilcrops, pulses, starchy roots and vegetables. Sugar crops, stimulants, alcohol and spices are not included. This fact is one reason why only 743 mln hectares of arable land was used for "food production" in 2005, compared to a total arable land area of 1.4 bln hectares. Other reasons are: the other 'uses' of crop production such as wastage, seeds and biofuel which are not included; and the inconsistency relating to soybeans referred to in section 3.3.1.1.

Under the optimal diet, 691 mln hectares would have been required in 2005, rising to 1,045 mln hectares by 2050; some 41% ahead of the 743 mln hectares of arable land actually used in 2005. Arable land requirements under the minimum scenario are the lowest; 580 mln hectares would have been required in 2005. 2005 land use from the maximum (baseline) scenario would be surpassed in 2030, and land requirements would finish at 847mln hectares in 2050, only slightly ahead of the 2005 baseline number (Figure 19).

3.3.2. The demand for water and energy

3.3.2.1. Methodology and issues

It should be noted that water requirements for crop production depend on the farming system used. Estimations relating to water requirements in this section are based on the average of figures from studies referred to in Table13. Estimations for fossil fuel requirements are based on the average of figures quoted in Table 16; fossil fuel estimations used exclude the energy required for processing to produce the final product. The energy required for processing can be relatively high in some cases.

Estimations for fossil fuel requirements in this section are expressed in barrels of oil equivalent, however, the figures quoted are for all fossil fuels used, not just oil. For example, fossil fuel inputs in fertilizer are generally gas or coal rather than oil. It should be noted that it may also be possible to meet some of the energy requirements outlined in this section through the use of renewable energy sources.

3.3.2.2. Energy requirements

The maximum (baseline) scenario shows fossil fuel requirements for livestock production increasing from 899 mln barrels of oil equivalent in 2005 to nearly 2 bln barrels equivalent in 2050 (Figure 20). Based on the fact that global oil production was 73.81 mln barrels per day in 2005, the 2005 requirement represents the equivalent of 3.3% of global oil production. Looking into the future, the consensus is that world oil production will begin to decline over the next decade or so, and may reach a level of 30-40 mln barrels a day in 2050. With such estimations, meat production under the maximum (baseline) scenario would require the equivalent of 13-18% of global oil production in 2050.

The amount of fossil fuel energy required for total food production is significantly higher than that required for meat production alone. Under the maximum (baseline) scenario, nearly 4.3 bln barrels of oil equivalent were required in 2005; around 16% of 2005 global oil production of this 4.3 bln barrels of oil equivalent, 2.3 bln were used by plant based food production, 0.9bln by meat production, 0.7 bln by fish production and 0.4 by dairy production.[24]

[24] Barrel of oil requirements for plant based food may be overestimated, as data on fossil fuel per kg product has been taken from European based studies. Due to climate conditions in Europe, a large amount of fossil fuel is used in the production of tomatoes and certain other vegetables due to heating and light requirements.

By 2050, the amount of fossil fuel required under the maximum (baseline) scenario would almost double to 8.4 bln barrels of oil equivalent (between 60 and 75% of predicted 2050 oil production). While fossil fuel requirements under the optimal and minimum scenarios are lower for the period 2005-50, the difference is not great. Under the optimal scenario, fossil fuel requirements are only 5-8% lower than under the maximum (baseline) scenario; under the minimum scenario, they are 10-20% lower (Figure 21).

3.3.2.3. Water requirements

5,654 km3 of water were required for agricultural food production in 2005. Approximately 40% of this water was used in meat production, with a further 20% used in dairy and fish production. Under the maximum (baseline) scenario, the amount of water required is forecast to increase to 11,200 km3 by 2050[25].

Water requirements under the optimal scenario are slightly lower than those under the maximum (baseline) scenario. There is a significant difference under the minimum scenario; water requirements are around 35% lower than the maximum (baseline) scenario (Figure 22).

3.3.3. Greenhouse gases

3.3.3.1. Methodology and issues

It has already been noted that the volume of greenhouse gas emissions depends on farming systems and feed quality. Estimations of the evolution of greenhouse gas emissions for meat and dairy use the average figure from studies in Table 15, and estimations for plant derived food use the either averages of each food group from the table, or the estimations from Wallen et al[26].

3.3.3.2. Results

In 2005, emissions from food production are estimated to have been 5.6bln tonnes. 1.9bln tonnes, or 1/3 of these emissions were due to meat production, with a further 14% caused by dairy production, and 5% by fish production. With 2005 global GHG emissions in the range of 28-40 bln tonnes, livestock[27] was therefore responsible for between 6.5 and 10% of all global emissions. Under the maximum (baseline) scenario, GHG emissions from food production are forecast to reach 10.6bln tonnes in 2050. 64% of these emissions will be attributable to livestock and fish. Total emissions from food production under the optimal and minimum scenarios would be significantly below those of the maximum (or baseline) scenario (Figures 23 & 24).

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[25] Aquastat places global water usage at 4,000km3 in 2000, with over 60% of this water used in agriculture. However, Aquastat only measures water used in irrigation, and does not account for rain fed agriculture. This explains why the model generates a higher number.

[26] Due to absence of data about greenhouse gas emissions from pulses, this category is treated as vegetables

[27] Meat and dairy only

3.3.4. Socio-economic effects

Due to a lack of hard data regarding consumer health issues at different levels of meat consumption, it is difficult to draw solid quantitative conclusions as to the effects under the different scenarios. Findings from section 2.5 on health costs seen in conjunction with consumption of red meat[28] under the different scenarios can provide some indication of potential dimensions.

As mentioned in section 2.5, Sinha et al identified a high level of red meat intake as over 51kg per capita per year, and a low level as 11kg per capita per year. The higher level was associated with a 27-50% higher chance of heart disease, and a 20-22% higher chance of cancer, with the risk increasing at levels of red meat consumption falling between this (Table 18).

Figure 25 provides an overview of the evolution of per capita red meat demand for different regions under the maximum (baseline) scenario. Under the maximum (baseline) scenario, red meat consumption in North America, Europe and Oceania would start above Sinha's high level of red meat consumption. Latin America would reach this level in 2040, while developing Asia and European ex-USSR per capita meat consumption would finish just below this level. Estimations using data from Sinha et al (Table 18) indicate that deaths from heart disease attributable to red meat consumption could increase by around 19% in Latin America, 19%-23% in developing Asia and around 10% in European ex-USSR during the period as a result. Deaths by cancer attributable to red meat consumption could increase by 8-13% in Latin America, 12-18% in developing Asia and 4-13% in ex-European USSR. One would also expect an increase in the occurrence of diabetes in the aforementioned regions.

Under the optimal scenario, red meat would be considerably lower, with no regions approaching Sinha's high level of red meat consumption (Figure 26). As a result there would be health benefits, in particular for developed country citizens vis-à-vis the status quo (maximum/baseline scenario). Once again the data from Sinha et al has been used to provide some indications as to the direction and possible scale of the effects. Deaths from heart disease attributable to red meat consumption could fall by 18-28% in North America, and 13-18% in Europe. Similarly, deaths from cancer attributable to red meat consumption could fall by 16-32% in North America, and 8-19% in Europe. Reduced red meat consumption could also lead to a fall in the prevalence of diabetes.

[28] The USDA definition of red meat is used; beef, lamb and pork. While pork is sometimes considered a white meat, most of the studies cited in section 2.5, including the study by Sinha et al classify it as a red meat.

Finally, the minimum scenario poses different health issues. The FAO concluded that 20g of animal protein per day were necessary to effectively combat malnutrition. Figure 27 shows the evolution of animal protein intake under the minimum scenario. Animal protein consumption would start above this FAO's identified level in all developed regions and European ex-USSR. While in Latin America animal protein intake would start at 15g per day in 2005, the 20g per day threshold would be reached by 2025. Developing Asian intake would start considerably below the 20g level at 11g, but like Latin American intake it would breach the 20g threshold by 2025. Africa would remain under the threshold for almost the entire period under this sceanario; animal derived protein intake would start at only 6g per person per day in 2005, and would only touch the 20g target in 2050. For reference, actual 2003 animal derived protein intake in Africa was 10g per capita per day.

4. POSSIBLE POLICY OPTIONS AND ACTIONS

The previous sections have demonstrated that the expansion of certain western consumption patterns at current rates to the developing world is environmentally unsustainable. Furthermore, the literature reviewed suggests that such consumption patterns have negative health effects. In view of these facts, a reduction in meat consumption in those parts of the developed world where it is currently deemed to be excessive, as well as avoidance of the replication of these dietary patterns in parts of the developing world where rapid industrialisation, income growth and urbanisation are currently occurring, would be advantageous.

Potential alternatives to meat have already been examined in section 2.6. However, as seen in this section, fish does not appear to constitute an environmentally sustainable alternative to meat on a global scale as resources are already being overused by this sector; also, algae and in vitro technologies remain several years away from being realistic alternatives. These alternatives are therefore not currently considered to be viable for wide introduction at world level, although research in these areas could and should be further encouraged.

Assuming a move in the direction of an 'optimal' scenario is seen as desirable there are a number of areas of policy or actions set out below which could be undertaken to move towards this goal. This section is divided as follows: first, existing legislation is examined, and then policy options are suggested based on three different areas: taxes; subsidies; mitigation techniques; awareness raising and market change. These measures may be targeted at the meat production chain or at consumers. It is noted that these suggestions do not address the issue of meat and feed supply and the fact that options in this area could also be developed e.g. in the form of measures which might be needed to ensure improved availability of feed by means of greater investment in agriculture notably on measures to reduce inputs as well as increasing output.

It is noted that the options and actions discussed below are not meant to provide an exhaustive list, or to advocate a single approach. Addressing the environmental and health impacts of alternative diets requires a multidisciplinary approach because it touches both on issues of the supply chain and of consumer behaviour. This effectively means that there are several points along the supply and demand chain at which these issues can be tackled.

Policy options discussed in this section are therefore only intended as food for thought, and are rather conceptual. Before more serious consideration of any of the policy options were to be undertaken it would be necessary to (1) further develop the concepts outlined, and (2) complete an impact analysis in order to ascertain the effects, both desired and undesired, of the implementation of any such policies. Such a comprehensive impact analysis is beyond the scope of the current study.

4.1. Existing legislation

Currently there a number of items of European legislation which deal directly or indirectly with pollution problems arising from livestock production activities. For background these are summarised briefly below.

Directive 2001/81/EC, aims to decrease emissions from atmospheric pollutants (sulphur dioxide (SO2), nitrogen oxide (NOx), volatile organic compounds (VOC) and ammonia (NH3)). The Directive provides for national emission ceilings by country.

The 'Nitrates Directive' (91/676/EEC) aims to reduce the level of nitrates in the soil and water used in agriculture activities by limiting the used amount of fertiliser and manure (containing nitrates up to a certain level). National programmes have been implemented to decrease water and soil contamination.

Directive 96/61/EC established the need for measurement and registration of emissions caused by intensive poultry and pig farms (above 40,000 chickens, 2,000 pigs (over 30kg) and/or 750 sows). It is compulsory for these installations to implement techniques to reduce ammonia emissions. In 2008 it was replaced by the Directive 2008/1/EC (also called the 'IPCC Directive') which consolidated all initiatives to decrease air, water and soil pollution in one framework.

Directive 97/11/EC requires an Environmental Impact Assessment (EIA) to obtain permission for the building of installations of a particular dimension. This assesses the potential environmental impact for human beings, fauna and flora, soil, water, air climate and landscape, material assets and cultural heritage, and the interactions of all these factors with the proposed installation.

Consideration could be given to extending the scope of one or more of these measures to address the climate change impacts of livestock production which are not currently taken into account.

4.2. Taxes and subsidies

4.2.1. Taxing externalities

The direct cost of meat production (breeding, fattening, and slaughtering, processing, packaging, transport) are normally passed on to consumers, with the amounts differing depending on the level of subsidies received by the livestock sector. Walker *et al.* suggest one of the ways to decrease meat production is by passing on to consumers the externality costs of meat production. Externalities are those costs which do not arise directly from the meat production process, but can be related to the livestock industry in one or more stages of meat production. Examples of such externalities might be natural resources depletion, health hazards arising for farm workers and nearby communities, and the impact on the environment of the use in agriculture of highly polluting substances.

The key problem in terms of potentially having these costs 'internalised', i.e. built into the cost of production, is how such costs are to be measured i.e. what value society places on the avoidance of such costs[29]. Assuming this can be done in a fashion which society agrees on it is argued that if these costs were passed on to the livestock production chain, e.g. in the form of a tax, it would encourage this chain to take action to mitigate costs e.g. by reducing potential pollution. The effect and benefit of such an action would, however, need to be weighed against the cost to consumers and particularly those in lower income groups who spend a higher proportion of their income on food, arising from increased food costs.

4.2.2. Grants/financial support

Unless there is legislation to force compliance with standards individual producers do not have a strong incentive to invest in technology/farm management techniques which reduce adverse external effects as these costs are not borne by them directly. This is compounded by the fact that the capital needed for the implementation of e.g. GHG mitigation techniques (which may require on-farm structural changes) and investment in better quality products to lower emissions may be high. This decreases farmers' willingness to take such steps e.g. by joining animal waste management schemes. Governments may therefore address the public interest in having such measures introduced by introducing grants, low interest loans or other support measures to cover these 'non-market' costs.

4.2.3. Emissions ceilings

In order to enforce the implementation of "greener" techniques, governments could consider the application of emission ceilings per farmer/sector and agricultural chain – along the lines of what is already implemented for large industrial livestock units for other potentially polluting substances. To enforce the policy, producers who exceeded the ceilings would have to pay a penalty or have a reduction in entitlement to support payments.

4.3. Mitigation techniques

4.3.1. Biogas production

Biodigestors are elements of animal waste management schemes (AWMS) designed to minimise GHG emissions, odours, water and soil contamination produced by livestock manure. The use of biodigestors in livestock production may generate a number of environmental and economic benefits as these produces energy in the form of gas and fertiliser, increasing the self sustainability of farms. The principle is to collect manure from livestock and place it in a covered lake containing water. The bacteria in the manure in contact with the water will start a 'digestion' process and release methane[30].

[29] According to Pretty et al, the external costs of modern agriculture (water, air, soil, biodiversity, landscape and health (this includes pesticides, nitrates and microorganisms/disease agents)) were £2.342 billion in the UK, £21billion in the USA and £1.230 billion in Germany.

[30] Manure from grain fed animals is more efficient when in contact with water in the biodigestor than manure from grass fed animals. The ratio of water and manure is 1:1 for grain fed and 2:1 for grass fed.

The gas collected expands inflating the plastic/fibre which covers the lake (like a balloon). Through pipes connected to the biodigestor, the gas produced is directed to farmhouse appliances and the remaining manure is used as fertiliser. It is estimated that emissions may be reduced by up to 50% in cold climates and up to 75% in hot climates by implementing this technique (FAO, 2006).

AWMS may additionally provide benefits to intensive livestock farms as the introduction of biodigestors enables certification for carbon market trading – considered to be a way to offset the high price to build the biodigestor. This could be supplemented by additional public support for such investments.

4.4. Carbon market awareness and support

Large farmers are already able to trade carbon credits in the market, but the level of bureaucracy procedures, market uncertainties and a lack of awareness of this possibility, constrain the use of the scheme and there may therefore also be scope for more public assistance in this field.

