Assessment of resource efficiency in the food cycle

Final report

European Commission (DG ENV)
December 2012

In association with:

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Table of Contents

List of Tables

List of Figures

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Abstract

This study provides an appraisal of cycle of production, consumption and recycling in the food sector. The purpose is to support environmental policy development in the European Union with scientific evidence and to inform the development of sustainability criteria for use in the food system.

A conceptual model of the European food cycle was developed to examine the flow of agricultural and fisheries commodities used. Combined with an outline of the economic sectors in the food cycle, this provided the foundation for a quantification of resource flows into and through the food cycle. Results of screened life-cycle assessments of food commodities and products were used to examine the environmental impact of food. These assessments were complemented by a descriptive audit of the key policy issues relevant to improving resource efficiency in the food system. This is provided in relation to waste from the food cycle, consumption, farming and fishing, and pre-farm activities. On the basis of the information presented, the development of environmental sustainability criteria is discussed. Recommendations for the development of policy are presented.

The European food cycle is characterised by the provision of adequate quantities of food, even in member states with lower levels of per capita income. In addition, protein consumption is universally higher than requirements and the proportion of protein supplied from animal sources is high. This characterises the Europe's food cycle as typical of developed industrialised economies. Despite this high level of consumption of resource intensive foods, levels of self-sufficiency are high at the EU level. External trade is dominated by imports of tropical food products and soy. The EU is a major exporter of food in terms of economic value, but this trade is small in quantity compared with domestic consumption. The effect is a net reliance on 35 million ha of land outside the EU.

Even considering the reliance on third country land, the level of self-sufficiency is remarkable and is made possible by intensive production systems supported by nitrogen fertilisers and imported soy in particular. Crop production is dominated by starch-rich crops (e.g. cereals) and 60% of the cereal harvest is used for animal feed. This is complemented by grassland and by about 40 million tonnes of protein-rich soybean meal that is mostly imported. The combination of high reliance on fertiliser nitrogen and on imported soy puts protein provision are at the heart of processes determining resource use and environmental impacts. The concentration of livestock production in particular regions (for example in north-west Germany) using purchased feedstuffs and large-scale housed systems presents major challenges for resource conservation, particularly nutrient cycling. The fisheries sector is dominated by the catch from wild-fisheries (many depleted) and by aquaculture based on piscivorous (fish-eating) species. The production of farmed fish-eating fish is resource intensive compared with the consumption of farmed herbivorous fish or plant-based foods.

The study confirms that the EU food cycle is resource intensive, particularly with regard to the provision of foods high in protein. The consumption of protein in excess of needs and especially

the reliance on animal sources is a consumption-based structural weakness in the food cycle from a resource efficiency viewpoint. The study confirms that consumption change (include waste reduction) is central to measures to reduce resource use and environmental impacts. Starting with consumption change, system level social and cultural innovation is needed. There is also a role for technical change to products and processes at field, farm and factory level, but these need to be focused on key resource flows and cycles such as the nitrogen and water cycles.

The EU food sector is subjected to a well-developed and complex regulatory system, which extends from regulation of the production inputs such as pesticides, the regulation of farming and fishing under the common agricultural and fisheries policies, through to the provision of healthy eating guidelines and supervision of labelling. These policies and regulations have evolved over the last 50 years each with their own drivers and effects. There is great scope for policy integration achieved by focusing on some key resource cycles and flows and potential synergies between policy areas, especially environment and public health, to raise the resource efficiency and environmental sustainability of the European food cycle.

Executive summary

Contents *Page Number*

Introduction

This report sets out the results of an appraisal of the European food cycle with respect to resource use and emissions to the environment. The study examines how resources are processed in the cycle, from extraction to transformation (including feed), distribution, consumption and waste and look possible gains in resource efficiency in these different steps. Environmental sustainability criteria at each stage of the food cycle are identified. The scope of the study is the whole food cycle (including beverages).

Main conclusions

When considering improvement potentials, system-level innovation could provide the greatest benefits, as shown in Figure 1, such as shifts in dietary patterns, avoiding waste, and closing of resource cycles.

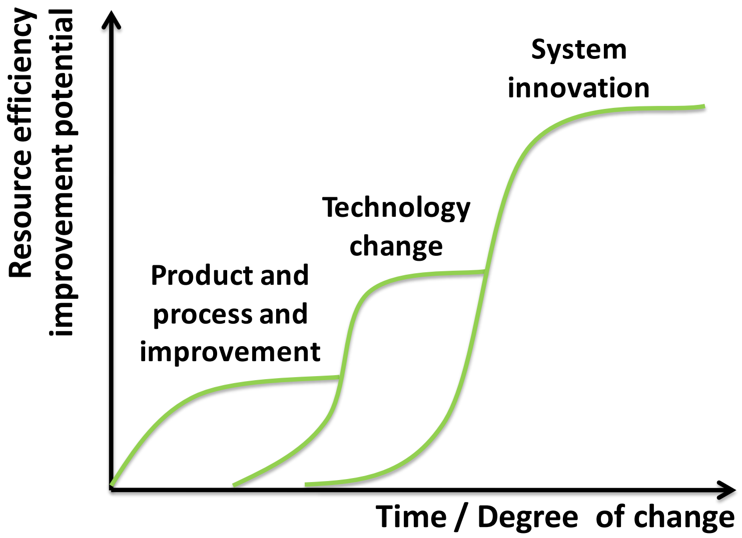

Figure 1: Resource efficiency improvement potential at different levels

There are many interacting processes and many potential points of intervention at which negative effects of different stages of the food cycle on the environment, resource efficiency and human health can be addressed. There are "win-wins" for improvements in many cases.

Of the estimated total EU food waste, households produce the largest fraction (42 %), with evidence showing that over 60% of this fraction is avoidable. In addition, as the significant proportion of environmental impacts occur across production and processing stages, changes at the end of life and consumption stages could lead to significant reductions in environmental impacts (a unit of product saved at the end of its lifecycle reduces the impacts that occur throughout its lifecycle). Priority options for improving resource efficiency include:

- Reducing waste and closing resource loops
- Increasing consumer awareness of sustainable choices and support for action on this awareness
- Enable/require efficient cycling of nutrients and improvement in agricultural processes
- Reduction of wild fisheries catch
- The continuation of optimisation of industrial processes

These options can help to reduce some of the main environmental impacts of the food cycle: land use change leading to habitat loss and pressure on biodiversity; nutrient run-off and eutrophication adding to pressure on biodiversity; greenhouse gas emissions that contribute to climate change; food shortages that impact food security; human health; among others.

Existing policies mainly relate to pre-farm gate activities, covering different aspects of resource use and other issues such as water, air and soil, plant protection products, animal welfare, farm assurance schemes and farm income support. However, the analysis of the existing EU policy framework highlights a number of deficiencies and areas where policy response is needed. There is significant scope for integrating existing policies to improve resource efficiency, particularly the Common Agricultural Policy, health policy, nitrates, water policy, pesticides, and plant breeding. A complex array of policies has grown up over the last decades, but little attention has been given to systemic effects. An example of such a policy gap at the system level is the absence of policies that address nutrient use and surpluses holistically.

Objectives

A methodological approach was developed (Chapter 2) to meet the objectives of the study, which were:

- To document and synthesise relevant trends and developments, including an overview of the different stages and main product groups of the EU food cycle, and material flows and markets (Chapters 3 to 5, Appendix A and Appendix D).
- To review state of the art in the quantification of life-cycle environmental impacts (Chapter 6 and Appendix B).

- To summarise current EU policy relevant to the food cycle and discuss the main issues at the different stages (Chapter 7).
- To analyse existing environmental sustainability criteria that address resource inefficiency and environmental impact (Chapter 8 and Appendix C).
- To describe improvement options (Chapter 9) and propose policy recommendations related to possible gains in resource efficiency in the different steps of the food cycle (Chapter 10).

Approach

There are three main stages to the analysis. The first stage is the provision of an overview, or 'map', of the EU food cycle, through quantification of resource flows and environmental impacts. Data on the flows of commodities and nutrition were extracted from FAOSTAT and Eurostat, while data for resource use and emissions are extracted from a variety of sources. An assessment of LCA studies available was conducted, and extraction of data on environmental impacts confined to studies assessed as of high quality.

As there is no clear definition of 'sustainability' that can be rigorously applied to the food cycle, the second step involved identification of criteria based on a pragmatic approach, including a review and listing of current existing thresholds for environmental performance, targets and criteria at global, EU, Member State, industry organisation, and product level.

Thirdly, an analysis is made of policies affecting the resource efficiency of the food cycle.

From these three steps, recommendations for policy options to address resource efficiency in the EU food cycle are made.

Results

The project's findings highlight that, although there is significant variability between food types and production systems, the majority of environmental impacts occur at primary production stage. Factors and processes influencing resource use which are assessed as being significant drivers of resource efficiency and/or environmental impacts (these do not cover specific emissions, as these are driven by the use of resources) are set out in Table 1.

Table 1: Factors or processes influencing resource use across the food cycle

<table>
<tr><th rowspan="2">Food group</th><th rowspan="2">General factors</th><th colspan="10">Stage in food chain</th></tr>
<tr><th>Pre-production</th><th colspan="3">Primary production</th><th>Processing</th><th>Packaging</th><th>Storage and retail</th><th>Transport</th><th>Use/ maintenance</th><th>End of life</th></tr>
<tr><td>Crops</td><td rowspan="3">Energy

Water

Waste

Wastewater (sewage)

Scale of operations affects impacts</td><td rowspan="3">Water supply

Energy supply

Fertiliser production

Breeding technology</td><td rowspan="3">Management of production:

Choice of location of production (climate and local conditions)

Yields

Intensive farming/ overfishing

Land use change</td><td colspan="2">Fertiliser management: application technique and dosage

Crop protection management: application technique and dosage

Management of water: particularly in water scarce areas

Soil management: (e.g. by-products left on field)

Energy management: Heating for greenhouses (i.e. for fruit and vegetables)</td><td rowspan="3">Energy management: refrigeration storage, lighting, heating

Water management

Waste generation: product losses (e.g. in batch processing)</td><td rowspan="3">Packaging design: Choice of material (e.g. plastic, metal); size or volume of packaging; reuse- and recycla-bility</td><td rowspan="3">Energy management: refrigeration, lighting, heating

Choice of refrigerants

Waste generation (product losses, e.g. stocking practice and sell-by/best-by dates)</td><td rowspan="3">Distribution: mode of transport, distance, how filled are the vehicles

Consumer: mode of transport, distance</td><td rowspan="3">Purchase and consumption: Catering and hospitality - serving sizes, menu choices; Household: diet, overconsumption, choice of food types (e.g. out-of-season)

Energy and water use:
Storage and preparation – choice and use of equipment (e.g. size and energy efficiency of appliances)

Waste generation: Product losses during preparation and food waste(e.g. correct storage, serving sizes, sell-by/best-by dates)</td><td rowspan="3">Management of waste: Choice of waste management practices (e.g. composted, incinerated, landfill)

Management of wastewater: Choice of wastewater (sewage) treatment</td></tr>
<tr><td>Livestock</td><td>Rearing method: pastures, free range

Energy management: heating, lighting

Water management

Manure management</td><td rowspan="2">Feed selection: type, composition and source (i.e. for livestock and aquaculture)

Veterinary care: antibiotics, etc.</td></tr>
<tr><td>Fish</td><td>Wild: Fuel efficiency of fleet, by-catch management, fishing gear and practices

Aquaculture: effluent</td></tr>
</table>

Issues affecting the sustainability of the food cycle, including resource efficiency and environmental impacts, are described.