4.5. Awareness and market changes

4.5.1. Increase in plant-derived ingredients in minced-meat and meat based products

According to Smil, worldwide 30-40 million tonnes of meat are consumed in either ground form or in processed food. Substitution of meat by plant-derived protein of up to 5% of the total amount of meat in some foodstuff is already in place. Increasing the percentage level of substitution of meat using plant-derived protein throughout the food industry would contribute to a decrease in meat consumption, without major effects on people's dietary habits – but with an implied lower intake of meat.

4.5.2. Information and awareness campaigns

Organisations from the private, public and third sectors regularly campaign on healthy eating and climate change through television adverts, pamphlets and publications. These initiatives are important to increase people's awareness but are normally restricted to a particular area or audience. If a consensus could ever be achieved on the contentious and difficult measurement issues involved, the option of labelling the carbon emissions (possibly also other pollutants or resource use such as water) arising from food production could be an efficient way of informing consumers and raising environmental awareness on what the consumption of alternative food product entails.

Concerted actions could also play a role. All around the world, many organisations from different sectors promote days in the year to highlight particular issues. In periods of meat shortage, governments established meat free days as a way of tackling the food deficit and conversely now. With the aim of encouraging healthier diets (and changing habits in the long-term) governments and organisations from the meat and plant-production sector could promote meat free days. This idea is supported by UN specialists on climate change who claim one meat-free day per week would help to tackle climate change more than reducing car journeys.

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APPENDIX

1.1 Tables

5.1. 1.2 Figures

Table 1 Human consumption of agricultural products in 2003 (kg per person per year)

Source	Meat[31]	Fish and seafood	Animal fats	Eggs	Milk excl. butter	Plant derived[32]
World[33]	39	16	3	8	80	407
Developed countries	80	23	8	12	201	414
North America Developed[34]	121	21	7	14	256	426
Europe (inc. Russian Federation)[35]	74	20	11	12	214	440
Developing countries	28	13	2	7	48	404
Latin America and Caribbean[36]	59	8	2	7	105	348
Asia developing (Asia exc. Japan)[37]	27	16	2	8	42	412
Africa[38]	14	7	0	2	38	395
LDC	9	7	0	0	28	306

Source: FAOStat

Note: FAOStat collects this data on an annual basis via a country based questionnaire. Consumption is calculated by totalling production, exports, imports and start / end of year balances, then subtracting non-human consumption uses (e.g. feed, waste, etc). In this sense, the accuracy of the consumption data is dependent on the both the country's collection methods (e.g. whether it manages to include factors such as backyard farming) and the accuracy of data relating to non-human consumption uses of products.

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[31] Beef, mutton, pigmeat and poultry, expressed as carcassweight

[32] Cerals, fruits, vegetables, pulses, starchy roots and oilcrops. Weights are based on fresh or dry weights (depending on the commodity).

[33] The groupings used in this table are the principle groupings which will be used during the duration of the study. The footnote by each grouping indicates the countries included in the FAO's definition of this region. It is worth noting that not all countries submit data to the FAO – this explains the absence of some countries.

[34] USA and Canada

[35] EU-27 – Cyprus, + Albania, Belarus, Bosnia and Herzegovina, Croatia, Iceland, Moldova, Norway, Russian Federation, Serbia and Montenegro, Switzerland, FYROM and Ukraine.

[36] Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, Grenada, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Netherland Antilles, Nicaragua, Panama, Paraguay, Peru, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and Grenadines, Suriname, Trinidad and Tobago, Uruguay, Venezuela

[37] Bangladesh, Brunei, Cambodia, China, Cyprus, India, Indonesia, Iran, Jordan, DPR Korea, Republic of Korea, Kuwait, Lao, Lebanon, Malaysia, Maldives, Mongolia, Myanmar, Nepal, Occupied Palestinian Territory, Pakistan, Phillipines, Saudi Arabia, Sri Lanka, Syria, Thailand, Timor-Leste, Turkey, UAE, Vietnam, Yemen

[38] Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, CAR, Chad, Comoros, Congo, DRC, Cote d'Ivoire, Djibouti, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome e Principe, Senegal, Seychelles, Sierra Leone, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia, Zimbabwe

Table 2 WHO safe limits for protein intake for normal adults

Body weight (kg)	Safe level of protein intake (g per day)
40	33
50	42
60	50
70	58
80	66

Source: WHO

Note: WHO notes that it is unlikely that intakes of twice the safe level are associated with risk, though caution is advised with intakes beyond this. Corrections may need to be made for the quality of protein.

Table 3 Daily dietary reference intakes (DRI) for U.S. and Canada

Age category (years)	Male			Female†		
	14-18	*19-50*	*51+*	*14-18*	*19-50*	*51+*
Water (litres)	3.3	3.7	3.7	2.3	2.7	2.7
Carbohydrate (g)	130	130	130	130	130	130
Fibre (g)	38	38	38	26	25	21
Fat (g)	Unidentified	Unidentified	Unidentified	Unidentified	Unidentified	Unidentified
Linoleic acid (g)	16	17	14	11	12	11
Alpha linoleic acid (g)	1.6	1.6	1.6	1.1	1.1	1.1
Protein (g)	52	56	56	46	46	46

Source: USDA / U.S. National Academy of Sciences / U.S. Institute of Medicine / U.S. Food and Nutrition Board

Notes: † Pregnant and lactating females have different, generally higher requirements.

Table 4 The protein content of selected popular foodstuffs

Source	Protein (g) per 100g
Raw soya beans	36.5
Cooked leg of pork	30.9
Cooked (roasted) chicked breast	29.8
Raw Spanish peanuts	26.1
Cooked ground beef	24.1
Oats	16.9
Sun-dried tomatoes	14.1
Fried egg	13.5
Boiled chickpeas	8.9
Raw carrots	1
Raw bananas	1

Source: USDA

Table 5 Protein intake in grams per capita per day for different regions of the world

	Total	Meat	Fish and seafood	Eggs	Milk excl. Butter	Plant derived
World	67	13	4	2	7	41
Developed	92	27	6	3	17	39
North America Developed	105	40	4	4	22	35
Europe inc. Russian Federation	90	25	5	3	18	39
Developing	61	9	3	2	4	43
Latin America and Caribbean	70	20	2	2	9	37
Asia developing	63	9	4	2	4	44
Africa	53	5	2	0	3	43
LDC	47	3	2	0	2	40

Source: FAOStat

Table 6 World population trends until 2050

	2005	2010	2020	2030	2040	2050
World	6,514,751	6,906,558	7,667,090	8,317,707	8,823,546	9,191,287
Developed	1,215,636	1,232,457	1,253,852	1,260,770	1,256,835	1,245,247
Developing	5,299,115	5,674,101	6,413,238	7,056,937	7,566,711	7,946,040
LDC	766,816	863,394	1,075,104	1,300,634	1,527,425	1,741,959

Source: UN Population Division

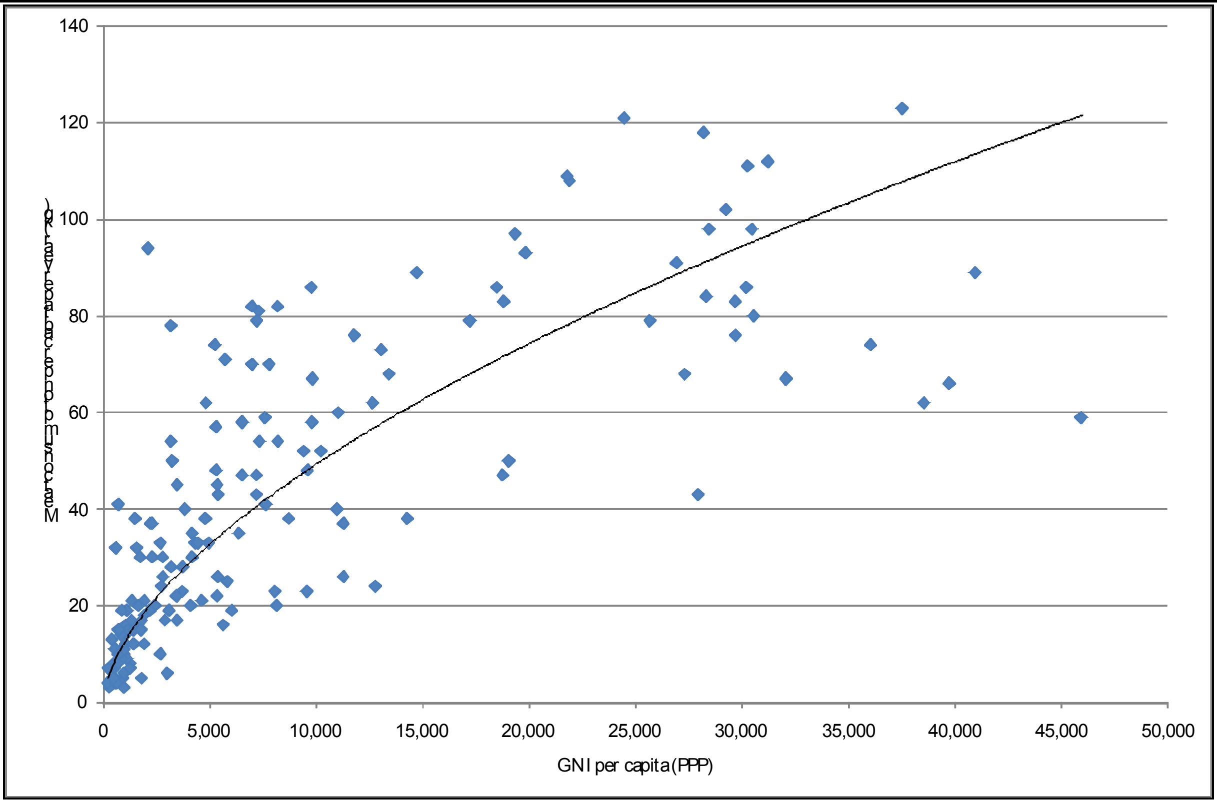

Figure 1 Relationship between income and meat consumption, 2003

Source: Agra CEAS Consulting based on figures from World and Bank and FAO

Table 7 Income elasticities for different meats

Real per cap GDP USD (1985)	1,000	2,000	3,000	4,000	5,000	6,000	7,000
Real per cap GDP USD (2003)‡	1,725	3,450	5,175	6,900	8,625	1,0350	1,2075
Pork	1	0.85	0.75	0.65	0.6	0.55	0.5
Beef	2.75	2.2	1.85	1.65	1.5	1.35	1.25
Poultry	1.8	1.3	1.05	0.8	0.7	0.55	0.45
Lamb	3.8	2.4	1.5	0.8	0.4	0	-0.4

Source: Schroeder, Berkley and Schroeder

Notes: ‡ Converted using the average of the Consumer Price Index (1.71) and the average value of the annual expenditure of a family/household (1.74) rates for the period 1985-2003

Table 8 GDP (PPP) per capita annual growth rate projections 2006-2050

Country / Region	2000-2006 (actual growth)	2006-2025	2025-2050
United States	1.6	1.6	1.6
Canada	1.6	1.9	1.6
Japan	1.5	1.7	1.5
China	9.0	6.1	3.3
India	5.6	6.3	5.1
Brazil	1.5	3.0	3.5
Russian Federation	6.7	4.0	2.5
Australia-New Zealand	1.9	2.0	1.6
EU27 + EFTA	1.7	2.3	1.8
OPEC + Other oil producers	2.9	3.0	4.2
Rest of the World	2.8	3.3	3.7
Total world	2.5	2.8	2.9

Source: OECD

Table 9 Urban elasticity of animal derived product demand for developing regions

Product	Urban population share elasticity
Beef	-0.20
Pork and mutton	0.46
Poultry	0.38
Milk	-0.17

Source: Agra CEAS adapted from IFPRI 1999

Table 10 Forecast urbanisation rates, 2005-2050 (% of population living in urban areas)

	2005	2010	2020	2030	2040	2050
World	48.6	50.6	54.9	59.7	64.7	69.6
Developed	74	75	77.5	80.6	83.5	86
North America Developed	80.7	82.1	84.6	86.7	88.5	90.2
Europe excl. Ex Russia	71.9	72.6	74.8	77.8	81	83.8
Developing	42.7	45.3	50.5	56	61.6	67
Latin America and Caribbean	77.5	79.4	82.3	84.6	86.8	88.7
Asia developing	38.8	41.7	47.5	53.6	59.9	65.9
Africa	37.9	39.9	44.6	50	55.9	61.8
LDC	27	29.4	35	41.5	48.4	55.5

Source: Agra CEAS adapted from UN Population division

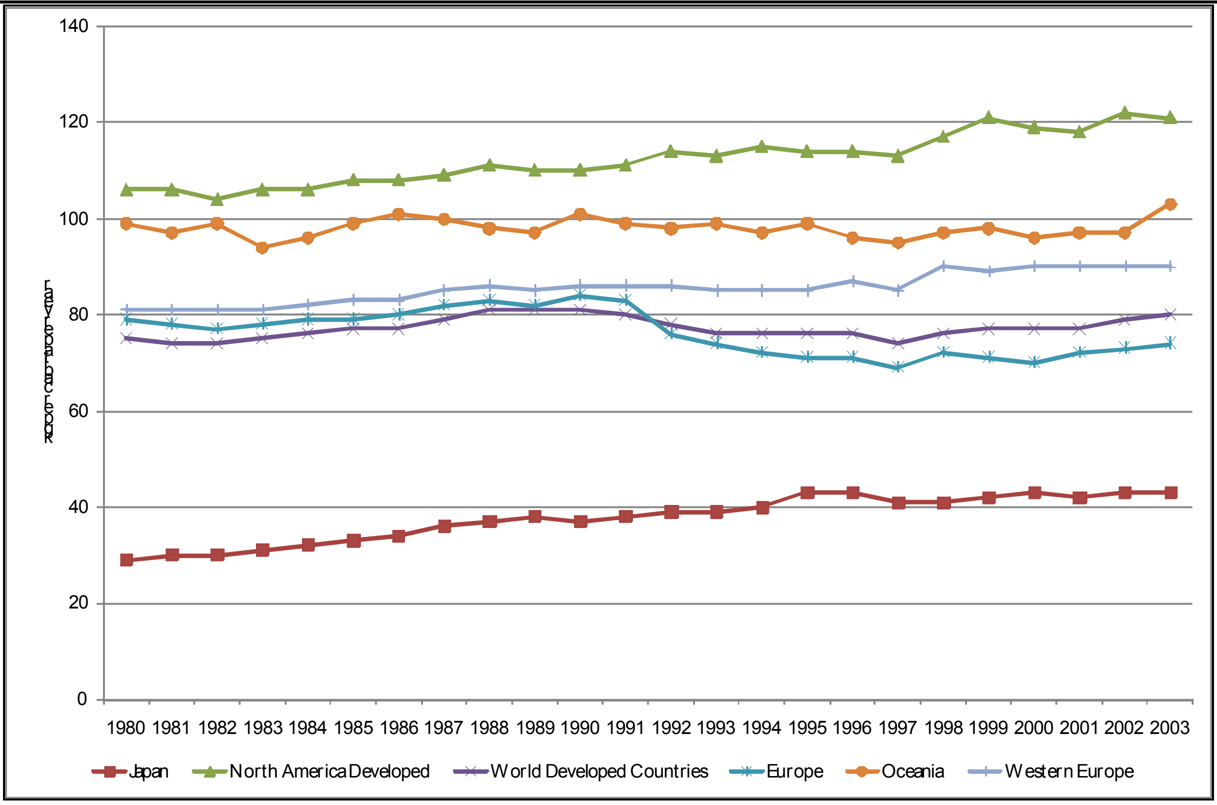

Figure 2 Meat consumption per capita in different developed regions (kg per year)

Source: FAO Stat

Note: the 1991/92 fall in European and developed world per capita meat consumption, and part of the subsequent recovery is due to the inclusion of European Ex-USSR in the dataset (including the Russian Federation).

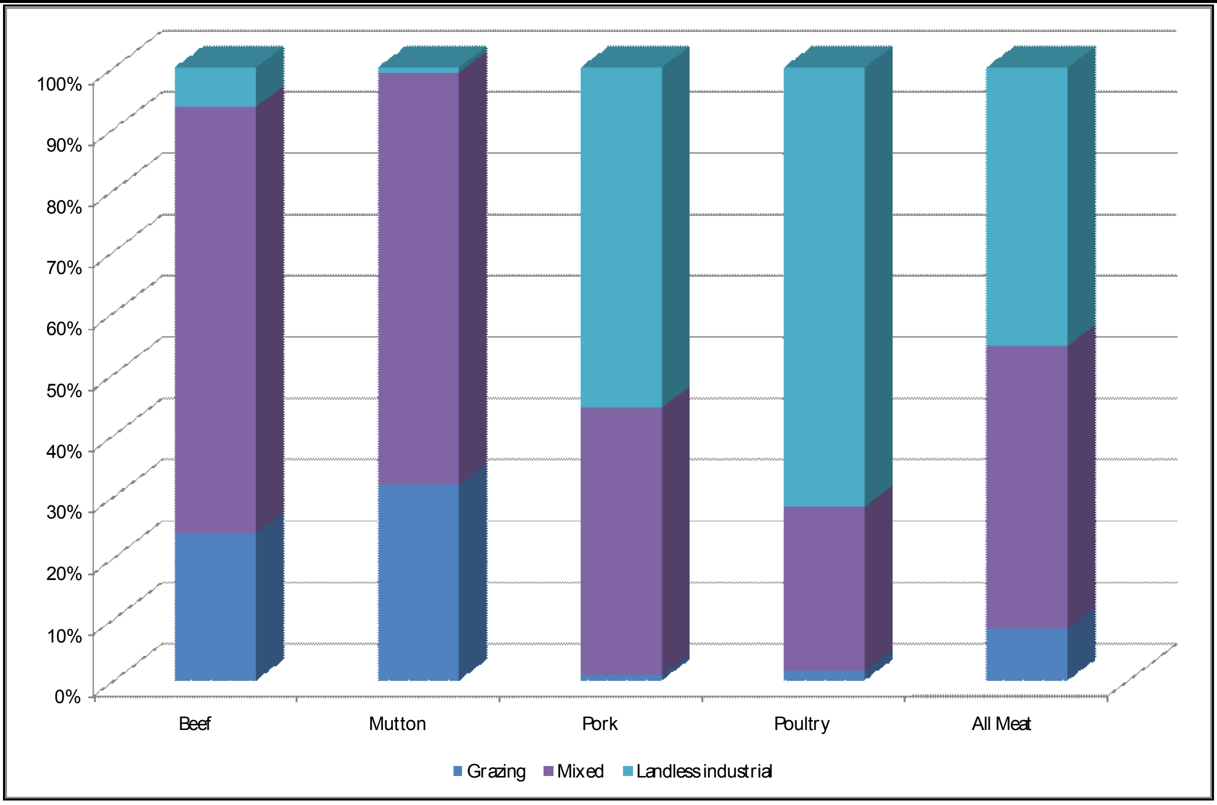

Figure 3 Percentage of meat produced under various production systems, 2001-2003

Source: FAO elaborated by Agra CEAS Consulting

Table 11 Feed conversion ratios (grain feed (kg) required per 1kg of meat)

Author	Pigmeat	Poultry	Beef	Mutton
McMichael et al 2005	4kg	2kg	9kg	-
Walker et al 2005	4kg	2kg	7kg	-
Dalgaard et al 2007	2.64kg	-	-	-
FAO 2006 (feed conversion ratios)	-	2-4kg	7kg	7kg
National Pork Board (feed conversion ratios)	3.4-3.6kg	2kg	7-10kg	-
Aikin and de Boer (2006)	4-5.5kg	3kg	10kg	-
Pimentel and Pimentel (2003)	5.9 kg	2.3-3.8 kg	13 kg	21 kg

Note: Based on industrial production unless otherwise stated

Source: Agra CEAS

Table 12 Global crops used for feedstock, 2003 (million tonnes)

Crop	Amount
Cereals (total)	681.4[39]
Wheat	91.6
Rice	7.1
Barley	95.2
Maize	414.2
Rye	8.1
Oats	19.4
Millet	3.2
Sorghum	26.6
Other	16.2
Starchy roots	147.2
Sugarcrops	19.9
Pulses	11.5
Oilcrops	23.0
Vegetables	30.1
Fruits	5.1

Source: FAO

[39] Total may be different from the sum of individual crops due to rounding

Table 13 Agricultural water requirement (litre per kg)

Livestock/Crop	Defra – env burden & resource use – Aug/06	Hoekstra & Hung 2003	Chapagain & Hoekstra 2003	Zimmer & Renault 2003	Oki et al 2003	Liu and Savenije, 2008†	Pimentel and Pimentel, 2007	Water-footprint
Cattle (beef)			15,977	13,500	20,700	12,560	43,000	15,500
Cattle (dairy)			865	790	560	1,000		1,000
Sheep						4,500		6,100
Goat								4,000
Swine			5,906	4,600	5,900	4,460		4,800
Poultry			2,828	4,100	4,500	2,390	3,500	3,900
Eggs			4,657	2,700	3,200	3,550		3,333
Fish and seafood						5,000		
Potato	0.021 (irrigation)	160		105		230	500	
Tomato	0.039 (irrigation)							
Barley		1,057						1,300
Bean dry		3,171						
Maize		450		710	1,900	840	1,400	900
Millet								5,000
Oats								
Sorghum							1,100	2,800
Soybean		2,300		2,750	2,500	3,200	2,000	1,800
Sweet potato								
Vegetables				1,160		190		
Wheat		1,150			2,000	980	900	1,300
Alfafa							900	
Rice		2,656		1,400	3,600	1,310	1,900	3,400
Apples						500		700
Oranges						500		
Other Cereals						1,240		
Fish						5,000		
Cheese								5,000

Notes: †Original data in m^3/kg. Final values by taking the given number and x 1000 (litre/kg).
‡ Original data in m^3/ton. Final values by taking the given number and /1000 (litre/kg)

Source: Agra CEAS

Table 14 Global livestock emissions per year (million tonnes of GHG)

Livestock	Carbon dioxide	Methane (enteric)	Methane (manure)
Cattle	1,906	75	8
Sheep and goats	514	9	0.3
Swine	590	1	8
Poultry	61	-	1

Source: McMichael, 2007
Notes: Includes dairy cattle which are estimated to be responsible for one quarter of total cattle methane emissions.

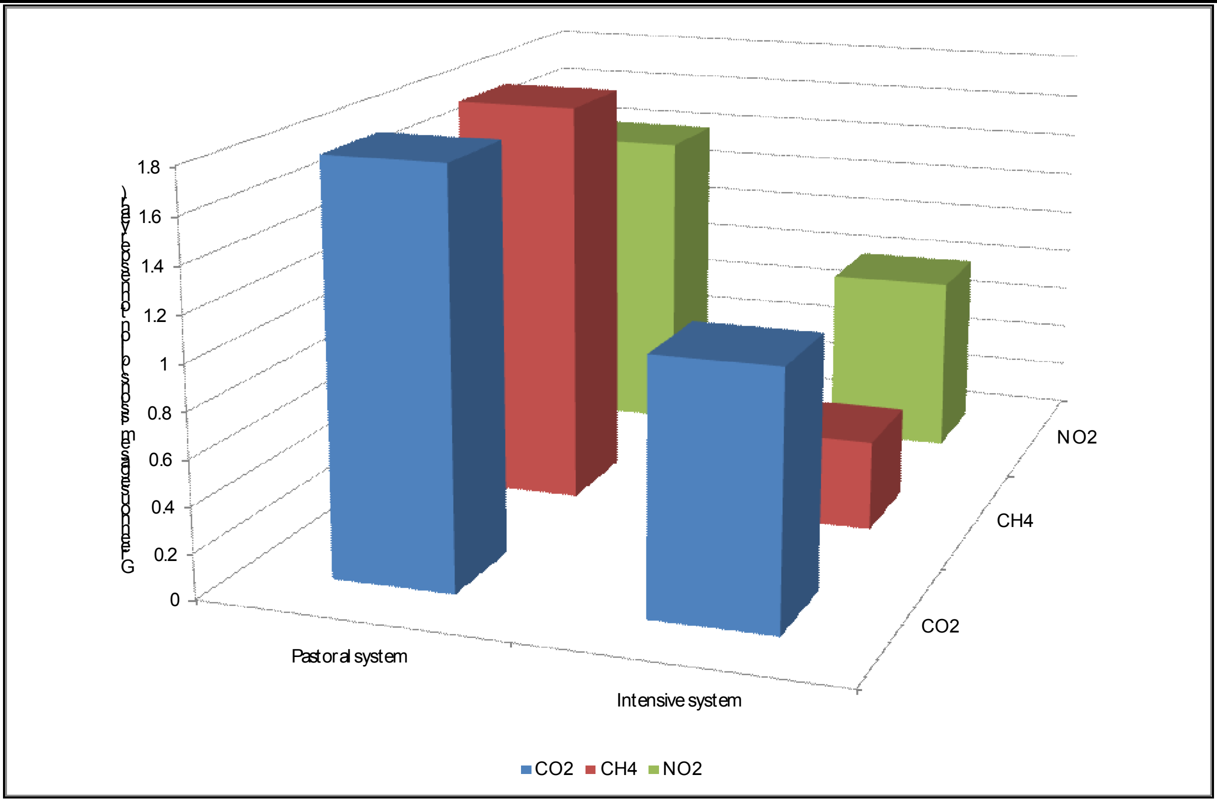

Figure 4 Direct emissions from pastoral and intensive livestock systems per year worldwide (billion tonnes of GHG)

Source: FAO

Table 15 Greenhouse gas emission estimations by different authors (kg CO2 eq per kg product)

Livestock /Crop	American association for the advance of science	Defra – env burden & resource use – Aug/06	Kramer et al, 1999	Dalgaard, Halberg and Hermansen – Nov/07	IDD Institute-Wallon-Vito†	Phetteplace, Johnson, Seidl-2001	Fiala, 2008	Wallen et al. 2004
Cattle (beef)		16		37.0	14.8	15.5	14.8	6.25
Cattle (dairy)		1.1				1.38		0.41
Sheep		17			7.6			
Swine		6.4		3.6	3.6		3.8	6.1
Poultry		4.6		3.6	2.1		1.1	2.81
Eggs		5.5						2.48
Bread wheat		0.80						0.76
Oilseed rape		1.7						
Soybean meal				0.934				
Barley				0.694				
Potato		0.24						0.17
Tomato*		9.4						3.29
Root crops								0.5
Onions / cabbages								0.5
Vegetables other than onion / cabbage								3.3
Apples								0.24
Bananas								0.45
Oranges								0.25
Other fruit								0.29 1.68
Rice			0.40					
Wheat			0.32					
Barley			0.04					
Sugar beet	1.8-3.3							2.60 8.0
Fish								0.98
Cheese								
Butter								

Notes: ‡ Emissions high due to transport from Rotterdam port to farms.
†Indirect emissions

* Emmissions from tomatoes vary greatly based on the growing method used (e.g. if they are greenhouse grown with artificial heat and light) and how they are shipped. The full range of estimates is from 0.1 to10kg CO2 per 1kg tomatoes.

Table 16 Fossil fuel input required for different agricultural outputs (MJ/kg)

Livestock/Crop	Roberto Sainz – non FAO[1]	Boer, 2002	Brand & Melman (1993)*	DEFRA (2005)	Wallen et al (2004)
Cattle (beef)			15.5	28	55.56
Cattle (dairy)		2.7		2.5	3.62
Sheep			19.3	17	
Swine			18.9	17	21.06
Poultry			18.1	12	25
Eggs				14	22.18
Alfafa	1.59				
Barley	3.81				
Cane molasses	5.81				
Hay	2.77				
Maize	5.13				
Oats	2.75				
Sorghum	5.87				
Soybeans	5.90				
Wheat	4.03				
Potatoes				1.4	1.17
Oilseed rape				5.4	
Bread wheat				2.4	8.14
Rice					8.82
Pulses					4.88
Root crops					2.32
Onions					2.33
Cabbages					2.33
Tomatoes					37.68
Other vegetables					37.79
Apples					2.87
Bananas					5.34
Oranges					2.96
Other fruit					3.42
Cereal grains (average)	4.72				38
Fish products					26.41
Cheese					8.75
Butter					

Notes: Includes energy from production, transport and processing
* Includes feed production, animal production and fattening. Transport of final goods not included.

Table 17 Fossil fuel input: output ratio for selected livestock and crop

Livestock (kcal)	Ratio of energy input to protein output (kcal)
Lamb	57:1
Beef cattle	40:1
Eggs[40]	39:1
Pig	14:1
Dairy cattle	14:1
Poultry	04:1
Corn	02:1

Source: Pimentel and Pimentel, 2003.

Table 18 Increase in risk of death by heart disease and cancer due to red meat consumption

Quartile (1=lowest intake, 5=highest intake)	Q1	Q2	Q3	Q4	Q5
Male red meat intake (g/kcal)	9.3	21.4	31.5	431	68.1
Female red meat intake (g/kcal)	9.1	21.2	31.2	42.8	65.9
Adjusted cancer mortality (male)	1 (reference)	1.05	1.13	1.18	1.22
Adjusted cancer mortality (female)	1 (reference)	1.02	1.06	1.20	1.20
Adjusted cardiovascular disease mortality (male)	1 (reference)	0.99	1.08	1.18	1.27
Adjusted cardiovascular disease mortality (female)	1 (reference)	1.13	1.26	1.39	1.50

Source: Sinha *et al*, 2009

[40] The high ratio of energy input per protein output in egg production is due to hen's high consumption of grains during this phase.

Table 19 BMI measure in male and female meat and non-meat eaters

BMI (kg/m²)	Men		Women	
	Meat eaters	Non-meat eaters	Meat eaters	Non-meat eaters
<20.0	91 (9%)	163 (17%)	265 (18%)	622 (33%)
20.0 – 25.0	676 (69%)	684 (73%)	1,010 (69%)	1,137 (60%)
25.0 – 30.0	187 (19%)	89 (9%)	166 (11%)	129 (7%)
>30.0 (Obese)	21 (2%)	3 (0%)	29 (2%)	20 (1%)

Source: Appleby *et al*, 1998

Table 20 Mean nutrient intake per person/day (% of energy intake)

	Men				Women			
	Meat-eater	*Fish-eater*	*Vegetarian*	*Vegan*	*Meat-eater*	*Fish-eater*	*Vegetarian*	*Vegan*
Energy (*total kcal*)	2,233	2,153	2,120	1,967	1,921	1,859	1,824	1,681
Protein	15.8	13.9	13.0	12.9	17.1	14.8	13.8	13.4
Fat	32.4	31.4	31.2	28.5	31.6	30.8	30.4	27.9
Saturated fat	10.9	9.6	9.4	5.1	10.4	9.4	9.4	5.1
Polyunsaturated fat	5.2	5.7	5.7	7.7	5.1	5.4	5.3	7.2
Monounsaturated fat	10.0	9.0	8.7	8.2	9.5	8.7	8.4	7.8
Carbohydrates	46.7	49.4	51.1	54.3	48.3	51.0	52.8	56.1
Total sugars	23.1	23.3	23.7	23.3	24.5	25.2	25.8	25.0

Source: Spencer et al, 2003

Table 21 Risk of diabetes type 2 associated with consumption of processed meat

Total processed meat	<1 month	1-3 month	1 week	2-4 week
Cases/person	114 / 61,065	278 / 113,393	251 / 104,561	443 / 131,701

Source: van Dam et al, 2002

Notes: Total processed meat: bacon, hot dogs, sausage, salami and bologna.