- Improvements to address horizontal issues (e.g. food waste, research and innovation, etc.): **See section 9.1**
- Improvements to address issues across the food chain stages (e.g. production, retail, etc.): **See section 9.2**

Policy options

Table 2 sets out the policy options proposed, and lists the relevant improvement actions (to increase resource efficiency and decrease environmental impacts) highlighted during the study that each policy option could help to stimulate. Policy needs to address actions and behaviours of actors along the whole cycle. In particular, significant influence in the food cycle derives from the actions of consumers and retailers.

Table 2: Policy options to increase resource efficiency and decrease environmental impacts of the food cycle

Policy option	Relevant improvement actions stimulated
Mandates for measurement methodologies and setting of environmental sustainability criteria	**Research and innovation:** - Cross-sectoral initiatives to develop criteria to distinguish between sustainable and less sustainable food and drink products - Greater cooperation between policymakers and the statistical offices or research institutes responsible for producing resource efficiency indicators - Communication of clear messages on sustainable food and monitoring of the progress - Indicators for global land use **Consumption:** - Examination of the trade-offs and synergies with other social and environmental goals, notably in dietary guidelines, and biodiversity - Improved uptake and use of Green Public Procurement criteria, and the development of more product groups - Environmental sustainability standards and certification schemes **Development of criteria to support:** - Nutrient balances to be calculated at the farm level or the regulation of the type of feed used - Limits to inputs at specific stages of the life cycle, e.g. for livestock (where husbandry methods are less impacted by local conditions) and manufacturing stages
Consumption	
Awareness-raising and education campaigns (and harmonisation of nutrition and sustainable diets guidance)	**Food waste:** - Education on use of leftovers, date labelling, and when food is not long fit for consumption. - Home delivery of groceries and household meal planning. **Food choices and diet:**

Policy option	Relevant improvement actions stimulated
	- Sustainable food and health agendas developed in parallel: 'win-win' opportunity for environment and public health improvements through reducing intakes of meat and dairy products. - Adjustment of intake recommendations to target health effects unique to some fish and promotion of fish from sustainable stocks - Discouragement of the consumption from out-of-season production
Product labelling for environmental sustainability guidance/certification	**Food choices and diet:** - Encouragement of the purchase from in-season production and farming methods that promote high environmental quality - Promotion of fish from sustainable stocks **Research and innovation for sustainable food:** - Communication of clear messages on sustainable food and monitoring of progress **Retail:** - Increase awareness of consumers of the consequences of their expectations and emphasise in-season produce, changing offer to match seasonal availability
Pricing (taxes for consumption of specific food groups)	**Food choices and diet:** - For example, increasing VAT rates for meat or dairy products, or reducing VAT for sustainable fish
Green Public Procurement for catering in public institutions	**Food choices and diet:** - Making the GPP criteria for food and catering services mandatory, or setting an EU-wide target - Re-design of menus - Provision of more food products that serve as alternatives to meat and fish - Reduce need to provide late diners with a full range of menu options. Reduce over-supply at buffets, etc.
Retail	
Voluntary agreements (packaging and products offered)	- Use 'choice editing', e.g. removing endangered fish species from shops - Lightweight packaging, using retail transit packaging, or shelf-ready packaging **Food waste:** - Date labelling better designed to discourage waste - Increase the use of home deliveries **Food choices and diet:** - Reduced consumption of fragile and out-of-season produced produce; change offer to match seasonal availability
Reassess/relax marketing standards for fruit and vegetables (according to their size and shape)	- Relax standards and/or offer optically lower grade produce **Food waste:** - Reduce/eliminate standards that are not related to food safety

Policy option	Relevant improvement actions stimulated
Processing and manufacture	
Voluntary agreements to reduce waste and improve water efficiency	- Process optimisation, plant /machinery efficiency increase - Metering of water use (benchmarking) and setting targets for water reduction (or the introduction of key performance indicators) - On-site processing wastewater management and rainwater harvesting, with return via the soil to the aquifer (irrigation and ponds etc.) - Reduced consumption of certain products – esp. from the cool chain will impact the food chain equipment and the cool chain - Producer responsibility for waste - impose obligations to report on waste and achieve prescribed levels of waste minimisation, recovery and recycling - By-products recovery to reduce waste (AD and other alternatives)
Production	
Develop labels for high environmental quality farmed foods and sustainable fish (promoting diversity of consumption)	- Farming systems are often categorised in labelling schemes in relation to 'branded' approaches to farming – organic, etc. What matters is not the brand, but the practices and resource flows that the farm uses. Farm system improvements can be achieved through the use of key inputs and practices, and integrating resource flows between crop and animal production has the greatest potential. Depending on the situation, this requires change at all scales – for example, from methods used by farmers 'on-field' to European-level policy and infrastructure. - Reduce consumption of marine fish and farmed fish that are fed on feed produced from other marine species **Food choices and diet:** - Encouraging purchase of less out-of-season production - Promoting of fish from sustainable stocks **Research and innovation for sustainable food:** - Increasing demand for farming methods that promote high environmental quality - Communicate clear messages on sustainable food and monitor the progress **Retail:** - Increase awareness of consumers of the consequences of their expectations and emphasise in-season produce, changing offer to match seasonal availability
Voluntary agreements in farming and fisheries industry	- Incentivise best practice and technologies: improvement possible throughout the cycle - Phosphorus and nitrogen: better use of manures through better distribution of the manure resource in relation to crop production, and the systematic recovery of nutrients post consumption (i.e. from sewage, AD digestate from of waste) - Soil: improvement requires a broad range of measures, including halting the loss of soil. Reducing cultivation intensity to leave crop residue on the surface can protect soils from erosion but claimed benefits for soil organic matter are disputed. Leaving crop stubble and residue over-winter has the same effect and improves biodiversity. - Water use: drip irrigation technologies can provide 'more crop per drop'

Policy option	Relevant improvement actions stimulated
	- Energy use: further optimisation measures to reduce tillage intensity, increase CHP, and reduced greenhouse cropping - Choice of crop and cropping sequence: More diverse crop cover improves farm biodiversity, reduces pesticide and fertiliser use. Nutrient enrichment (e.g. legumes). Crop by-products can be better used for animal feed or soil improvement. Erosion protection-endangerment (soil degradation prevention). Water availability improvements (vegetation cover conserves soil moisture). Varieties with better pest resistance may reduce inputs (pesticides). Crop rotations systems can also be optimised for carbon mitigation (reduced emissions from soil). - Land use change: in Europe (grassland to arable) a major source of C emissions and cause of biodiversity loss. Globally, LUC (mainly deforestation) causes more GHG emissions than agricultural production and is the most important driver for terrestrial habitat loss and thus pressures on biodiversity. - Farmland biodiversity loss: less intensive farming practices, habitat conservation/restoration, organic farming (pesticide-free) - Feed: Reduced livestock production, more efficient feeding, more precise nutrition, greater use of co-products - Manure: Reduced local/regional concentration of livestock production and/or advanced manure processing - Animal welfare: impact on resource use and emissions is overall relatively small, but specific measures can be positive or negative - By-catch and wasteful discarding: reducing with improved technology and management, e.g. better fishing gear, different trawling methods, selective gear, area closures, discard bans and data enhancement. Better monitoring, reporting and standards could be a means to reduce by catch of seabirds in fisheries. Encouraging larger variety of species fished (linked to demand-side measure to increase profit to be gained from other fish species) - Control fishing intensity to allow stock recovery (virtuous circle leading to more efficient fishing) **Food waste:** - Reduce/eliminate standards that are not related to food safety
Funding for agricultural and, fisheries research and development	- Support to research to assess potential resource efficiencies: feed strategies, benefit of aquaculture products compared to other animal protein sources, nutrient and water recycling, and other sustainable management methods - Support to pilot projects: technologies to reduce by-catch and enable energy efficiencies (e.g. fishing gear, trawling methods, etc.)
Develop the regulatory approach for farming (continuation of the Common Agricultural Policy "greening" and cross-compliance) and fisheries (sustainable resource management in the Common Fisheries Policy (CFP)	**Agriculture:** - Continued 'greening' and cross-compliance measures coupled to environmental performance provide the most robust means of improving resource efficiency and environmental performance of agricultural systems, practices such as farm-gate nutrient balancing could be incorporated - Requirements could also be made for the environmental impacts of inorganic fertilisers (e.g. max GWP per kg) **Fisheries:** - Continued development and enforcement of the CFP, with focus on ecosystem approaches, sustainable resource management (biodiversity, stock management) and producer responsibility - Reduce fishing capacity and effort, remove tax exemption on marine fuel - The marine spatial planning approach may provide further opportunities for improving resource efficiency

Policy option	Relevant improvement actions stimulated
	- Stock recovery allows more efficient fishing creating a virtuous circle – provided fishing intensity is controlled
Pre-production	
Introduce pricing for water	- Pricing to reduce water consumption and promote water efficiency technologies: water recycling and use of waste water from processing for aquifer recharge (feasibility depends on the discharged waste water and willingness of the processing sector to invest in water treatment), more precise irrigation and reduced consumption of water-demanding crops
Revise WFD and nitrates directive to actively achieve nutrient cycling and reduce discharges (enforce stricter standards on wastewater and enhance sewage management)	- Increased efficiency of use of phosphorus from animal manures, especially in areas with high animal populations **Production:** - Improved recycling of phosphorus and nitrogen - better use of manures through better distribution of the manure resource in relation to crop production - The systematic recovery of nutrients post consumption (i.e. from sewage) - Manure: Reduced local/regional concentration of livestock production and/or advanced manure processing
Reduce regulatory and financial hurdles for biological plant production products and new varieties	While PPP manufacture has been the cause of major incidents in the past (e.g. Bhopal, Seveso), recent legislation has reduced risks. **Production:** - Choice of crop and cropping sequence: more diverse crop cover improves farm biodiversity, reduces pesticide and fertiliser use. - Varieties with better pest resistance may reduce inputs (pesticides). - Land use change: in Europe (grassland to arable) is a major source of C emissions and a major cause of biodiversity loss. Globally, LUC (mainly deforestation) causes more GHG emissions than agricultural production and is the most important driver for terrestrial habitat loss and thus pressures on biodiversity. - Farmland biodiversity loss: less intensive farming practices, habitat conservation/restoration, organic farming (pesticide-free)
Research funding for plant breeding	- The GMO (herbicide tolerant crops) regulation policy that has considered system impacts one of the few examples of regulation drawing on system-level considerations - The regulation of new crop cultivars has implications for the use of crop genetic improvement to reduce impacts - GMOs have in the medium term the potential to reduce resource use and impacts - Investment in plant breeding can provide traits that reduce resource use and impacts **Production:** - Choice of crop and cropping sequence: varieties with better pest resistance may reduce inputs (pesticides). - Support to research assessing potential resource efficiencies: e.g. crop cascade utilisation potentials

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Chapter 1: Introduction

The goal of the study "*Assessment of resource efficiency in the food cycle*" reported here is to provide scientific and technical support to the development of policy positions on the resource efficiency of the European food cycle. It was conducted for European Commission Directorate General for Environment (under framework contract ENV.G.4/FRA/2008/0112). Its scope includes food, feed and beverages. It is particularly relevant to the European Commission's 'Roadmap to a Resource Efficient Europe'[1], which calls for a Communication on sustainable food by 2013 and the development of a methodology for sustainability criteria for key food commodities by 2014.

The aim of the work is to provide an appraisal of resource use and environmental impacts arising from the production and consumption cycle for food used in Europe and to provide recommendations on policy actions. The work includes an overview and quantification of resource flows and environmental impacts at the different life cycle stages and for the main product groups, a summary and assessment of existing environmental sustainability criteria that address the main drivers of resource inefficiency and environmental impact, and an analysis of policies affecting the resource efficiency of the food cycle. From these three steps, recommendations for policy options to address resource efficiency in the EU food cycle are made.