Table 22 US expenditure related to cardiovascular diseases in 2006 (US$ billion, estimate)

	Coronary heart disease	Stroke	Hypertensive disease	Heart failure	Total cardiovascular diseases
Direct costs (total expenditures)[1]	75.2	37.3	47.5	26.8	257.8
Indirect costs[2]	67.3	20.6	16.0	2.8	145.5

Source: American Heart Association, 2006.

Notes: [1]Includes expenditure on: hospital, nursing home, physicians/other professionals and drugs [2] Includes costs due to lost productivity, morbidity and mortality.

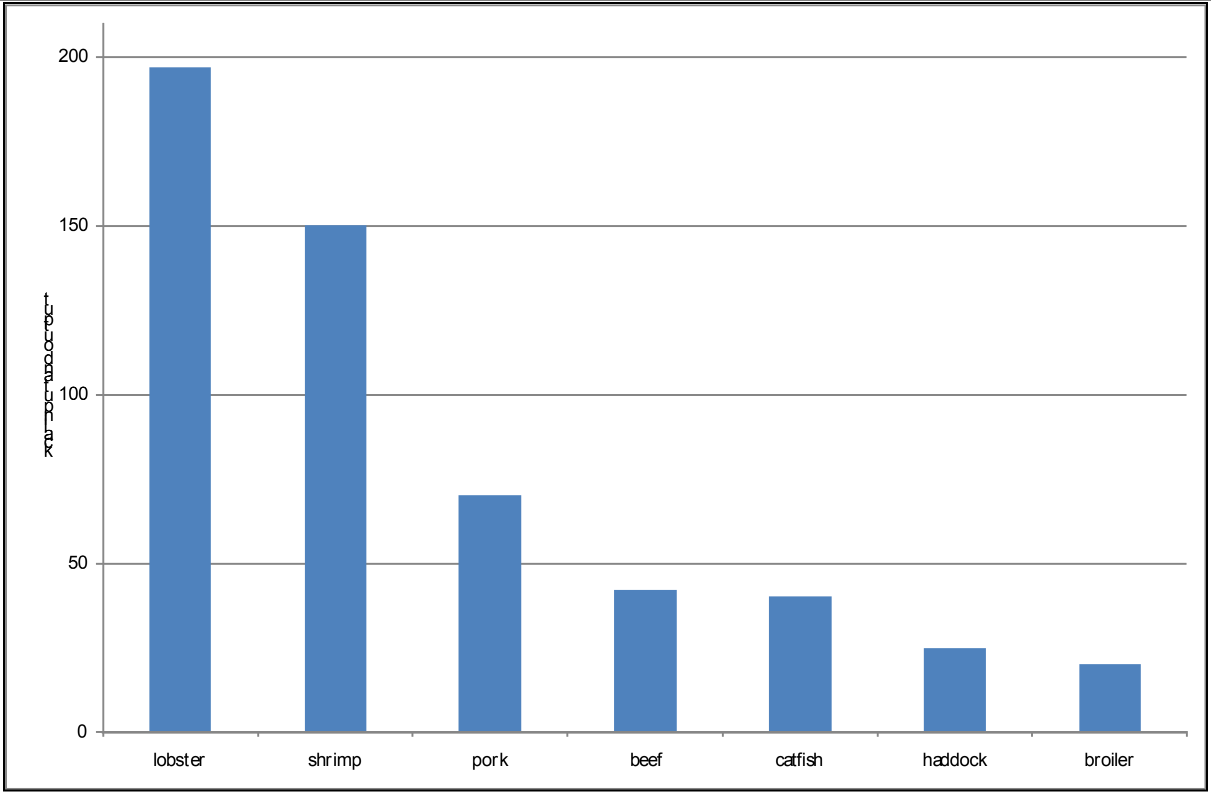

Figure 5 Fossil energy input per protein output

Source: Pimentel *et al*, 2007

Table 23 Wild fish intake per kg of farmed fish

Farmed fish	Ratio: kg of wild fish per kg of farmed fish produced
Marine finfish†	5.16
Eel	4.69
Marine shrimp	2.81
Salmon	3.16
Trout	2.46
Tilapia	1.41
Milkfish	0.94
Catfish	0.84
Carp	0.75

Source: Naylor et al, 2000

Notes: †Includes flounder, halibut, cole, cod, hake, haddock, redfish, seabass, congers, bonito, tuna and billfish

Table 24 General composition of algae and other types of food

Product	Protein	Carbohydrate	Lipid
Meat	43	1	34
Milk	26	38	28
Rice	8	77	2
Soybean	37	30	20
Anabaena cylindrical	43-56	25-30	4-7
Algae varieties			
Chlamydomonas rheinhardii	48	17	21
Chlorella vulgaris	51-58	12-17	14-22
Dunaliella salina	57	32	6
Porphyridium cruentum	28-39	40-57	9-14
Scenedesmus obliquus	50-56	10-17	12-14
Spirulina maxima	60-71	13-16	6-7
Synechococcus sp.	63	15	11

Source: Spolaore et al, 2005

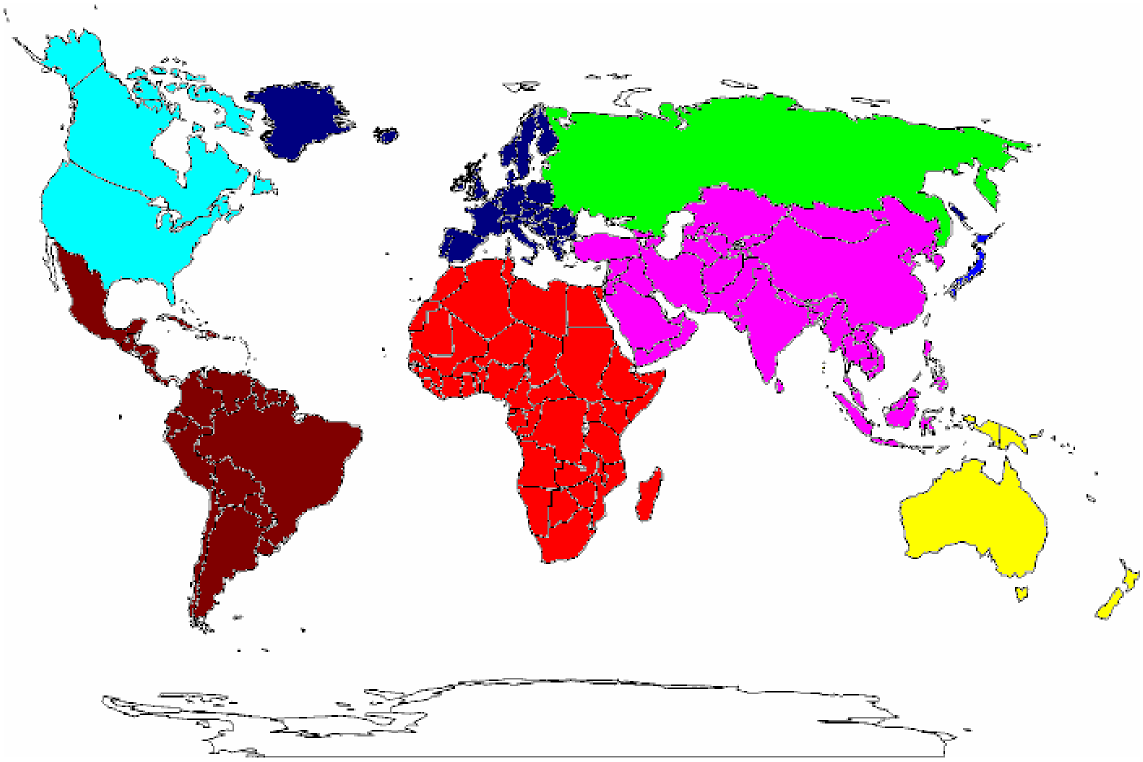

Figure 6 Regional groupings for model

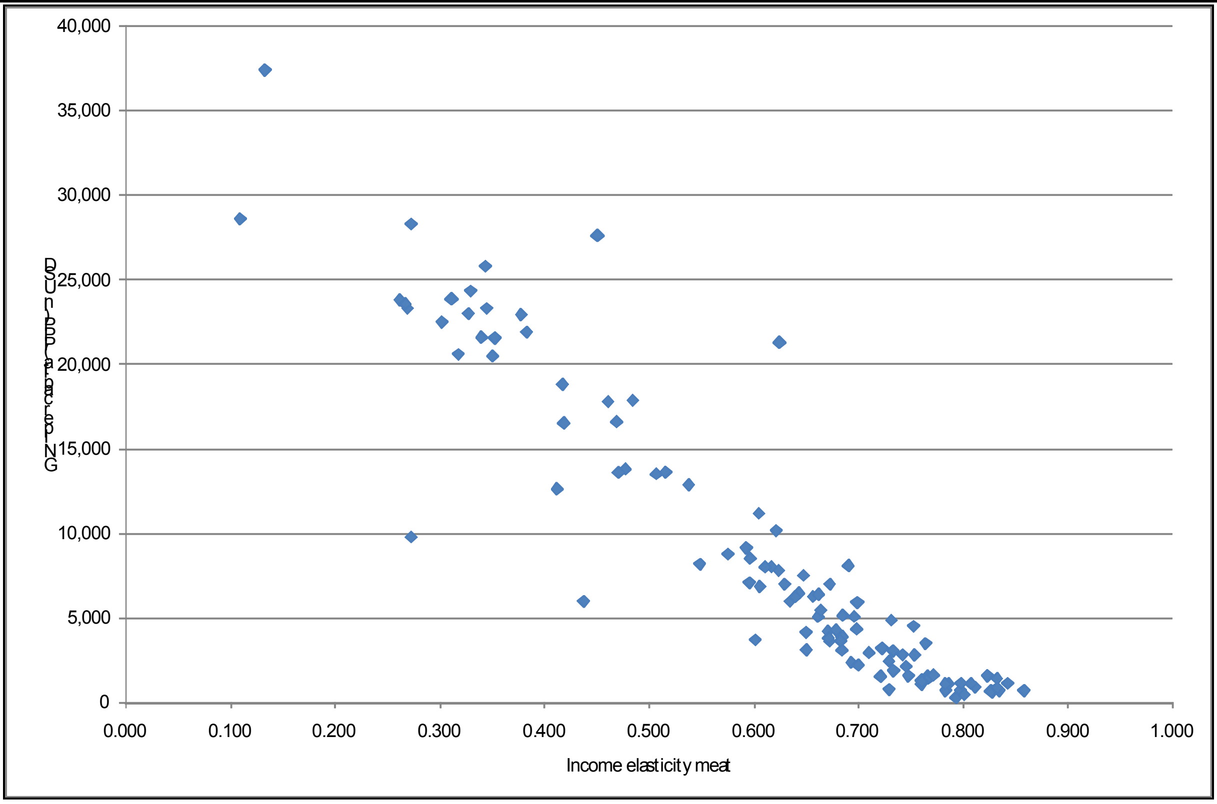

Figure 7 Income elasticities for meat at different levels of income

Source: Agra CEAS own elaboration based on data from ERS and World Bank from 1996

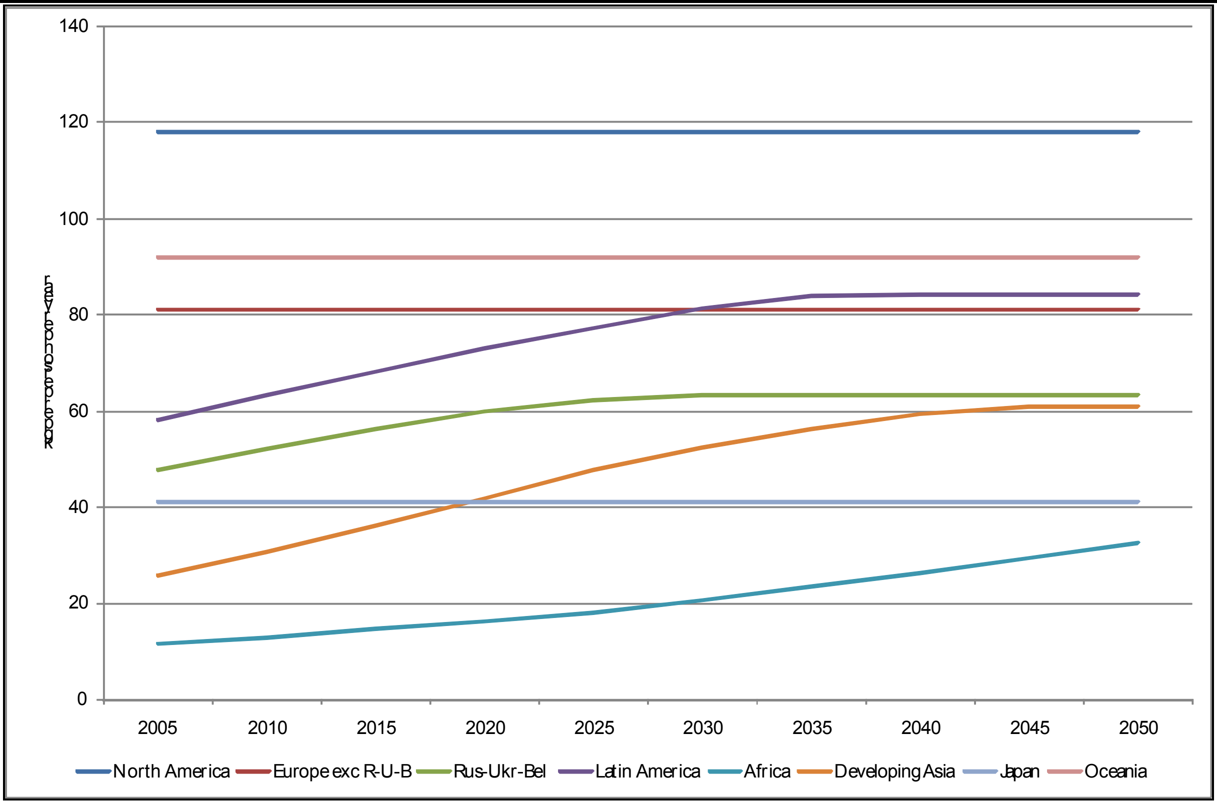

Figure 8 Forecast evolution of meat demand under the maximum scenario (kg per capita per year)

Source: Agra CEAS own calculations

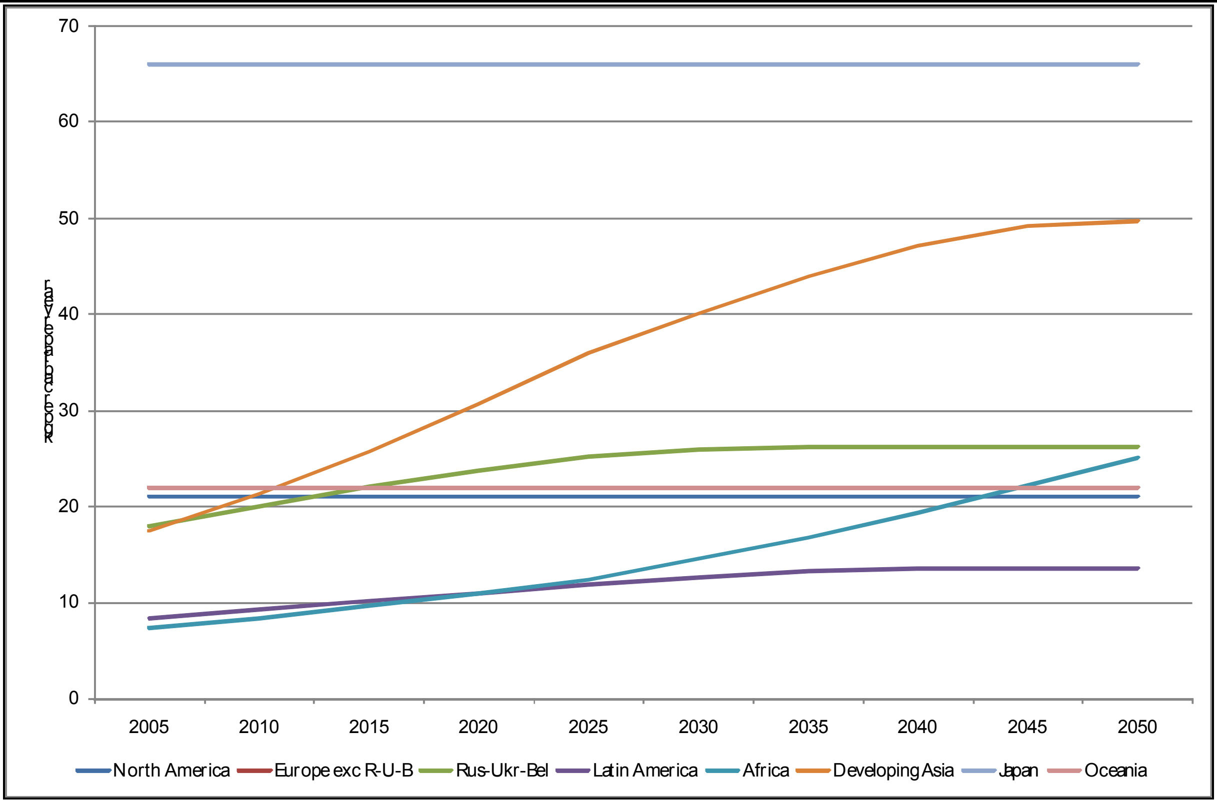

Figure 9 Forecast evolution of fish demand under all scenarios (kg per capita per year)

Source: Agra CEAS own calculations

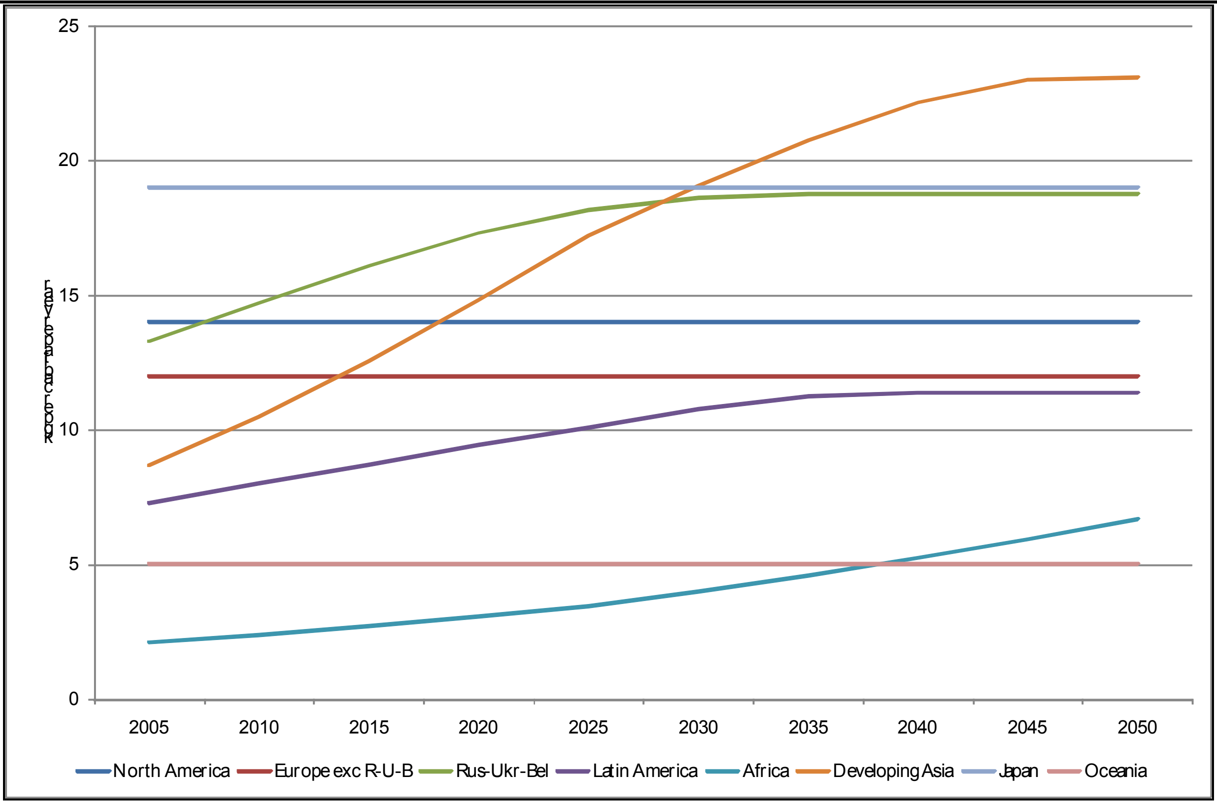

Figure 10 Forecast evolution of egg demand under the maximum scenario (kg per capita per year)

Source: Agra CEAS own calculations

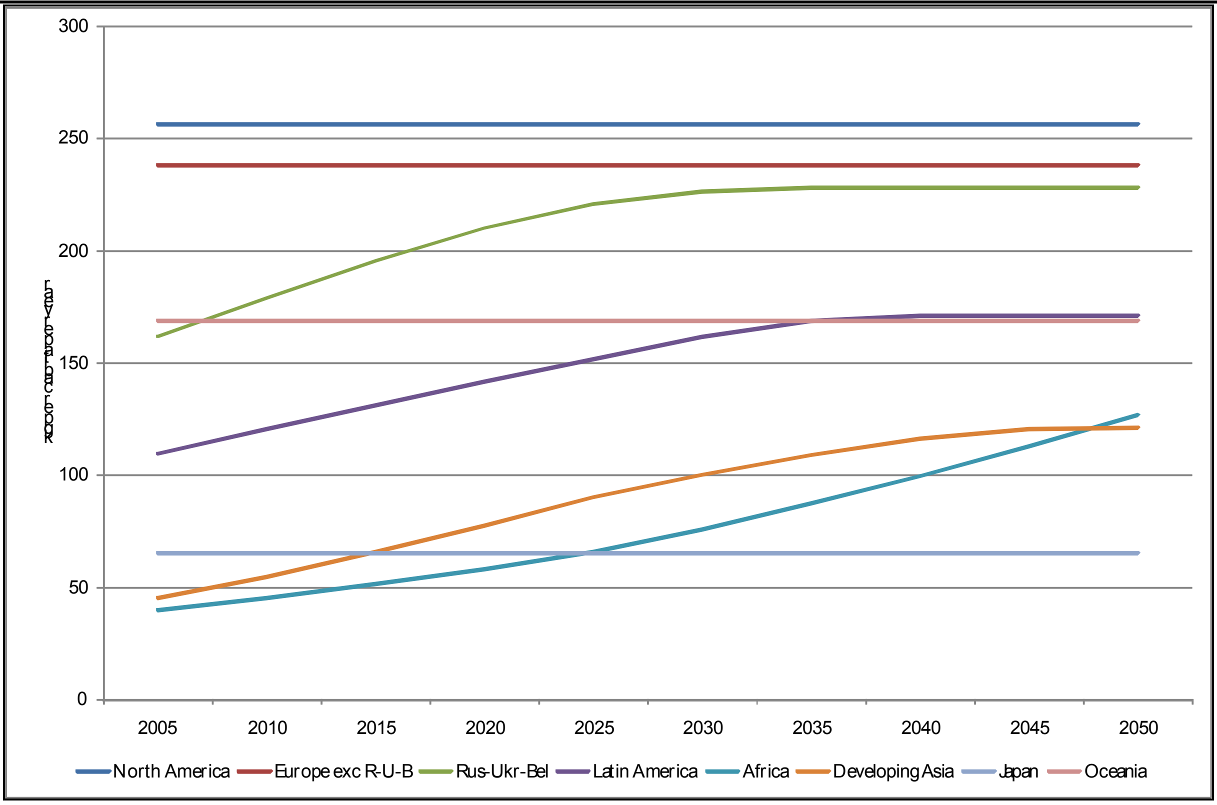

Figure 11 Forecast evolution of milk demand under the maximum scenario (kg per capita per year)

Source: Agra CEAS own calculations

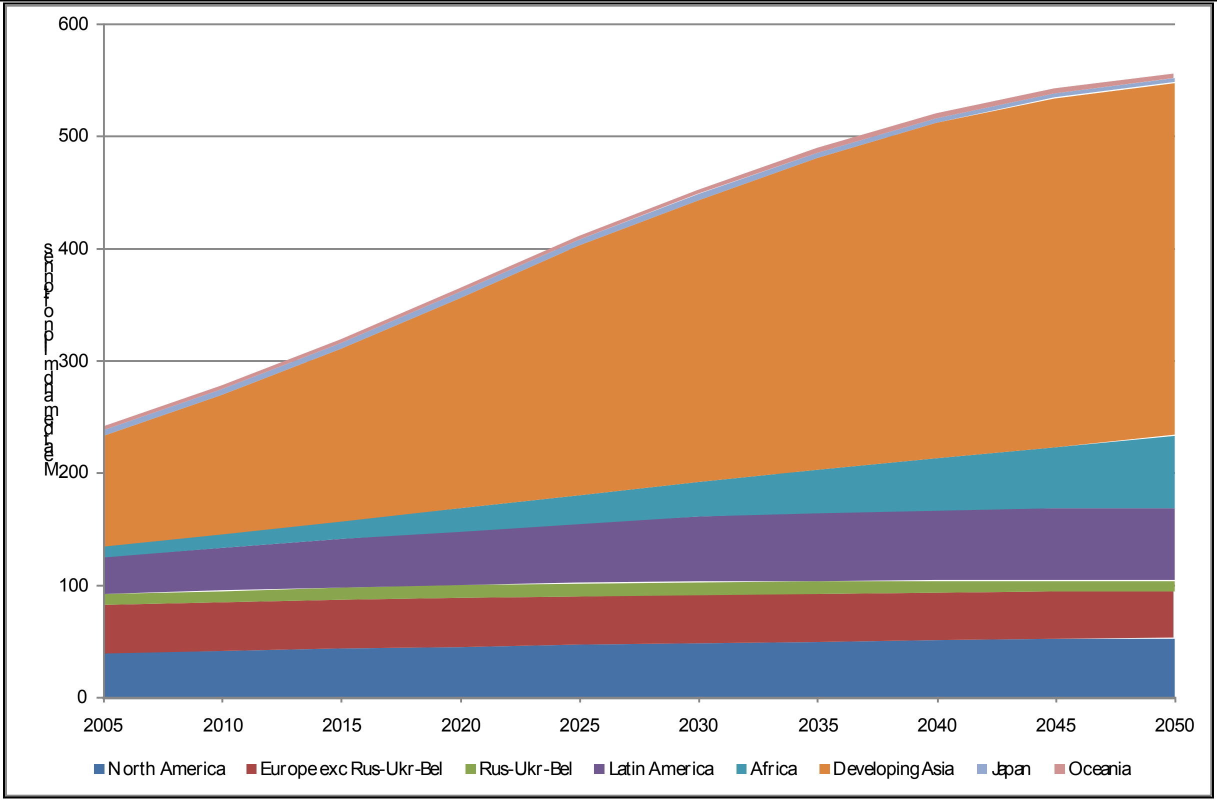

Figure 12 Forecast evolution of global meat demand under the maximum scenario (million tonnes per year)

Source: Agra CEAS own calculations

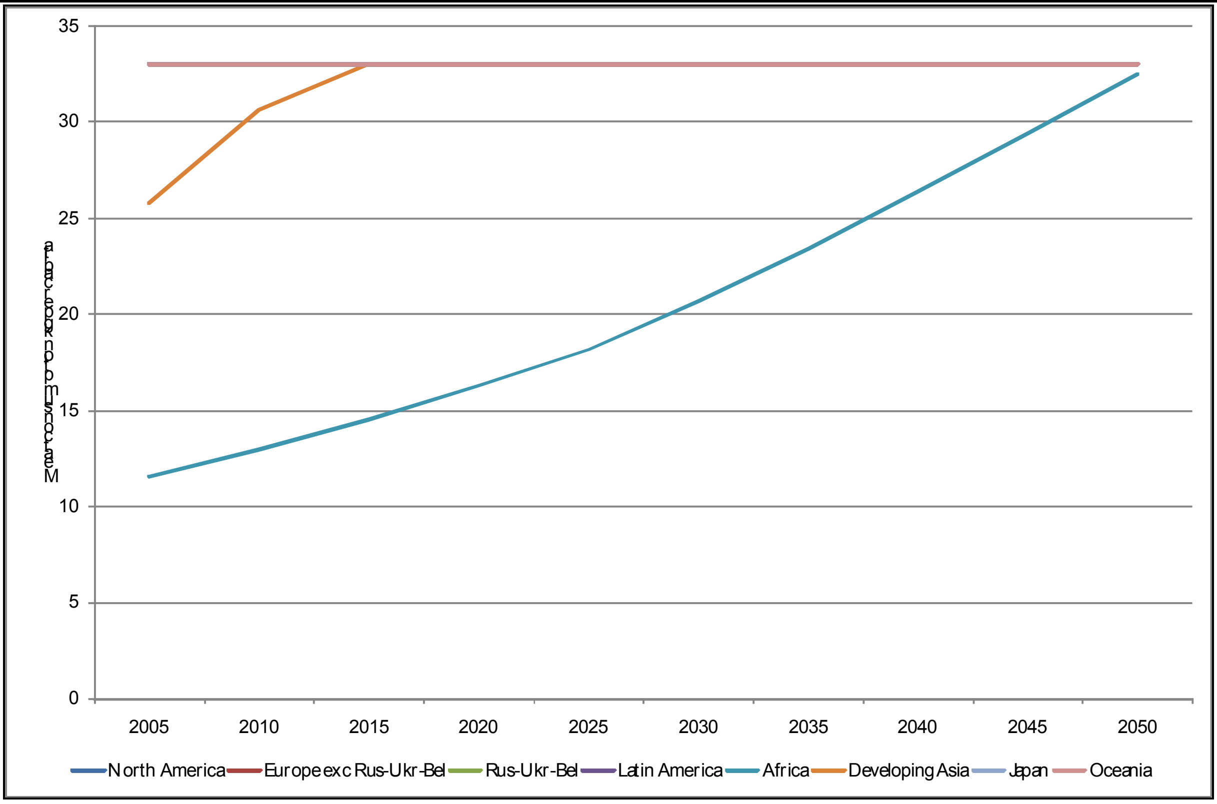

Figure 13 Forecast evolution of per capita meat consumption under the optimal scenario (kg per capita per year)