Food production and consumption results in very significant resource use and emissions to the environment. Global food consumption trends[2], production methods[3] and trade[4] place an increasing demand on natural resources, such as land, water, energy and minerals, leading to a large and growing environmental footprint. As the world population grows to 9 billion by 2050[5] and average income rises, competition for food and resources increases. This has far-reaching environmental, social and economic implications. Against this background, the EC has set out resource efficiency as a key part of the Europe 2020 strategy as set out in Resource Efficient Europe.

For many people, it is not immediately obvious how important the food cycle is in determining our resource use and emissions. A wide range of studies shows that the European food system in its widest sense is responsible for between 20 and 30% of European greenhouse emissions on a life-cycle basis. Emissions of ammonia to air, nitrate to water and phosphorus to water come predominantly from the food cycle, especially the primary production phase. In addition, because production is an extensive user of land in particular, the food cycle has a great impact on a wide range of public goods, linked to land use, including food security itself. As a result, governments intervene in the food cycle for a wide range of reasons relating to food security, producers' incomes, resource and environmental protection and consumer protection.

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[1] European Commission (2011) Roadmap to a Resource Efficient Europe. COM(2011)571 final. September 20, 2011.
[2] Keyzer, M.A., et al. (2005) Diet shifts towards meat and the effects on cereal use: can we feed the animals in 2030? Ecological Economics 55, 187-202.
[3] Tilman, D., et al. (2002) Agricultural sustainability and intensive production practices. Nature 418, 671–677.
[4] Pretty, J.N., et al. (2005) Farm costs and food miles. Food Policy 30, 1–19.
[5] Bruinsma, J., (2009) The resource outlook to 2050: By how much do land, water and crop yields need to increase by 2050? FAO. Expert Meeting on How to feed the World in 2050 (12-13 October 2009)

Chapter 2: Methods

There are three main stages to the analysis. First, an overview, or 'map', of the EU food cycle was developed. This highlights the main issues by showing the major resource flows and environmental impacts. Second, an assessment of environmental sustainability thresholds, targets and criteria currently used was made. Third, an analysis of policies affecting the resource efficiency of the food cycle was made. From these three steps, recommendations for policy options to address resource efficiency in the EU food cycle are provided.

- **Mapping the flows and impact of the EU food cycle**

The overview of resource flows and environmental impacts of the EU food cycle set out the volumes of food produced, processed, imported, exported, consumed and wasted along the whole life cycle, and the inputs and emissions to and from this system.

Data on the flows of commodities and nutrition were obtained from FAOSTAT and Eurostat, while data for resource use and emissions were extracted from a variety of sources. An assessment of available LCA studies was conducted. On this basis, data on emissions were extracted from those studies assessed to be reliable for this purpose.

- **Assessing environmental sustainability schemes, thresholds and criteria**[6]

As there is no clear definition of sustainability that can be rigorously applied to the food cycle, the criteria we identified are based on a pragmatic approach, including a review and listing of current existing environmental sustainability thresholds, targets and criteria at global, EU, Member State, industry organisation, and product level. In addition, criteria aiming at supporting the sustainable development of the EU food cycle as a whole contained within various measures, such as certification schemes (e.g. Organic and Fairtrade) or policy actions (e.g. Green Public Procurement) were identified. Criteria that may not be currently applied to food cycle, but may be adapted for application to the food cycle, e.g. those used for biofuels, are also considered.

- **Assessing policies**

Based on the mapping of flows and impacts of the food cycle, the key decision-making stages in the food cycle were identified. Each of these were examined in relation to the effect or potential effect of policy. In addition, a workshop with stakeholders was conducted to gain stakeholder insights into the opportunities for resource efficiency improvements.

[6] Development of new indicators is not covered; the aim of this stage is to set criteria that are feasible to achieve and monitor with existing methods and indicators.

Chapter 3: The European food cycle

3.1 Conceptual model of the EU food cycle

The term 'food cycle' used here covers the whole life-cycle of all food and beverage products produced and consumed in the EU, including reuse and recycling. At each stage, resources and other inputs (energy, agrochemicals, packaging materials, land, etc.) are used, and waste and emissions caused. There are complex interactions between stages with for example recycling of nutrients from livestock to crops and in some cases from the post-consumption phase to crops. The food cycle also interacts with other economic cycles through the production of co-products for non-food use and the sharing of common resources.

Figure 2 provides a conceptual overview of the EU food cycle and the main resource flows. It covers the three main sources of food – crops, animals and fish – and has been split into four sections, to represent the broad sector divides: pre-farm, primary production (agriculture, aquaculture and fisheries), industry (processing, manufacture, distribution and retail), and consumption. Storage, transport, refrigeration and waste are not depicted in this simple overview, as they also occur throughout the system.

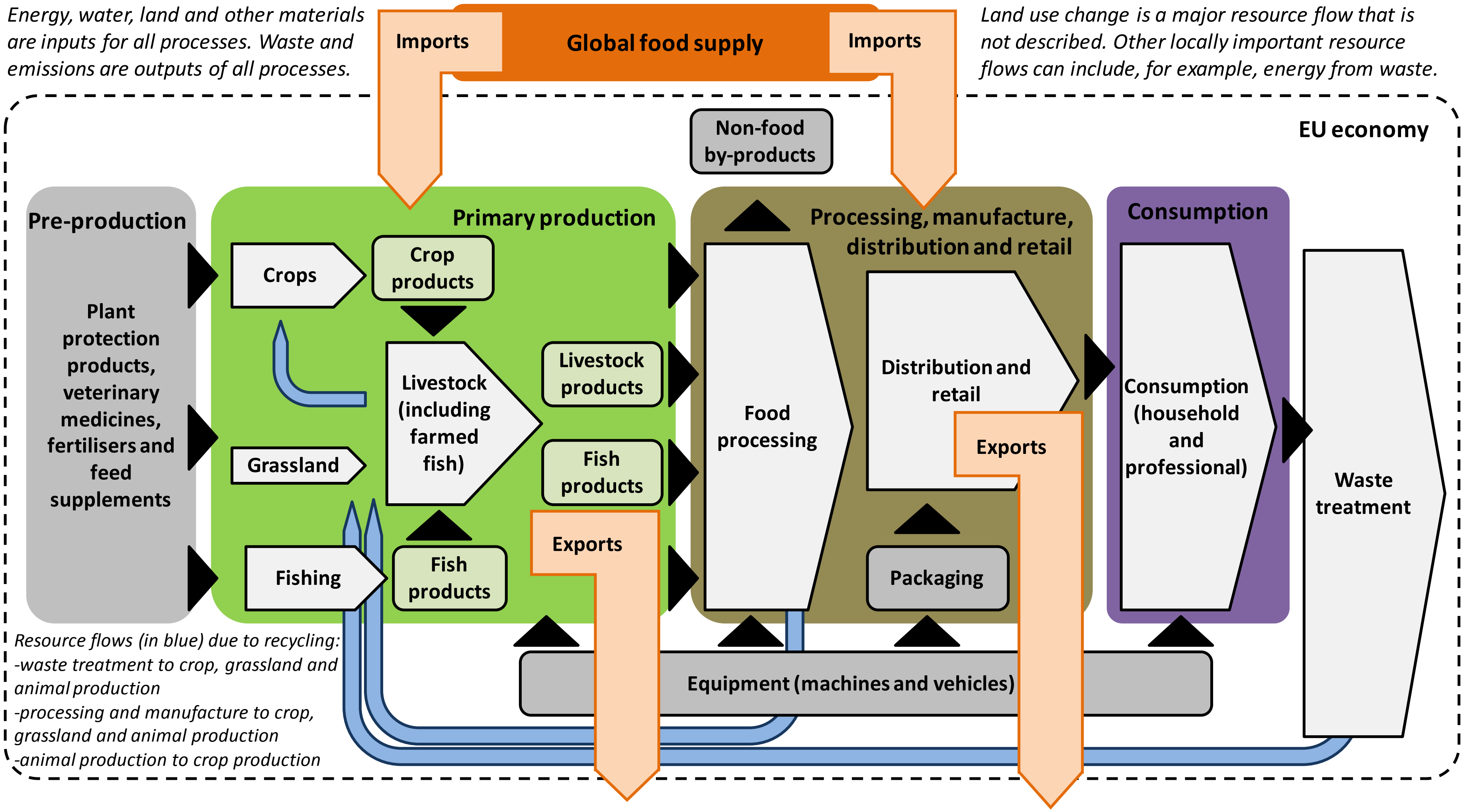
A key feature of the model is the distinction between primary production 'pre-farm gate', and 'post-farm gate'. The 'pre-farm gate' production phase is generally organised along commodity lines (milk, beef, top-fruit, etc.) and an extensive user of various natural resources (including domestic and global land use). Wild fisheries have a huge impact on aquatic biodiversity. The origin and production of inputs used by farms and fishers such as water, energy and chemicals might also be considered as a third preliminary sub-system, "pre-production".

The "post-farm gate" sub-system is organised largely along food product lines and operates mostly independent of the land and natural resource base supplying it. Resource use is straightforward, mainly related to energy and water, as are the impacts. However, the number of products and processes is huge, posing a challenge to detailed analysis.

The primary productive capacity of natural capital is largely determined by location (e.g. soil fertility, climate and disease risks) while the consumption of the food products in Europe is determined largely by population, culture and the level and distribution of wealth in societies. As a result, in Europe, trade in food commodities and products links the dispersed and partly global production base with consumption remote from production resulting in significant resource flows. Even though Europe has a high level of self-sufficiency for indigenous food products, Europe depends on significant flows of supporting resources, particularly animal feeds, vegetable oil, and tropical food products.

The extent of resource flows due to recycling (highlighted by blue arrows in Figure 2) has a major impact on resource use and are especially important in organic systems.

Figure 2: Major resource flows in the food cycle



3.2 Economic sectors

The European food cycle comprises a wide range of groups (sectors) and activities that have distinct political and economic identities. In particular, it connects four important sectors: the pre-production (farm inputs) industry, agricultural and fisheries sectors, the food and drink industry and the retail sector. The agricultural and fisheries sectors, the food and drink industry and the retail sector account for more than 5% of EU value added and 11% of EU employment. In 2008, together, they generated a total turnover of around €3,500 billion and provided employment to almost 25 million people.

- **Pre-production**

The pre-farm and fishery sector includes the farm machinery and equipment industry (including boat-building and electronics), plant breeding and seeds, plant protection and animal health products industry (now mainly a branch of the pharmaceuticals sector), the fertiliser industry, the veterinarian profession, and other support such as accountancy and legal.

- **Primary production – farming and fishing**

These primary producers make up a large number of sub-sectors, each with its own identity, particularly in terms of public policy (e.g. the Common Agricultural Policy). Within agriculture, three broad groups are identified: horticulture, arable and livestock.

Within **horticulture**, there are clear distinctions between field and protected cropping. Within horticultural field cropping, producers who use irrigation are distinct from those growing rain-fed crops. The 'top-fruit' sector (tree fruit such as apples and citrus) is also distinct in the sector.

Within the **arable** sector, differentiation tends to depend on the degree of reliance on small grain cereal crops (e.g. wheat, barley). There is a continuum between farms that rely heavily on cereals to arable-based farms with a diverse range of crops and including livestock. In general terms, arable farms which rely heavily on cereals and that use other crops such as oilseed rape for rotational reasons are distinguished from farms that use cereals as a break in rotations dominated by crops such as potatoes and maize.