Source: Agra CEAS own calculations

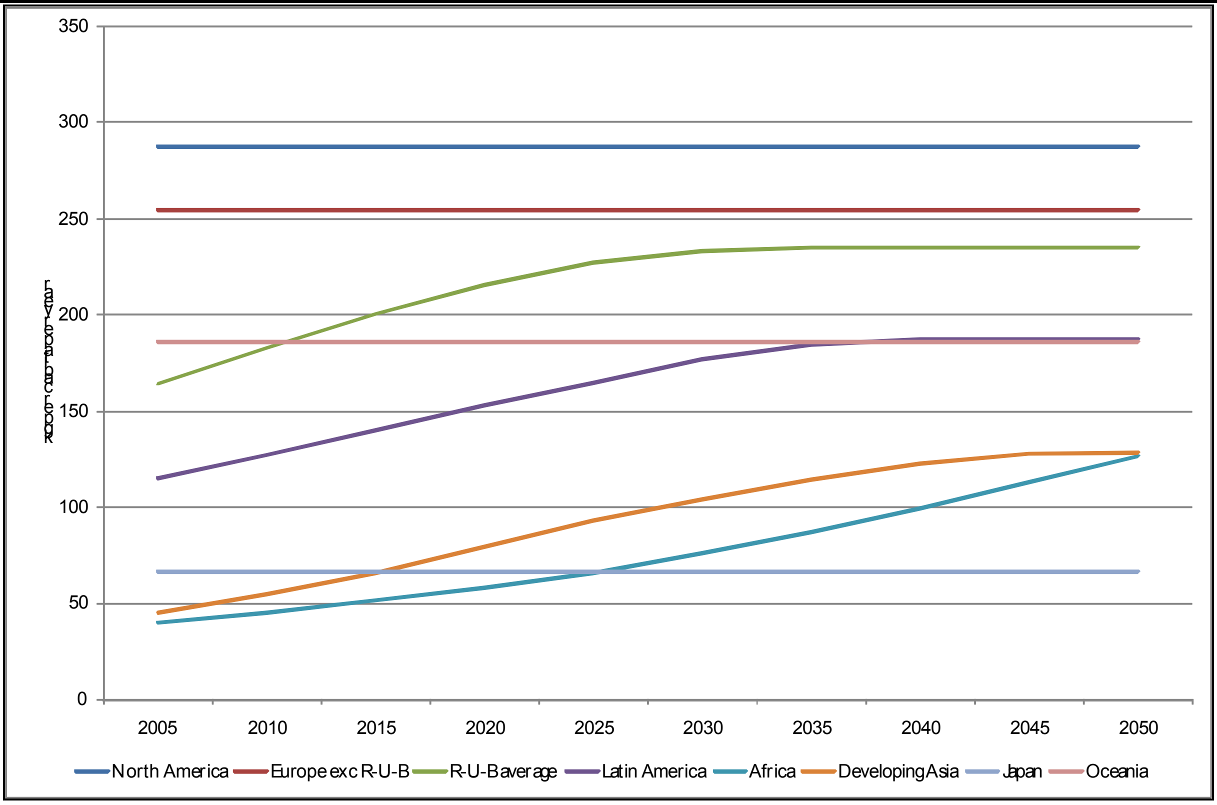

Figure 14 Forecast evolution of milk demand under the optimal scenario (kg per capita per year)

Source: Agra CEAS own calculations

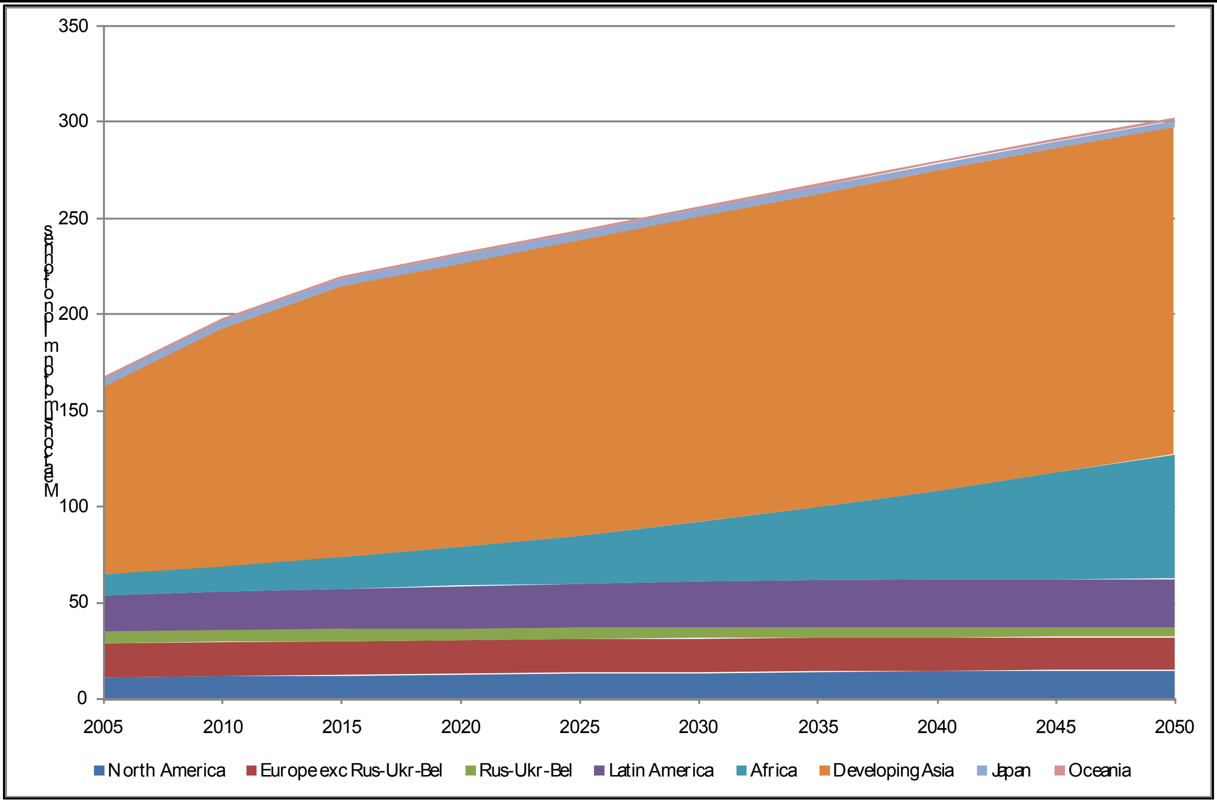

Figure 15 Forecast evolution of total meat consumption under the optimal scenario (million tonnes per year)

Source: Agra CEAS own calculations

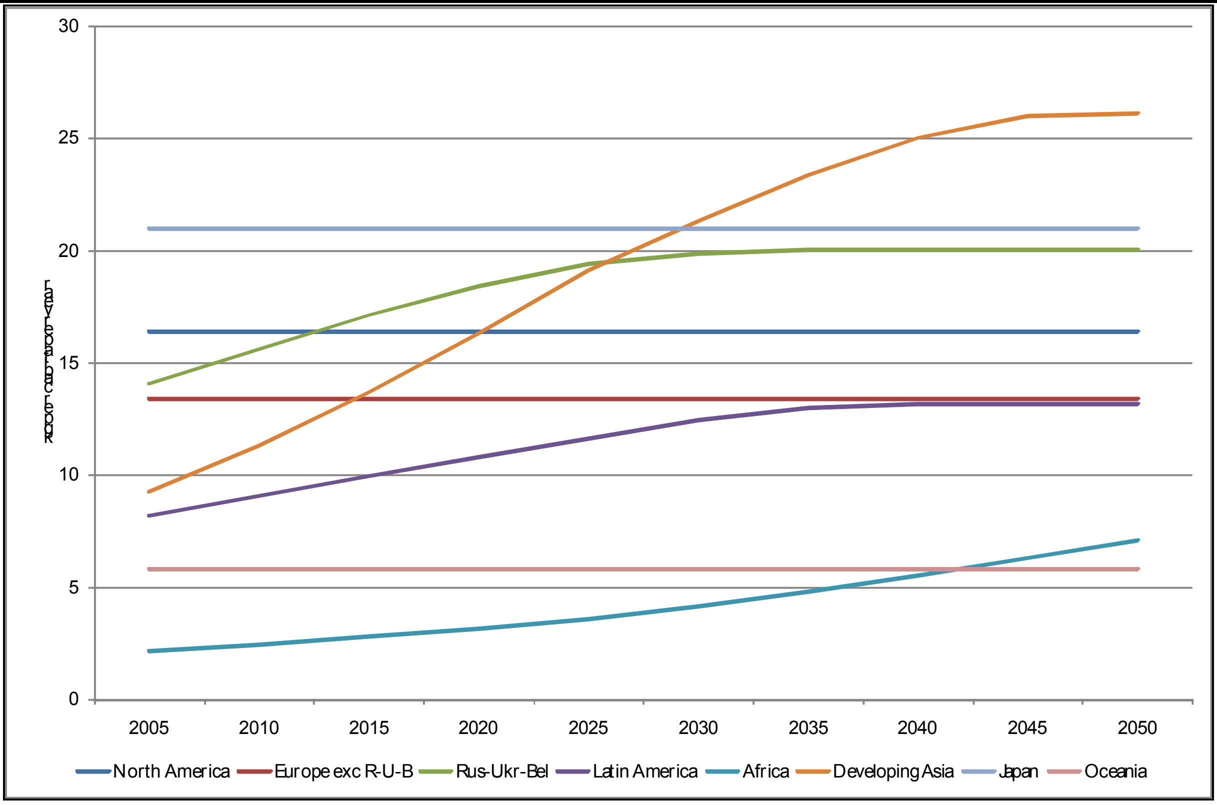

Figure 16 Forecast evolution of egg demand under the minimum scenario (kg per capita per year)

Source: Agra CEAS own calculations

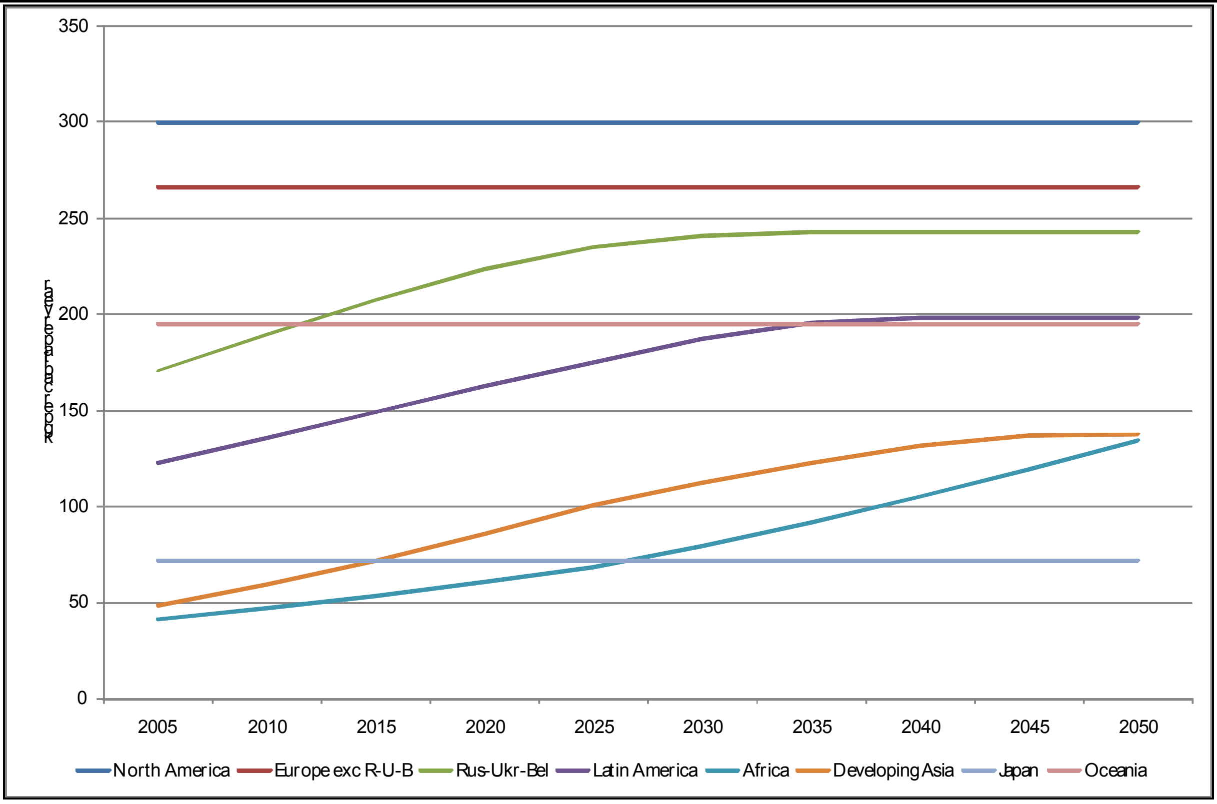

Figure 17 Forecast evolution of milk demand under the minimum scenario (kg per capita per year)

Source: Agra CEAS own calculations

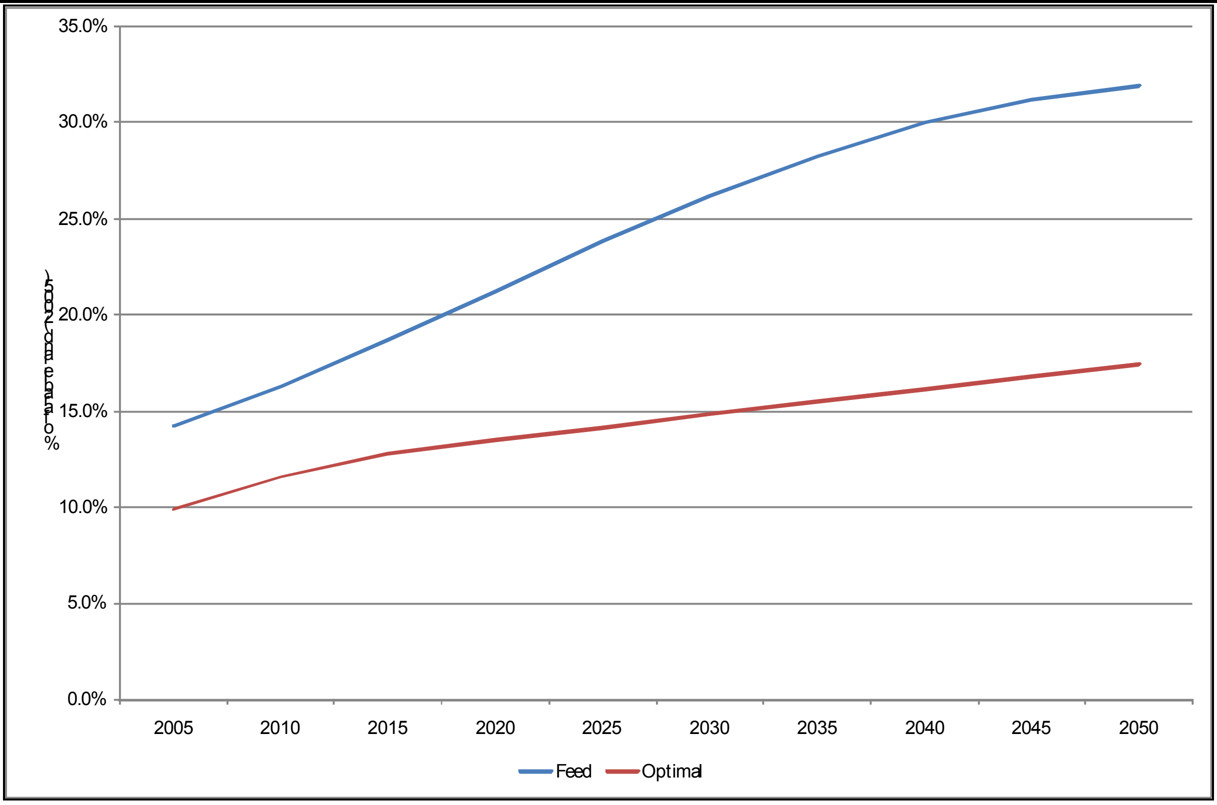

Figure 18 Forecast proportion of 2005 arable land used for animal feed production, 2005-2050, (%)