The **livestock** sector is very diverse and also has distinct sub-sectors. Three groups can be distinguished: dairy, beef and sheep, and monogastric meat (pigs and poultry). In terms of resources, the distinction between monogastric (pigs and poultry) and ruminant production (cattle and sheep) is an important one. The link between ruminants and forage production means that dairy, beef and especially sheep production is usually linked to the land base used to feed these animals (through direct grazing or housed systems supported by near-by forage production). In contrast, the biology of the monogastric digestive system of pigs and poultry, whereby diets are based on cereals and soy combined partly with the behaviour of these animals (particularly pigs), means that this sub-sector is largely based on intensive, housed production (and does not need to be coupled directly to the land resource used). This allows concentration, which has profound implications for resource use and emissions, particularly nutrients such as nitrogen and phosphorus.

Four broad categories of aquaculture or fish farming are recognizable depending on the feed requirements of the fish and whether production is in sea or fresh water. Marine aquaculture is largely based on high-value piscivorous (fish-eating) species such as salmon and bass, and shellfish, while fresh water aquaculture is based on both piscivorous (e.g. trout, catfish) and herbivorous fish (e.g. carp).

Like agriculture, **fishing** is a very diverse sector ranging from large scale industrial fishing to in-shore fishing for high-value species sold fresh. A major distinction can be made between demersal and pelagic fisheries, and between fined and non-fined species such as prawn.

- **Processing (and manufacture)**

Processing and manufacture are often combined in businesses, but there are distinct differences in terms of sector structure and approach. In integrated businesses, the processing side often has a distinctly different structure to the manufacturing side.

Processing is largely commodity specific with processing sectors matching the major primary commodity groups. These are cereals (esp. milling for a wide range of purposes, dairy processing, slaughter and meat processing, the fresh produce sector.

Manufacturing is a very diverse activity with structure often linked to the way food is preserved, packaged and retailed. There are distinct sub-sectors around freezing and the refrigerated supply chain, cooked chilled meat products, dried produced, fresh produce, and the chilled ready-meal sector. These activities cut across the primary production phase, meaning that the food cycle is really a network of flows rather than a series of linear supply-chains.

Some sectors maintain their primary production character through the supply chain, notably in pigs and poultry and some dairy products where there is vertically integrated supply chains.

- **Retail**

The characterization of food retailers is largely by the size of the business and, linked to this, the legal structure. The sector ranges from the single employee shop or market stall to some of the world's largest companies. Retailer concentration is high. The top 5 multiple retailers have a market share of around 70% in most EU countries. The top 25 global retailers, of which 60% have European headquarters, are active in several countries, and even in several continents.

Large retailers have significant influence on the EU food cycle through their large purchasing power and contact with consumers at point of purchase. This sector is not only of economic significance, its **structure and function has implications for short-term food security and system resilience**. Throughout the retail sector, a distinction can be made between retailers operating within **vertically integrated supply chains** and those operating on the basis of **wholesale markets and branded products**.

- **Consumption and food services**

In the EU about one third of food sales (turnover) are through food services. The major channels are restaurants and fast food outlets. The volume of food sold through food services is much lower, being about one fifth of food purchased.[7] Food services' significance may increase in future: US consumers spend almost 50% of the value of food purchases in food services outlets.

[7] DG ENTR (2007) Competitiveness of the European Food Industry: An economic and legal assessment, pg. 10

Chapter 4: Food consumption, production and trade

4.1 Consumption

The FAO statistics relevant to commodity consumption are based on the total quantity of commodity supplied to the food system. This is not just food eaten, it includes food wasted in the post-farm food system, and inedible components. FAOSTAT shows that the food system supplies[8] from 2766 kcal/day/capita in Bulgaria to 3819 kcal/day in Austria, with an EU mean of 3466 kcal/day[9].

Mean per capita supply exceeds WHO requirements in all countries for protein, taking into consideration losses (i.e. inedible proportion of food, for example animal bones) and waste between commodity supply and food eaten[10].

In general, the former East bloc countries tend to have lower levels of total commodity and livestock supply in dietary energy terms. Dietary energy supply from livestock commodities ranges from 22% for Bulgaria to 39% for Denmark, with a mean of 30%. Animal product energy supply ranges from 600 kcal/day in Bulgaria to 1301 kcal/day in Denmark, with a mean of 1024 kcal/day for the EU. The data indicate that lower intakes of animal products are compensated by high intakes of starch-rich foods such as bread and potatoes. These energy supply patterns are reflected in protein supplies. Protein supply in commodities ranges from 76g/day in Bulgaria to 115g/day in Portugal (protein supply data for Luxembourg and Malta are higher).

However, even the lowest national per capita supplies in the EU, on an energy and protein basis, are sufficient for a healthy lifestyle. The European food system is adequately supplied with commodity foods.

4.2 Production and trade

Natural resources, climate and other geographical features such as proximity to markets and ports determine production and trade.

- **Production**

Cereal production increased greatly until 2000 and then levelled off. The increase in cereal products combined with a decreased consumption of starchy roots may have been partly due to

[8] The analysis uses the phrase 'supply' as it is used by the FAO: Supply for domestic utilization = Production + imports - exports + changes in stocks (decrease or increase). See Appendix A, Box 1, for further explanation.

[9] FAOSTAT presents the supply of food commodities in terms of weight, dietary energy, protein and oils/fat for each country. This data set, which extends back to 1961, therefore allows examination of national supply in terms of quantity and dietary quality on a per capita basis.

[10] Westhoek, H., et al. (2011). The Protein Puzzle. Netherland Environmental Assessment Agency

changing diets in Europe, and thus a changing demand for these products. Technical developments in production allowed average wheat yields to increase and has resulted in the EU now being a substantial producer of crops worldwide: wheat (19.7% of global total) and coarse grains (12.8% of global total).

However, during this period direct human consumption has remained relatively static. This increased supply base of these cereals grains enabled increased use for livestock feeding. Poultry and pig meat production have increased the most rapidly. From the 1960 to 2000 poultry production has increased by approximately a factor of five and pig meat doubled. Since 2000 poultry production has remained below 10 million tonnes per annum, while pig meat production has continued to increase toward 20 million tonnes per annum. Beef and veal production has however remained comparatively stable, falling from a peak in the early 1990s.[11] The EU is now a substantial producer of meat worldwide: pig meat (23% of global total), poultry meat (12.9% of global total) and beef and veal (12.6% of global total); and also dairy products (40% of the world production of casein and cheese and more than 20% of the world production of milk, skimmed milk powder and butter)

Trade within the EU

Trade between countries in the EU is significant. In general terms, livestock products (particularly dairy and beef) are traded from north to south. There is a very clear reliance in the north on fresh fruit and fruit products (e.g. wine) and vegetables grown in the south. Countries with high meat consumption are also exporters of meat.

EU global trade

The imports and exports to and from countries outside the EU indicate that the EU imports more primary food products than it exports. In 2007, trade (exports and imports) in raw and processed agricultural products accounted for approximately 6% of total EU[12] trade in goods with non-EU countries. This figure compares to a 9% share in 1995. The decreased share of agricultural products in the EU trade with third countries is due to a steady increase in trade in industrial products during the last twelve years, compared to a relatively modest increase for agricultural products.[13]

Europe is net exporter of small-grain cereals and monogastric meats (pig and poultry meat), and net importer of beef and sheep meat. Exports of commodities are expected to remain approximately constant or fall to 2020, particularly for milk powder.

Future imports are expected to grow steadily or remain at current levels for most food categories, apart from a more significant increase in vegetable oil. Exports of wheat and coarse grains, which are expected to be highly variable over the coming years, with overall trend to 2020 of increased export of coarse grains only.[14]

[11] Westhoek, H., et al. (2011). The Protein Puzzle. Netherland Environmental Assessment Agency
[12] Romania and Bulgaria are included in the statistics from the date of their accession (January 2007)
[13] European Commission, (2009) publication Trade and agriculture – an overview of EU imports and exports based on EUROSTAT COM, 2008. Available at : trade.ec.europa.eu/doclib/cfm/doclib_section.cfm?sec=175&langId=en [Accessed online 28/02/2011]
[14] OECD-FAO 2010 Agricultural Outlook

The EU exports significant amounts of high value processed foods and is the world's largest exporter these products.[15,16] The food industry is one of the largest and most important manufacturing sectors in Europe, with exports valued at €66.4bn or 20.8% of the total world market share[17]. The US was the largest EU customer, receiving about 19% of EU exports, followed by Russia and Switzerland (10% and 7% respectively).[18] Examples of this include coffee, where a large part of it is imported and then roasted and refined in Europe before being exported again, and alcoholic beverages (produced from cereals) such as beer and whiskey. The EU is also the second largest processed food importer globally (18.1%).[19]

- **EU reliance on global trade**

The EU food system as a whole produces almost enough food to meet the nutritional needs of feeding the EU population. However, the EU food system cannot currently produce types of foods that are grown and imported from tropical regions. In addition, the EU food system currently imports large amounts of protein-rich animal feedstuffs, such as soy; this trade pattern is driven by the feeding of livestock and affected by political changes (removal of crop-specific payments during Common Agricultural Policy (CAP) reforms and the World Trade Organisation (WTO) agreements).

[15] FAOSTAT database, available at: faostat.fao.org/site/291/default.aspx [Accessed online 28/02/2011]
[16] Primary agriculture (farming) and fishery are not part of the food industry; they supply raw material to the food processing industry.
[17] European Commission Enterprise and Industry webpage: ec.europa.eu/enterprise/sectors/food/faq/index_en.htm#09012624850a6457 [Accessed online 20/05/2011]
[18] European Commission, (2009) publication Trade and agriculture – an overview of EU imports and exports based on EUROSTAT COM (2008). Available at : trade.ec.europa.eu/doclib/cfm/doclib_section.cfm?sec=175&langId=en [Accessed online 28/02/2011]
[19] European Commission Enterprise and Industry webpage: ec.europa.eu/enterprise/sectors/food/international-market/index_en.htm [Accessed online 20/05/2011]

Chapter 5: Resource flows

5.1 Overview

In order to provide an overview of the flow of food from primary production (agriculture and fishery) to final consumption, a Sankey diagram was built. This was inspired by the visual flow diagrams often constructed for domestic energy production, imports, exports, transformation and final consumption, a similar diagram was pieced together from a variety of different sources.

The Sankey diagram (see Annex D for full diagram) therefore tracks the major flows of food in the EU-27 from primary agricultural production and fisheries to waste, including imports and exports to and from countries outside the EU. All flows greater than 1 Mt are shown (amounts are rounded up). The year 2007 was selected for the diagram as it is the latest year with the most complete set of data. Details of the sources used can be found in Appendix A.

It should be noted that the food flows are based on weight and the water content is not tracked in this diagram (see e.g. the difference between sugar beet and refined sugar). The drastic reduction on quantities through a process does not necessarily mean that the process is inefficient, but could indicate that water is with-drawn from the food. The opposite is also the case; some processes add water to the food flow. For example, the amount of beer is much larger than the amount of barley (malt) that goes into the process.

Similarly the manner in which the data is structured or measured, leads to some interesting transformations. For example, the waste statistics show that 123.7 Mt of "Animal faeces, urine and manure" came from the agriculture, hunting and forestry sector in 2006, while the Eurostat nutrient balance agri-environmental indicators only provides data for manure in tonnes of N or P nutrient.

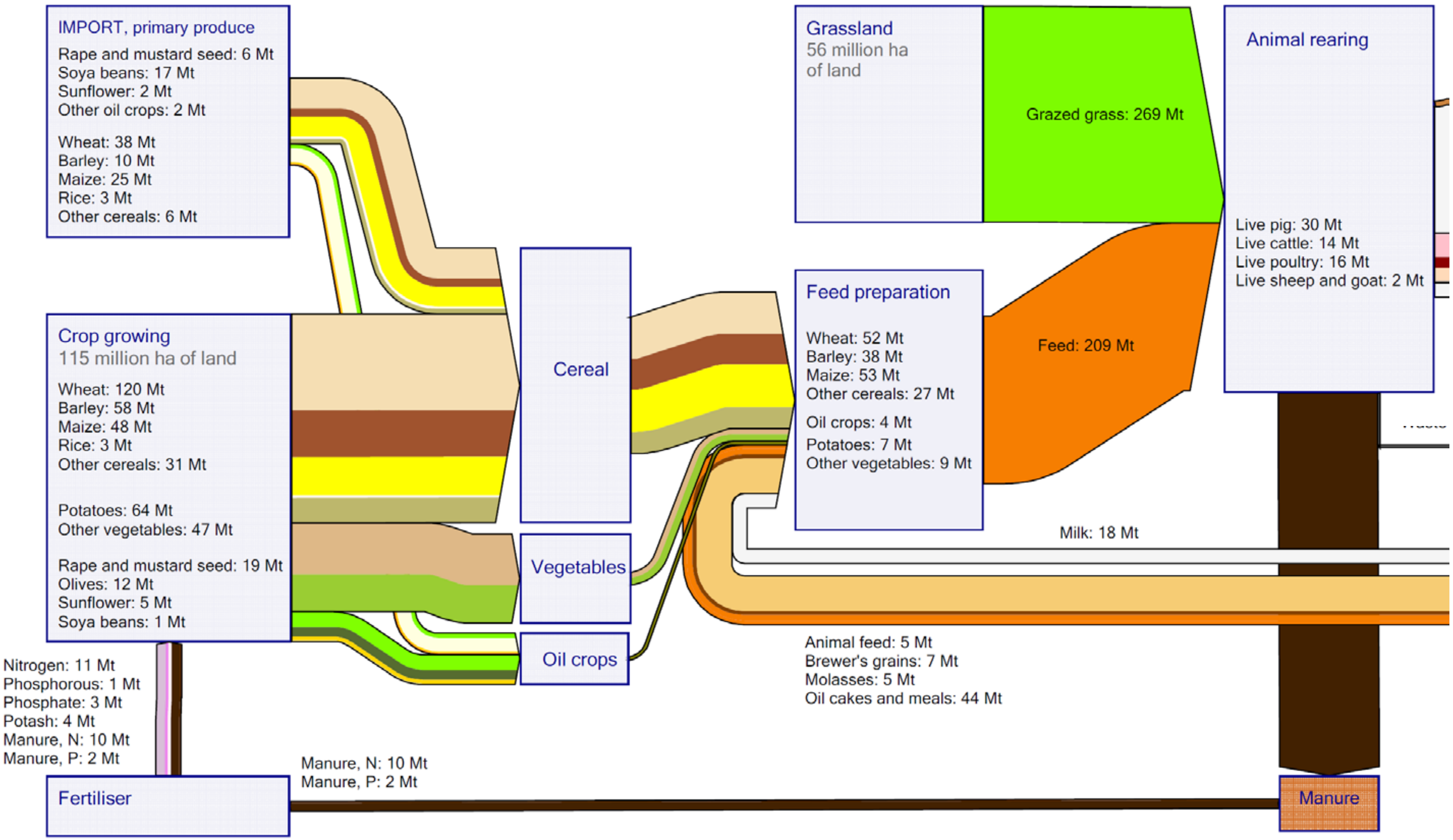
The flows related to processed food are not very clear, but this is due to the lack of data.

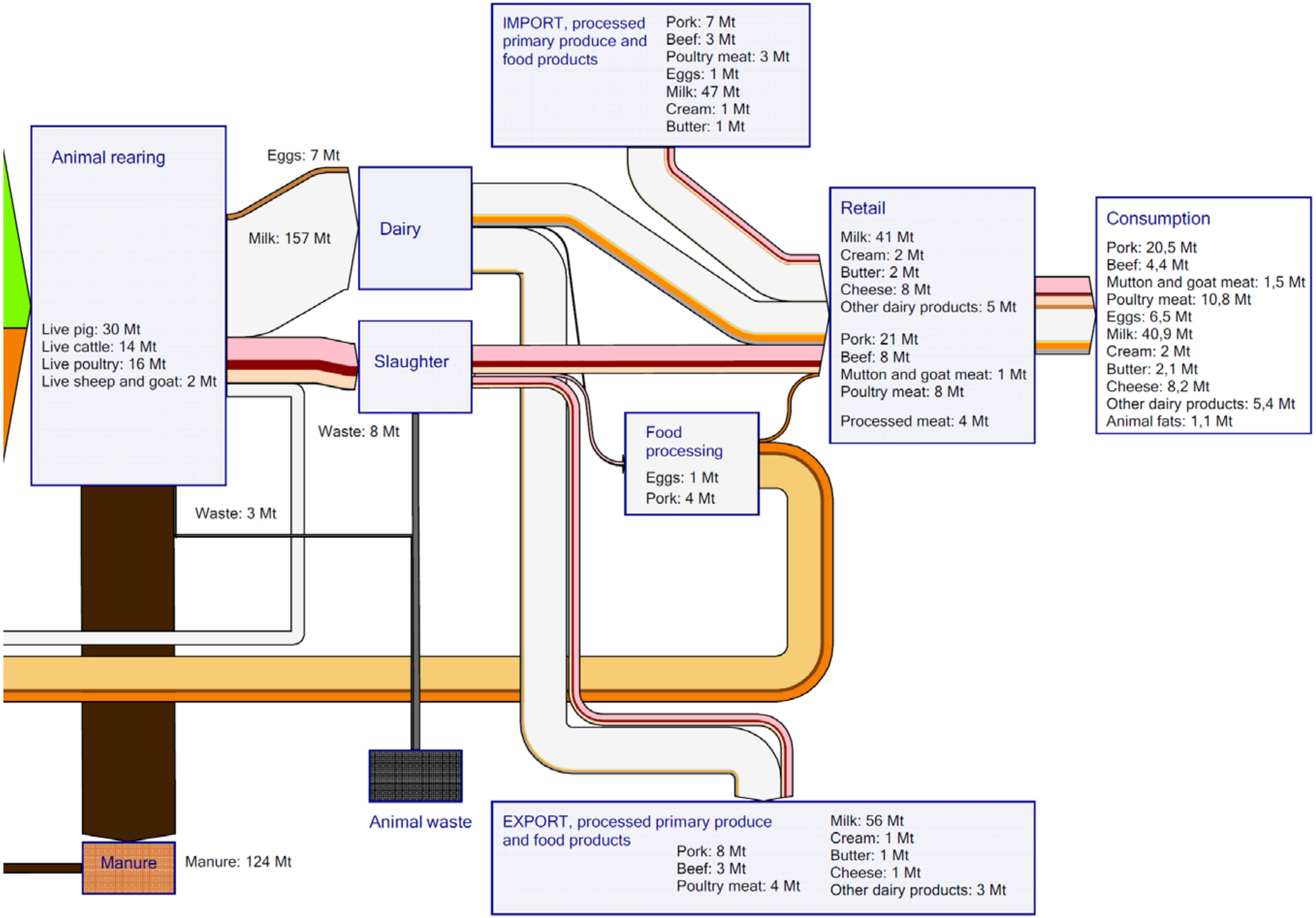
The amounts shown under consumption are amount of food (often given in 'equivalents') available for consumption.

The Sankey diagram shows that grazed grass, crops; milk and meat represent the greatest resource flows in the EU.

Figure 3 demonstrates the resource flows associated with meat and dairy products.

Figure 3: Flows of resources and related waste associated with meat and dairy products in the EU food cycle




IMPORT, processed primary produce and food products
Pork: 7 Mt
Beef: 3 Mt
Poultry meat: 3 Mt
Eggs: 1 Mt
Milk: 47 Mt
Cream: 1 Mt
Butter: 1 Mt
Animal rearing
Live pig: 30 Mt
Live cattle: 14 Mt
Live poultry: 16 Mt
Live sheep and goat: 2 Mt
Eggs: 7 Mt
Milk: 157 Mt
Dairy
Slaughter
Waste: 8 Mt
Waste: 3 Mt
Retail
Milk: 41 Mt
Cream: 2 Mt
Butter: 2 Mt
Cheese: 8 Mt
Other dairy products: 5 Mt
Pork: 21 Mt
Beef: 8 Mt
Mutton and goat meat: 1 Mt
Poultry meat: 8 Mt
Processed meat: 4 Mt
Consumption
Pork: 20,5 Mt
Beef: 4,4 Mt
Mutton and goat meat: 1,5 Mt
Poultry meat: 10,8 Mt
Eggs: 6,5 Mt
Milk: 40,9 Mt
Cream: 2 Mt
Butter: 2,1 Mt
Cheese: 8,2 Mt
Other dairy products: 5,4 Mt
Animal fats: 1,1 Mt
Food processing
Eggs: 1 Mt
Pork: 4 Mt
Animal waste
Manure
Manure: 124 Mt
EXPORT, processed primary produce and food products
Pork: 8 Mt
Beef: 3 Mt
Poultry meat: 4 Mt
Milk: 56 Mt
Cream: 1 Mt
Butter: 1 Mt
Cheese: 1 Mt
Other dairy products: 3 Mt

5.2 Main inputs to the EU food cycle

Land use and change (direct and global): Domestic land use for food production (excluding industrial crops) is 172 million ha[20] (approximately 40% of EU land). EU dependency on land in non EU countries is also significant as the result of complex trade patterns between different parts of the world[21,22]. For example, production of cereals and oilseeds accounts for approximately 58 million hectares within the EU[23] and 24 million hectares overseas.[24]

Water: The hydrological cycle is closed so water use is a local or regional issue. There is severe water stress in many regions within the EU and globally where water is used for production of food consumed in the EU. Currently about 35% of water abstracted in the EU is used for agriculture (globally it is 70%).

Fertilisers: The total consumption of fertiliser nutrients in the EU in 2007 was 17.8 Mt (10.8 Mt nitrogen, 3.3 Mt phosphate and 3.6 Mt potash).[25]

Energy: Within the EU, 'agriculture' and 'food and beverage processing' consume roughly equal quantities of energy. In total this accounts for around 6% of the EU total energy consumption.

Ecosystem services: The food cycle relies on provisioning (i.e. production of food and water) and supporting (e.g. nutrient cycling, soil formation) ecosystem services[26]. The value of these services, including regulatory (e.g. CO_2 sequestration), is increasingly recognized[27].

5.3 Main emissions from the EU food cycle

Waste: Of the estimated total 89 Mt EU food waste, households produce the largest fraction (37 Mt; 42 % of the total), representing 179 kg per capita[28], with evidence showing that over 60% of it may be avoidable[29]. Significant industrial (30 Mt; 39%), wholesale/retail (4 Mt; 5%) and food service sector (12 Mt; 14%) food waste also occurs. In 2005 global by-catch discards from fishing

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[20] Eurostat, 2007 – See Appendix A

[21] Eickhout, B., et al (2007) Economic and ecological consequences of four European land use scenarios , Land Use Policy, Volume 24, Issue 3, Pages 562-575

[22] Laura Würtenberger, Thomas Koellner, Claudia R. Binder (2006) Virtual land use and agricultural trade: Estimating environmental and socio-economic impacts , Ecological Economics, Volume 57, Issue 4, 1 Pages 679-697

[23] Eurostat [apro_cpp_crop], 2007

[24] FAOstat, Agricultural production and food balance sheets, based on imports and average world yields, 2007

[25] FAOstat, 'Fertilizers' module, 2007

[26] Millennium Ecosystem Assessment (2005) Ecosystems and human well-being: Synthesis. Preface & Summary for Decision-makers. Island Press, Washington DC, USA. (p. V-IX & 1-24).