Source: Agra CEAS own calculations

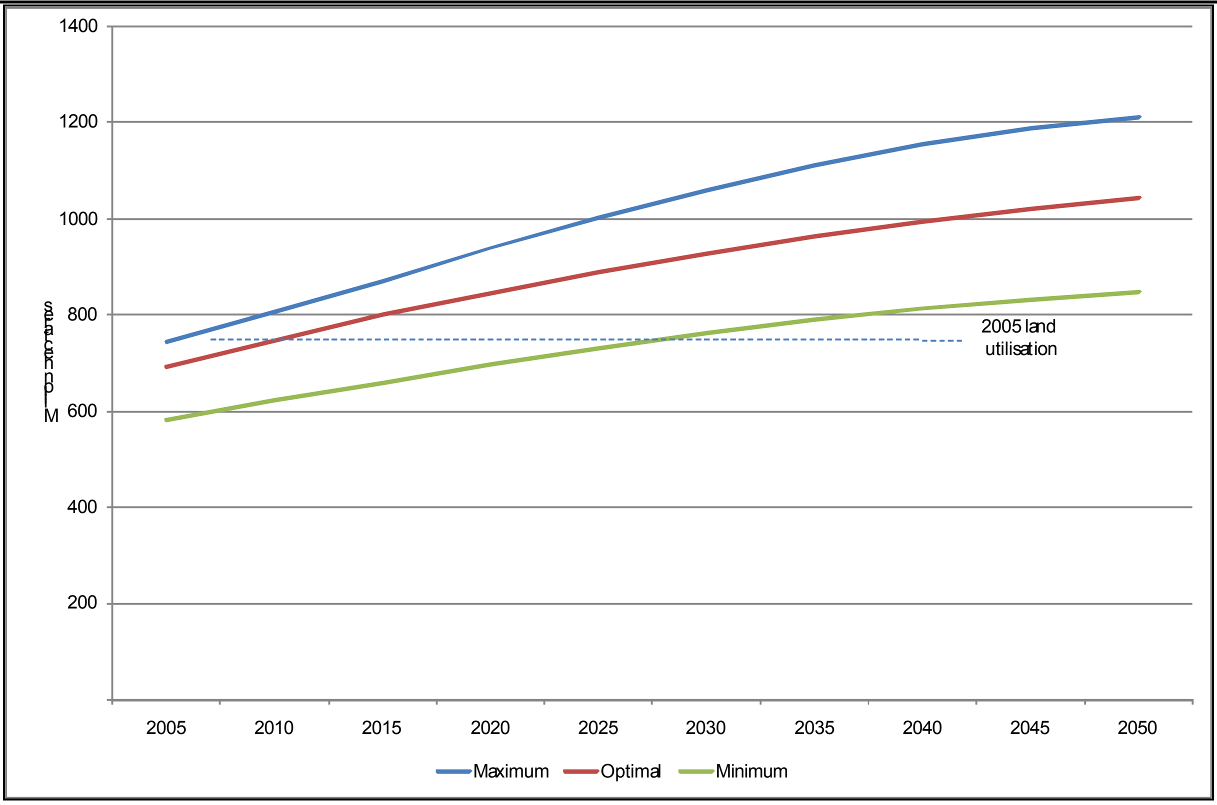

Figure 19 Arable land area required for food production (millions hectares)

Source: Agra CEAS own calculations

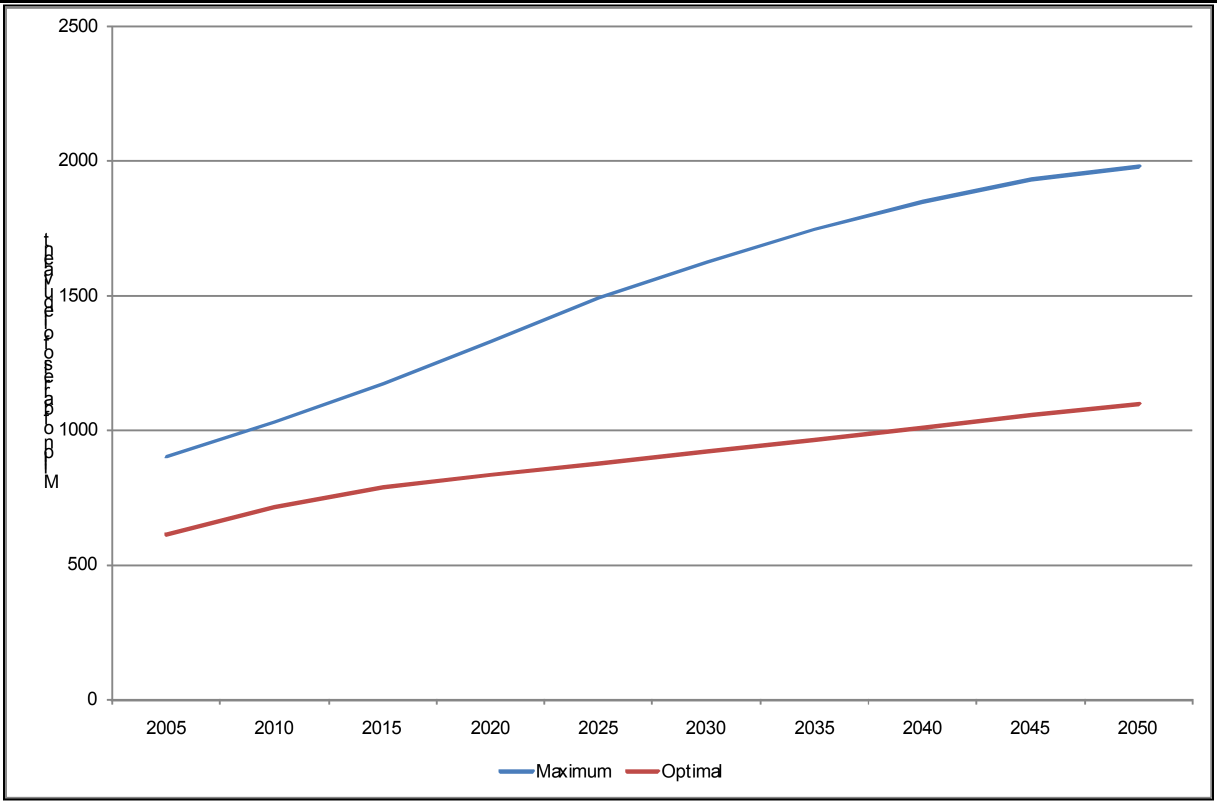

Figure 20 Forecast fossil fuel requirements for livestock production, 2005-2050 (million barrels of oil equivalent)

Source: Agra CEAS own calculations

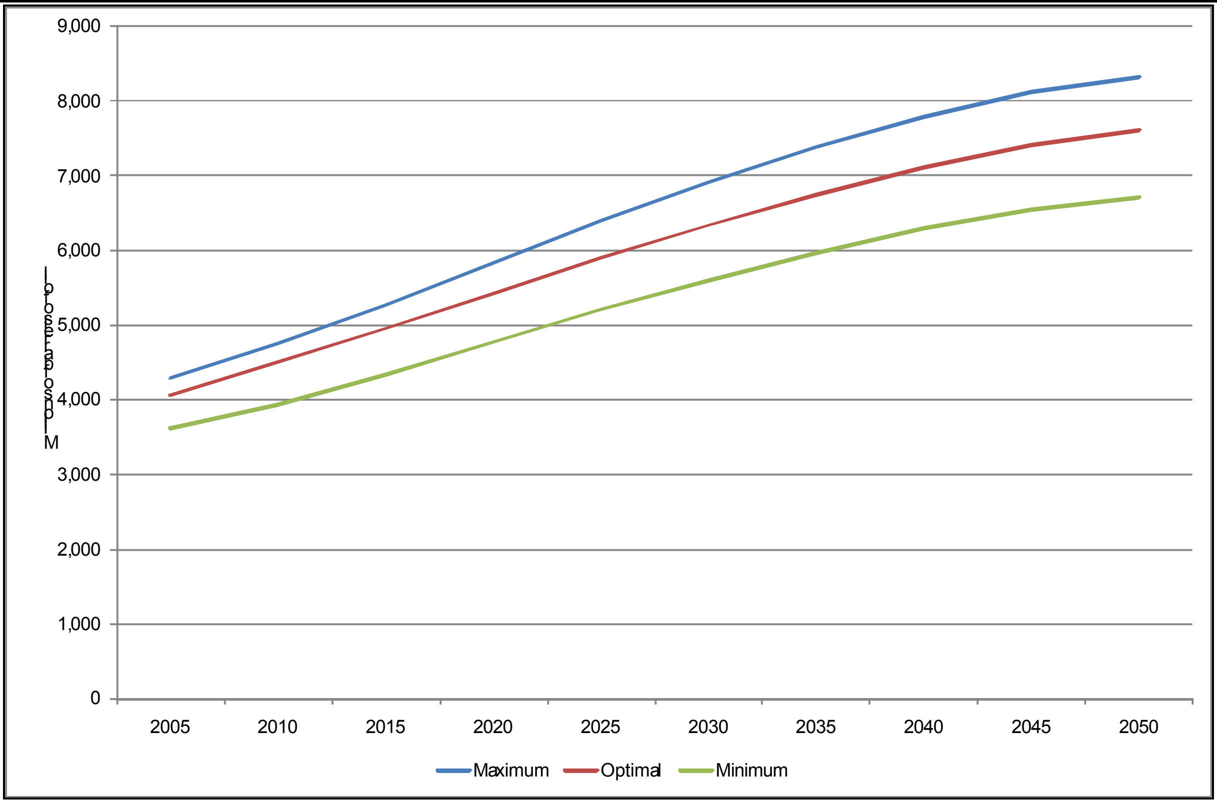

Figure 21 Forecast fossil fuel requirements for food production, 2005-2050 (million barrels of oil equivalent)

Source: Agra CEAS own calculations

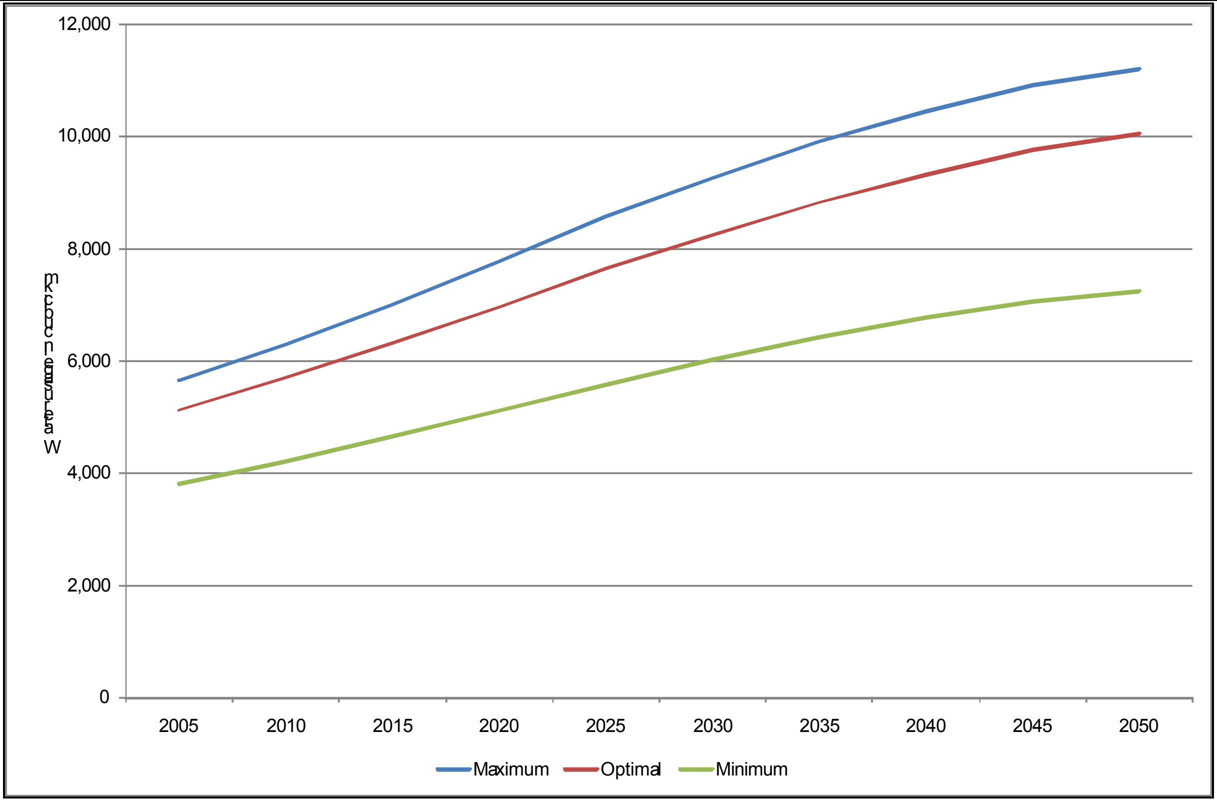

Figure 22 Forecast water usage from food production, 2005-2050 (cubic km)