[27] The Economics of Ecosystems and Biodiversity (TEEB) report for Local and Regional Policymakers www.teebweb.org/ForLocalandRegionalPolicy/tabid/1020/Default.aspx
TEEB for Policymakers www.teebweb.org/ForPolicymakers/tabid/1019/Default.aspx

[28] BIO Intelligence Service (2010) Preparatory study on food waste across EU27

[29] WRAP (2009) Household food and drink waste in the UK

was estimated at 7 Mt[30] (between 20-60% of the catch for the period 2003-05[31]). Production losses that may occur (farm or aquaculture) are not considered as food waste.

Nutrients: Both for phosphorous and nitrogen, there are significant losses along the food chain, due to fertiliser run-off, direct emissions (e.g. N2O), crop processing waste loss and manure loss.

GHGs: Agriculture produced 9.6% of the EU emissions of greenhouse gases in 2008, with a decrease of 5.6% between 2000 and 2008.[32]

5.4 EU food cycle outputs

- **Crop production**

260 million tonnes of cereals; 130 million tonnes of fruit and vegetables.

- **Livestock production**

150 million tonnes of milk; 8 million tonnes of bovine meat; 22 million tonnes of pig meat; 10 million tonnes of poultry meat.

- **Fish production**

5 million tonnes wild catches; 1.3 million tonnes aquaculture.

- **Consumption**

75 kg of meat; 23 kg of fish and seafood; 80 kg of milk; 75 kg of potatoes per capita per year in the EU.

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30 Kelleher, K. (2005) Discards in the world's marine fisheries: An update. FAO Fisheries Technical Paper No. 470. Rome, FAO. 152 pp.

31 Scientific, Technical and Economic Committee for Fisheries (STECF), Europa, Summaries of EU legislation, Reducing discards and by-catches: europa.eu/legislation_summaries/maritime_affairs_and_fisheries/fisheries_resources_and_environment/l66048_en.htm [Accessed online 8/2/2012]

32 European Union Directorate-General for Agriculture and Rural Development (2010) Rural development in the European Union, statistical and economic information Report 2010

Chapter 6: Environmental impacts of food

The food cycle has been described as one of the leading drivers of environmental impacts.[33,34,35,36] The various types of food and beverages we consume have different resource requirements and environmental impacts. An aim of the project is to quantify the environmental impacts of food product categories at different stages of their life cycle; identifying the drivers and pressures of food related environmental impacts and prioritising the areas with need for action. This chapter summarises the findings of the review of LCA studies. Detailed background data is provided in Appendix B.

6.1 Data review and availability

As set out in Appendix B, conversion factors were used to compare different functional units. Based on the judgement of BIO's LCA experts, the highest quality life cycle data have been used in the subsequent analysis (see Appendix B for discussion on LCA quality criteria). It was found that only a limited number of reliable and comparable LCA studies available, confirmed by other studies that have in similarly reviewed the existing food LCAs.[37,38]

The number of environmental impact potential categories varied from study to study, and although the food cycle has consequences for soil quality, land use change, fish depletion and biodiversity loss, these are not consistently addressed in current attributional LCAs. In addition, the impacts on water use and the generation of waste are seldom included in LCAs despite both aspects being significant for the food cycle. Typically, LCAs consider the environmental impacts of agricultural commodities to the farm gate (e.g. live animal or raw milk) or to the slaughterhouse (e.g. slaughtered carcass), or the life cycle impacts of very specific products (e.g. a pizza). In many cases, LCAs aim more to compare the relative difference in environmental impacts than to determine the absolute values of impacts, e.g. by answering questions such as: What kind of packaging is the best environmental choice?

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[33] UNEP (2010) Assessing the Environmental Impacts of Consumption and Production: Priority Products and Materials, A Report of the Working Group on the Environmental Impacts of Products and Materials to the International Panel for Sustainable Resource Management. Hertwich, E., et al.

[34] EC (2006) Environmental Impacts of Products (EIPRO)

[35] Pretty, J.N., et al (2005). Farm costs and food miles: an assessment of the full cost of the UK weekly food basket. Food Policy 30, 1–19.

[36] Tilman, D., et al (2002). Agricultural sustainability and intensive production practices. Nature 418, 671–677.

[37] Foster, C., et al (2006). Environmental Impacts of Food Production and Consumption: A report to the Department for Environment, Food and Rural Affairs. Manchester Business School. Defra, London

[38] ECOINTESYS (2008) Analyse du cycle de vie des produits agricoles. Study commissioned by ADEME, France.

6.2 Results

6.2.1 Impacts of the food groups

Figure 4 shows the Global Warming Potential (GWP) values gathered in the LCA study review. Average values are indicated with an 'X', while median values are indicated with a '—'. Similar charts for primary energy consumption, water consumption, acidification potential, eutrophication potential and photochemical oxidation potential are provided in Appendix B.

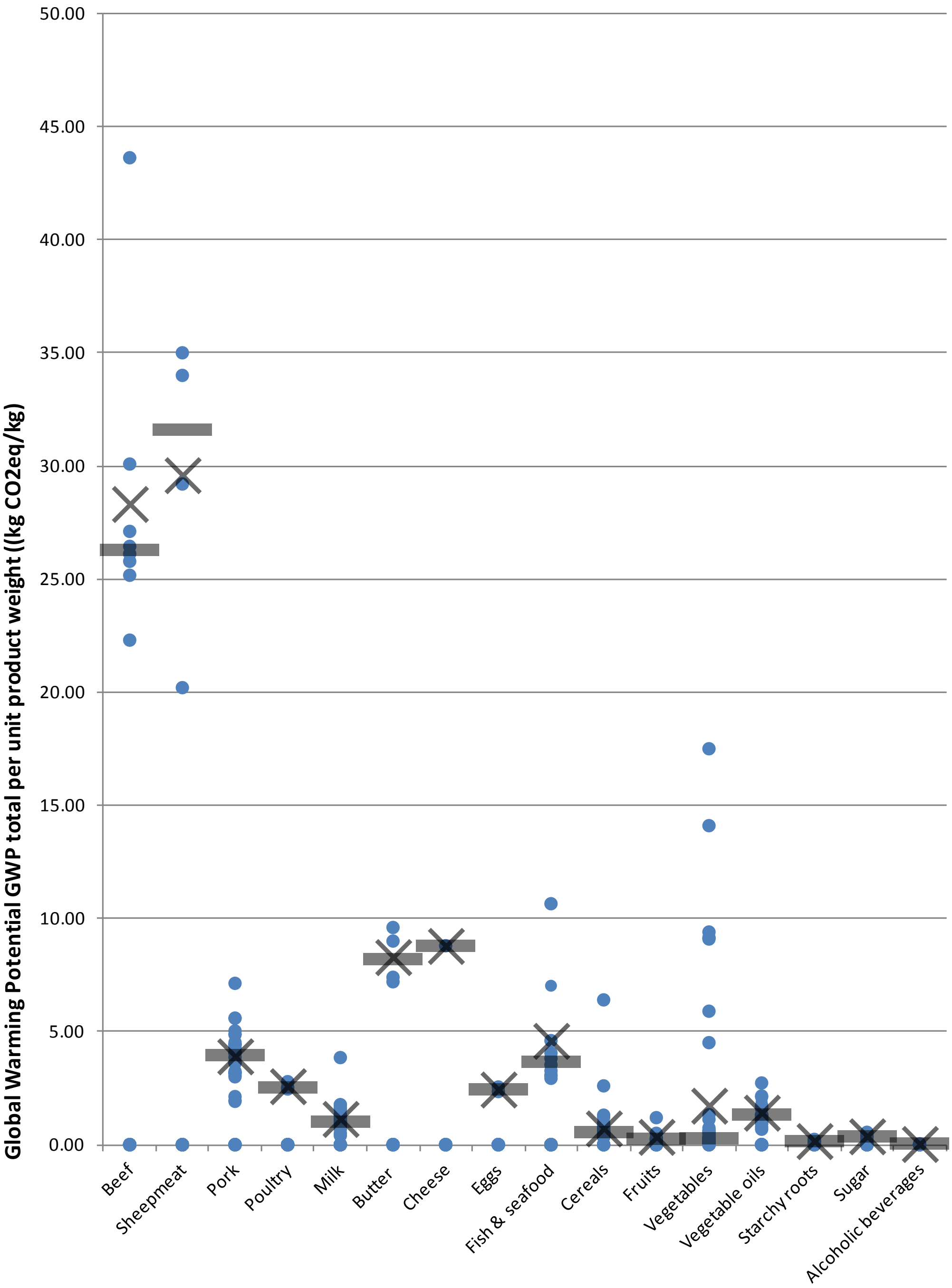

Figure 4: LCA review results - GWP (kg CO_2 eq.) per kg product weight

Figure 5 shows the estimates of GWP emissions for food groups, derived from LCA data and FAO commodity supply (i.e. EU consumption) figures for 2007, per kg food.[39]

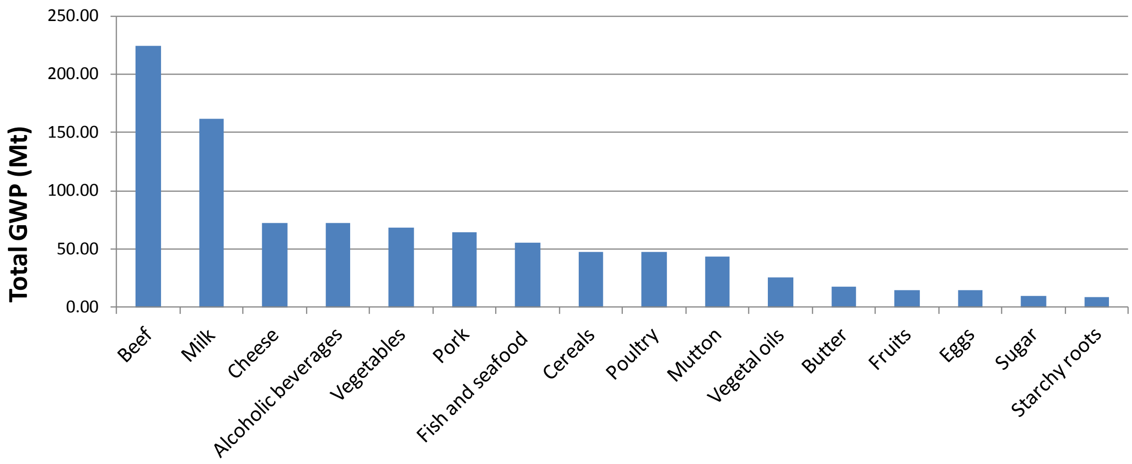

Figure 5: Total GWP (kg CO2 eq.) for supply of food to EU, by food group

Following review of the literature, general observations include the fact that livestock production has particularly high impacts[40]. Several studies have investigated the impact of livestock and meat production:

- in the EU, environmental impacts of beef have been estimated to be four to eight times larger per kilo slaughtered weight compared to poultry[41];
- the GGELS[42] project provided detailed product-based estimates of emissions from the livestock sector in the EU-27 according to animal species, animal products and livestock systems following a food chain approach. Some of the conclusions were:
  - 29% of GHG emissions are from beef production (approx. 6% by weight), 29% from cow milk production (approx. 70% by weight) and 25% from pork production (approx. 13% by weight), while all other animal products together do not account for more than 17% of total emission (approx. 11% by weight);

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[39] In the publications reviewed the number of environmental impact categories varied from study to study. In the context of environmental impacts related to the food cycle the most reliable indicators are: Global Warming Potential, Eutrophication Potential and Acidification Potential. Although the food cycle has severe negative consequences for soil degradation, fish depletion and biodiversity loss, the indicators and data for these impact categories in LCAs are not considered to be reliable. There are large variations in these environmental impacts according to production method, farming practices, production location, etc., and in many cases, the LCA aim more to compare the relative difference in environmental impacts across production systems than to determine the absolute values of impacts for food groups.