Source: Agra CEAS own calculations

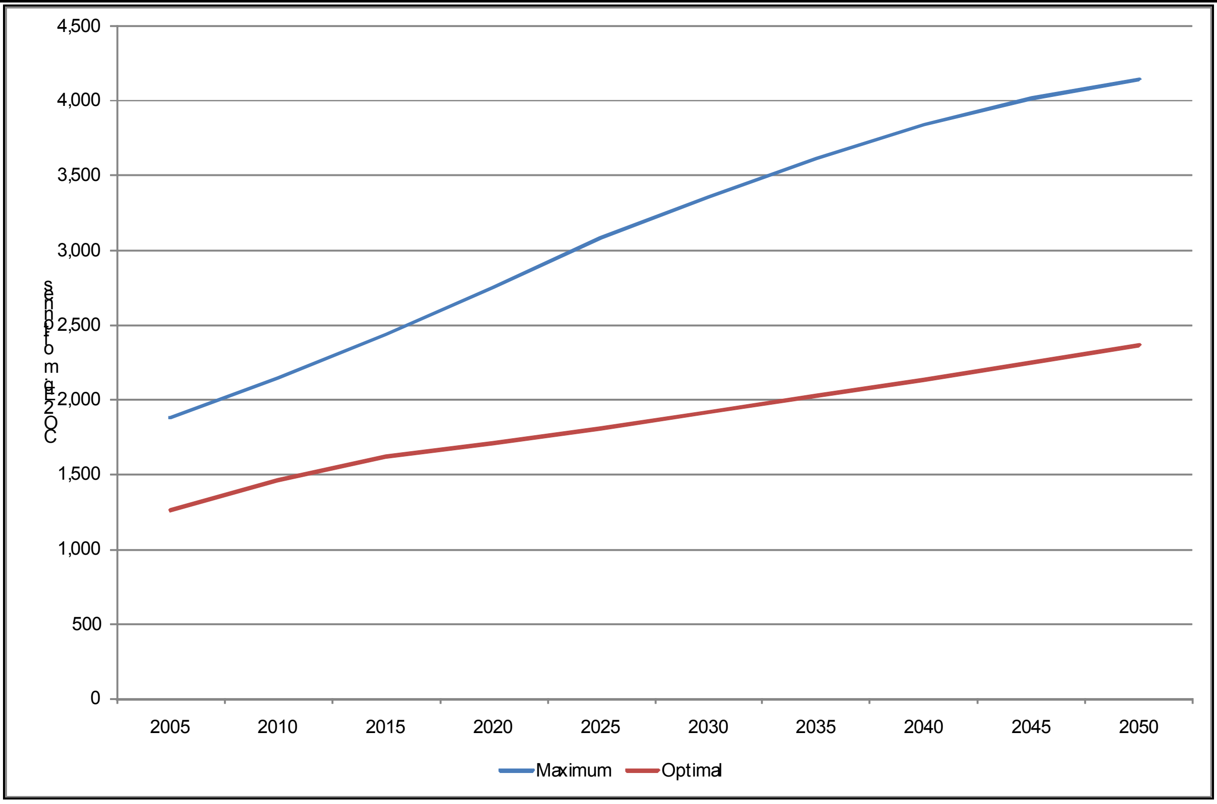

Figure 23 Forecast greenhouse gas emissions from the livestock sector under different scenarios (million tonnes CO2 equivalent)

Source: Agra CEAS own calculations

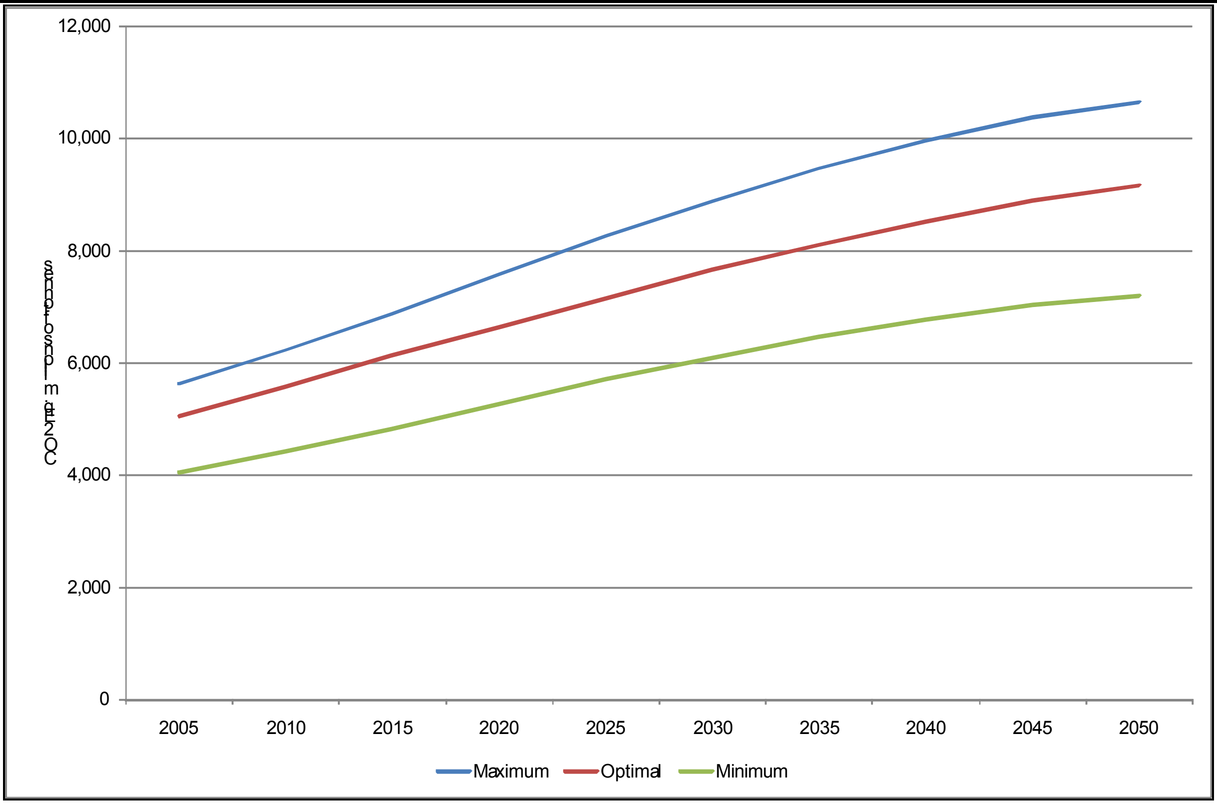

Figure 24 Greenhouse gas emissions from food production under different scenarios (million tonnes CO2 equivalent)

Source: Agra CEAS own calculations

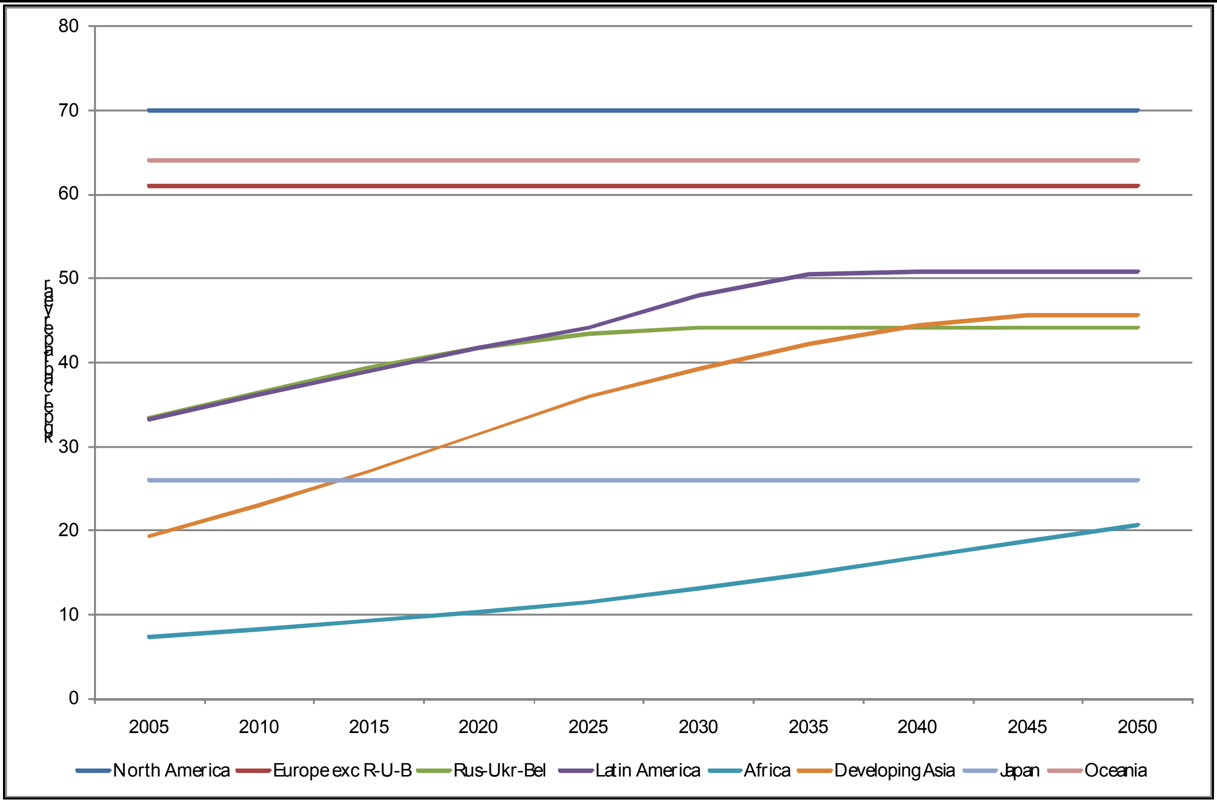

Figure 25 Forecast evolution of red meat consumption in the maximum scenario (kg per capita per year)

Source: Agra CEAS own calculations

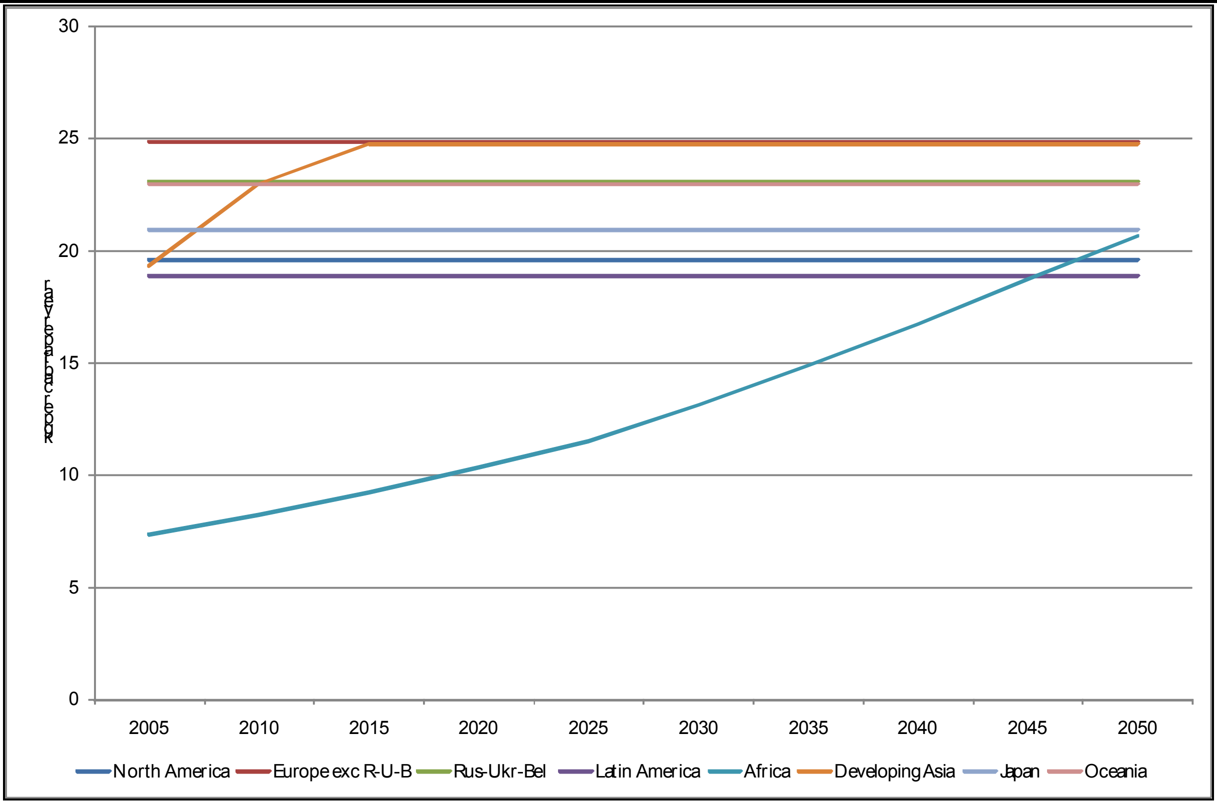

Figure 26 Forecast evolution of red meat consumption under the optimal scenario (kg per capita per year)

Source: Agra CEAS own calculations

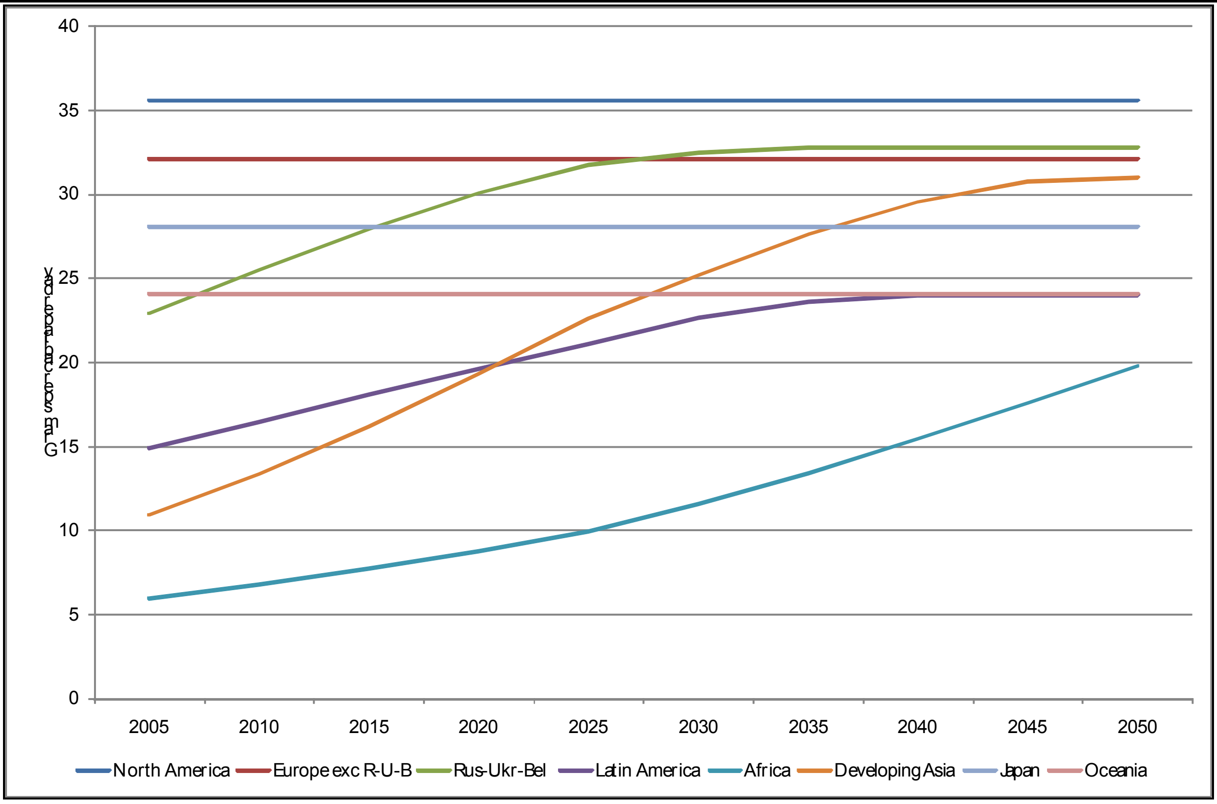

Figure 27 Animal protein intake under the minimum scenario (grams per capita per day)

Source: Agra CEAS own calculations