[40] UNEP (2010) Assessing the Environmental Impacts of Consumption and Production: Priority Products and Materials, A Report of the Working Group on the Environmental Impacts of Products and Materials to the International Panel for Sustainable Resource Management. Hertwich, E., et al.

[41] JRC-IPTS (2008) IMPRO Environmental Improvement potential of meat and dairy products

[42] Leip A., et al (2010). Evaluation of the livestock sector's contribution to the EU greenhouse gas emissions (GGELS) -final report, European Commission, Joint Research Centre

- according to calculations from the CAPRI model, 49% of total emissions are created in the agricultural sector, 21% in the energy sector and 2% in the industrial sector;

- reasons for low emissions in Austria (14.2 kg CO_2-eq per kg of beef) could be a high self-sufficiency in feed production and a high share of grass in the diet, whereas the Netherlands (17.4 kg CO_2-eq per kg of beef) benefit from an efficient and industrialised production structure with strict environmental regulations;

- For the UK food system which is similar to the European food system, livestock production accounts for nearly two-thirds of emissions from primary production but delivers only one third of the food calories.[43] Food as a whole accounts directly for about one fifth of UK consumption-related emissions. When global land-use change is considered, this rises to one third.

- livestock production is a major contributor to the world's environmental problems, contributing about 12% to global anthropogenic GHG emissions[44];

- ranking of environmental impacts according to the transgression of pre-defined aggregated impact indicator benchmarks[45], and the facts that: a) nitrogen pollution has been ranked at the global scale as one of the top 3 threats to biodiversity[46], and b) fertiliser accounts for 37% of all energy expenditure in US agriculture[47]; leads to the conclusions[48] that:

  - food production is a major driver of all impacts listed by Rockström et al. (2009);

  - among food types, the production of protein-rich foods is pivotal; and

  - the Rockström et al.(2009) top 3 impact categories (1. biodiversity loss; 2. nitrogen cycle disruption; and 3. climate change) are strongly interlinked by (animal) protein production, which is therefore on its own responsible for a very large share of the environmental impacts of food production.

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[43] Audsley, E., Brander, M., Chatterton, J., Murphy-Bokern, D., Webster, C., and Williams, A. (2009). An assessment of greenhouse gas emissions from the UK food system and the scope for reduction by 2050. How low can we go?. WWF-UK and the FCRN.

[44] Westhoek, H. et al (2011). The Protein Puzzle. Netherland Environmental Assessment Agency

[45] As proposed by Rockström, J. et al. (2009). Planetary boundaries: exploring the safe operating space for humanity. Ecology and Society 14(2): 32. [online] URL: www.ecologyandsociety.org/vol14/iss2/art32/

[46] Townsend, A.R. and Howarth, R.W. (2010) Fixing the Global Nitrogen Problem, Scientific American Magazine; February, 8 Page(s).

[47] Lang, T., Barling, D., & Caraher, M. (2009). Food policy: Integrating health, environment & society. Oxford, UK: Oxford University Press. p. 193

[48] Aiking, H. (2011) Future protein supply. Trends in Food Science & Technology 22(2-3): 112-120.

The production of livestock can have positive impacts:

- Traditionally, agricultural systems have fostered species-rich, diverse semi-natural ecosystems and habitats. Semi-natural habitats in European farmland are known to be biodiversity hotspots and some habitats important for biodiversity conservation were created by, and are still inherently linked to, livestock production.[49]
    - The main mechanism by which grazing livestock affect biodiversity in pastures is the creation and maintenance of sward structural heterogeneity. However, much depends on maintaining low grazing intensities and there is significant variation in impact on grazed communities between the different domestic grazing animal species, depending on, for example, body size of the animals[50].
- Animals can convert the energy embedded in biomass (e.g. grass, straw), which is not available to humans by digestion, into a product of high nutritional value.
- Livestock production can take place in parts of the EU (e.g. mountainous areas) where the crop production conditions may be restricted, bringing productivity and employment opportunities.
- Grazing is critical for maintaining many of Europe's cultural landscapes and sustaining some rural communities.

Therefore, although livestock production has both positive and negative impacts, the environmental impacts have been shown to be high (although differing depending on production practices). However, livestock is only one of the causes of environmental impact within the food system.

A study for the UK government of the effects of consumption and production change in the UK highlighted the link between consumption and the use of grassland.[51] However, it also drew attention to other uses for land now used for semi-natural grasslands that are also environmentally beneficial and that the grazing of these semi-natural grasslands is not dependent on the current high levels of livestock product consumption.

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[49] Leip A., et al (2010). Evaluation of the livestock sector's contribution to the EU greenhouse gas emissions (GGELS) - final report, European Commission, Joint Research Centre. Available from: EC Joint Research Centre: afoludata.jrc.ec.europa.eu/index.php/dataset/detail/236 [Accessed online 20/05/2011]

[50] A.J. Rooka, et al (2004) Matching type of livestock to desired biodiversity outcomes in pastures – a review Biological Conservation Volume 119, Issue 2

[51] Audsley, E., Chatterton, J., Graves, A., Morris, J., Murphy-Bokern, D., Pearn, K., Sandars, D. and Williams, A. (2010). Food, land and greenhouse gases. The effect of changes in UK food consumption on land requirements and greenhouse gas emissions. The Committee on Climate Change

6.2.2 Impacts along the life cycle

Data of Global Warming Potential tends to be the most robust and consistently quantified impact category, which can help to map impacts along the life cycle. Contributions to GWP at each life cycle stage for certain food groups are described in Figure 6.

- In most of the quantification studies, the (agricultural or fisheries) production phase remains the most impacting over the life cycle, and accounts for up to 70% of the environmental impacts of an average food basket (Munoz, 2010).
- There are large variations in these environmental impacts according to production method, farming practices, production location, etc.
- Other stages in the life cycle, such as processing and packaging, tend to have less impact compared to production, although there are exceptions (e.g. the type of transport used, especially air-freight vs. train or truck, or the packaging for some products such as bottled water).

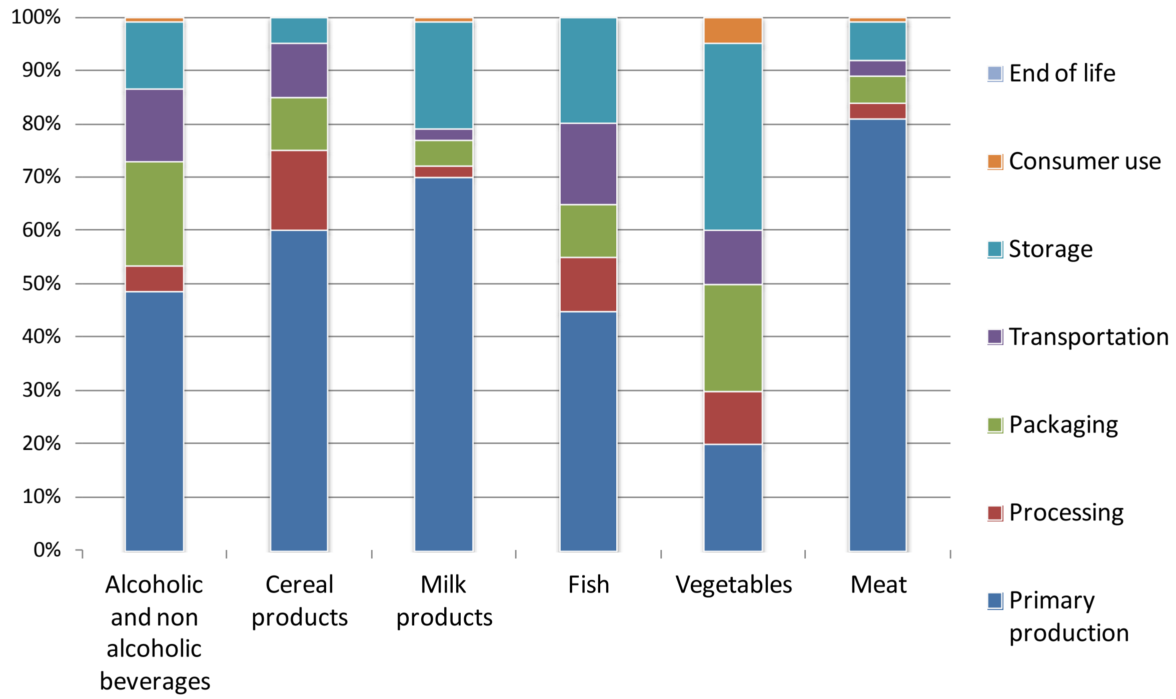

Figure 6: Life cycle stage GWP impacts for selected food groups[52]

If the total GWP impacts (Figure 5) of the respective food groups are weighted by the proportions in Figure 6, a rough estimation of proportion of total GWP impact of food supply, per lifecycle stage, is as follows: agriculture 55%; processing 4%; packaging 7%; transportation

[52] Notes – BIO Intelligence Service LCA data – average contributions of several results: Alcoholic and non-alcoholic beverages includes bottled water, wine, milk, fruit juices; Cereal products includes chocolate biscuits, "nature" biscuits, white bread, wheat flour, breakfast cereals; Milk products includes cheese, yoghurt and ice cream; Fish includes smoked salmon, smoked trout, fish-based preparations; Vegetables includes green peas, French beans, prepared salads including chicken salads; Meat includes: lamb, pork, beef, chicken.

5%; distribution 11%; consumer use 1%; end of life 1%. Foster et al. (2006)[53] have drawn some general conclusions, described in Table 3.

Table 3: General conclusions about the environmental impacts of different aspects of the food cycle

Question?	Conclusion
Organic versus conventional agriculture?	There is insufficient evidence to state that organic agriculture systemically has less impact on the environment than conventional agriculture, for example in terms of GWP per unit produce. This is mainly due to the significant difference in yields of the two types of agricultural practice. Organic agriculture has however been shown to provide local benefits to biodiversity.
Locally versus globally sourced food?	The evidence that locally grown food has a lower environmental impact is weak. In-season efficient production is generally a more important factor. For some foods, global sourcing from areas of efficient in-season production is a better environmental option.
Fresh versus cold versus preserved?	Although refrigeration involves additional energy consumption, this can be outweighed by the fact that less food is wasted when refrigerated or preserved. As there is little knowledge of food waste amounts, this general statement cannot be made. However, the ability to conserve food stuffs longer does allow food to be transported over longer distances and does drive the growth of refrigeration for food preservation and storage.

As can be seen from Table 3, the general answer is "it depends". One must consider the specificities of each food category and context to determine what is the more resource efficient alternative.

[53] Foster, C., et al (2006). Environmental Impacts of Food Production and Consumption: A report to the Department for Environment, Food and Rural Affairs. Manchester Business School. Defra, London

Chapter 7: Summary and discussion papers

This section summarises the key issues for the food cycle in the context of resource efficiency. The mapping of flows and environmental impacts has shown that most impacts occur at the agricultural stage and (although there is high variability within food groups) due to the supply of animal products. However, addressing resource efficiency of the food cycle is not straightforward, and it is important to consider other cross-cutting issues.

Following a section (7.1) on the policy context, sections 7.2 to 7.5 cover issues within the different stages of the food cycle. As the significant proportion of environmental impacts occur across production and processing stages, improvements at the end of life and consumption stages have high potential (as they embody all the environmental impacts occurring up to that stage). In addition, from a systems perspective, waste is a major source of resource inefficiency. Sections 7.2 to 7.5 are therefore set out in reverse order to the direction of resource flow in the system.

7.1 Policy context

The CAP and the CFP have been cornerstones of the development of the European Union. These two policy areas are the clearest example of European policy impacting on the daily lives of European citizens, especially producers. In addition, a wide range of EU Directives developed in more recent times seek to protect resources used in food production. The Nitrates Directive and the Water Framework Directive are the best known examples. There are also Directives protecting human health and animal welfare.

- **Considering the complexity of the EU food cycle as a system**

The EU food cycle is more like a complex system than cyclic flows of resources. It is characterised by a large variety of actors (e.g. farmers, fishermen, manufacturers, distributors, retailers, caterers, consumers), products (e.g. food, feed, fertilisers, equipment, packaging), processes (e.g. planting, animal breeding, harvesting, slaughter, food processing, distribution, retail, cooking), resource use (e.g. biomass, minerals, land, water, energy) and environmental impacts (e.g. GHGs, nutrient loss, waste, biodiversity loss).

- **Public goods and public policy**

The EU food cycle plays a substantial role in the EU economy (see Table 4) and because production is an extensive user of natural resources, the food cycle has a great impact on a wide range of public goods, including food security.

Table 4: The EU Food and Drink Industry (2009)[54]

- It purchases and processes 70% of EU agricultural production; exports €53.7 billion and imports €50.8 billion food and drink products to and from third countries
- It is the single largest manufacturing sector in terms of turnover and employment in the EU: annual turnover of €954 billion (12.9% of the manufacturing sector) and employment of 4.2 million (13.5% of the manufacturing sector)
- It is diverse with 310,000 companies, 99.1% of which are SMEs

Public policy has a profound role in shaping the food cycle. Until relatively recently, the policy effort was primarily developed (through the CAP and the CFP, etc.) in response to the need to address specific aspects of the food cycle such as farm income and pesticide safety. More recent policy measures are focused on the protection of more global public goods and resources. As a result, governments intervene in the food cycle for a wide range of reasons relating to food security, producers incomes, resource and environmental protection and consumer protection.

Review of current EU policy

The CAP has been successful in terms of agricultural output. In the past, the CAP heavily subsidised production. Farm businesses received subsidy linked to production or the production base. The current policy delivers subsidies decoupled from production and linked to the area of land farmed according to 'good agricultural practice' or 'cross-compliance'. The current negotiations about the next reform of the CAP are focused on the question of explicitly coupling public support for farming to the delivery of public goods (i.e. active environmental and resource protection – 'public money for public goods'.

The *Nitrates Directive* is one of the oldest policy instruments that directly affects the actions of farmers with respect to the environment and resource use on farms. It limits the application of organic N per hectare. It is focused on organic N inputs rather than the on-farm N cycle as a whole.

The *Water Framework Directive* is a relatively new set of instruments and aims to conserve and/restore whole water bodies and river basins to a 'good' ecological status. If implemented fully, this will have a major impact on agriculture.

Setting the limit at national level for ammonia emissions, the *National Emission Ceilings Directive* contributes significantly to reducing ammonia emissions to air. This Directive has been generally successful in relation to the targets set so far and almost all EU countries are meeting their targets. Further reductions are likely to be required and these will become increasingly challenging.

The negative consequences of livestock concentrations (pigs and poultry at North-West Europe) include high local ammonia burdens and also significant fish 'kills' in nearby water bodies (despite the *Nitrates Directive*). Despite the range of legislation that should counter it, the livestock concentration process continues, with inefficient use of manures and locally high ammonia emissions and nitrate levels in ground water.

[54] Confederation of the food and drink industries of the EU (CIAA) (May 2011), Annual Report 2010

While the EU *Soil Framework Directive* remains at proposal level, *soil* is the subject of specific legislation in only 9 countries of the EU, and also indirect legislation at the EU level, such as the *Sewage Sludge Directive*.

Plant protection products (pesticides) are heavily regulated. All EU countries have specific legislation governing the marketing and the use of pesticides within an EU framework. The EU-led legislation on the marketing of pesticides has recently increased emphasis on hazard, meaning that any plant protection product which is deemed to exceed a hazard threshold will be excluded from the market. It is an example of legislation becoming more focused on specific features or points at the expense of a systems approach – in this case the impact on ecosystems arising from the combination of hazard and exposure.

GMO related policy is an example of legislation taking a systems approach in some respects. For example in the UK, policy on GMO development has been led by concerns about the agro-ecosystem system effects of widespread use of GM herbicide tolerant crops informed by the so-call Farm scale Evaluations of herbicide tolerant crops.

There are voluntary measures supporting *organic farming,* an approach to farming that promises a significant divergence in farm practices from legal compliance in 'conventional' farming. This divergence is due to the removal some key technologies out of the system (synthetic pesticides and fertilisers) and setting standards or limits on land use (e.g. the linking of livestock production to land).

Table 5 summarises other relevant EU policies of significance.

Table 5: Summary of EU policy related to the food cycle

Policy area	*Description of policy instruments*
PRE-FARMGATE – influenced by a range of EU policy measures including agricultural and environmental policies	
Nature conservation	A wide range of legislation (e.g. Birds and Habitats Directives) to protect natural habitats and wild species
Animal health/welfare	Policies aimed at the control of animal disease and protecting animal welfare (e.g. Protocol on Protection and Welfare of Animals)
Fisheries and Marine Policies	European legislation governing the exploitation of wild marine fisheries to protect fish stocks and promoting sustainable fisheries
CROSS-CUTTING – many policies related to the food cycle are cross-cutting, relating also to post-farm gate, and non-farm activities (e.g. processing, marketing/trade, waste)	
Water	Legislation to secure the quality of ground and surface waters. In the case of surface waters, the Water Framework Directive seeks to maintain or restore water bodies to a 'good' ecological status.
Integrated Pollution and Prevention Control (IPPS)	IPPS directive aims at minimising pollution from various industrial sources. It affects agricultural operations (particularly large-scale livestock production)
Climate change	UNFCCC, Kyoto Protocol: a range of instruments to reduce greenhouse gas emissions
Food safety / human health	Policies, regulations and recommendations governing the whole food cycle
Food labelling	Regulation governing the provision of information on the ingredients in foods
Organic food	Legislation (EU organic certification and label) governing the production and processing of organic food
Waste policy	Legislation (Landfill Directive, Sewage sludge Directive) governing the use of landfill and sea discharge for general food waste disposal and sludge disposal respectively

Policy area	Description of policy instruments
Refrigeration	A range of instruments (EU Energy labelling for energy using products, Ecodesign, EU F gas Regulation)

Development of resource efficiency policy

As limits to resources may slow down future economic growth[55], the fears of energy resource scarcity and escalating prices (highlighted by energy crisis of the 1970s) has placed 'resource efficiency' and 'resource security' at the top of the agenda for the EU and internationally. Resource scarcity has significant implications for food price volatility and food security.

The EU has set out to reduce the negative environmental impacts of resource use by decoupling economic growth and environmental impacts and protect natural resources.[56] This embedded life-cycle thinking in the policy-making process, setting out actions for smart, sustainable and inclusive economic growth.[57] The High Level Group identified the establishment of coherent approaches to sustainable consumption and production in the food sector as a major challenge. To address this, the European Food Sustainable Consumption and Production Round Table[58] was established, and highlighted the importance of a holistic approach to policy making. In 2011 "Roadmap to a Resource Efficient Europe" noted the issues of food waste and environmental impact of food production and consumption patterns.[59]

Voluntary initiatives and the private sector

From private sector perspective, a number of private assurance schemes exist to address the whole supply chain. *Farm assurance schemes* are an example of such private sector policy measures. The *Assured food standards scheme (The Red Tractor Scheme)* in the UK guarantees that the food produced meets legal requirements. The systems and support provided to producers facilitate legal compliance. *EISA (European initiative for sustainable development in Agriculture)* similarly focuses on supporting and monitoring legal compliance, but in addition providing some awareness-raising on farms and training, especially regarding on-farm biodiversity. *Conservation farming assurance schemes* do require biodiversity related measures above those required by law. There are also private schemes, and labels supporting *organic farming*.

Information and best practice

Various informational and networking instruments aim to raise the performance of the food cycle (Table 6).

[55] Krugman, P. (2008). Running out of a planet to exploit. New York Times Web, 21 April 2008.
[56] Thematic Strategy on the sustainable use of natural resources. COM(2005)670 europa.eu/legislation_summaries/environment/sustainable_development/l28167_en.htm
[57] European Commission (2011) A resource-efficient Europe – Flagship initiative under the Europe 2020 Strategy. COM(2011) 21 final. January 26, 2011.
[58] www.food-scp.eu
[59] European Commission (2011) Roadmap to a Resource Efficient Europe. COM(2011)571 final. September 20, 2011.

Table 6: EU and MS instruments for information, learning and best practice

Stage	*Learning / best practice (EU, Member States (MS))*
Agriculture	EU: Specific **EU quality schemes**; **agri-environment measures**; **EU labelling of organic produce**; Learning via: farmers associations/, school/ university education MS: Certification schemes: Swedish Seal criteria (Svenskt Sigill, Sweden), Farm Advisory Systems
Animal production	EU: **BREF**[60] on Intensive Rearing of Poultry and Pigs; **EU labels** for organic animal products
Crop production	EU: **Best Practice Document** by the European Coexistence Bureau; **EU labels** for organic unprocessed Crop
Fisheries and aquaculture	EU: **EU labels for organic aquaculture;** Round tables: **Aquaculture Dialogues** by WWF; MS: **private labels on organic aquaculture**: Naturland e.V. (Germany), Bio Suisse (Switzerland), etc.
Processing	EU: **BREF**s on: Food, Drink and Milk Industries sector, Slaughterhouses and Animals By-products Industries; **EU labels for organic processed agricultural products**; **Voluntary food and drink industry' initiatives** within EU Integrated Product Policy: Sustainable Agriculture Initiative, eco-efficiency in production, Integrated Resource/ Waste Management, Partnership with EU Commission on Sustainable Production, Efficient Consumer Response
Distribution and retail	EU: **Sectoral Reference Documents (SRD)** for the Retail Trade Sector within EMAS (EU Eco-Management and Audit Scheme**)**
Consumption (household, catering, etc.)	EU: **EMAS** criteria, **GPP**, **European Week for Waste Reduction** (EWWR) MS: **Menu Dose Certa** or Right-Sized Menu project (Portugal), **Love Food Hate Waste campaign** (UK), **Responsible Purchase** campaign (France); **Flanders' waste prevention plan** (Belgium); **LIPOR** (Portugal
Waste (solid/ water) management	EU: **BREF** on Slaughterhouses and Animals By-products Industries MS: Industrial Symbiosis Programme (UK); Piedmont Home Composting Campaign (Italy); Waste Fund (Netherlands)

7.2 Waste

7.2.1 Food waste

As discussed in section 5.3, there is significant food waste in the food cycle. The difference between the total amount of commodity used by the food system (supply) and the total amount of food eaten (intake) is an indicator of the potential waste. A proportion of this comprises unavoidable losses such as bones and vegetable peelings that are either discarded or used in co-products such as bone-meal or as fuel for biogas. However, studies show that a significant proportion of this loss is avoidable waste, i.e. discarded food that could have been eaten.

An average of at least 1.9 t CO_2 eq./t is estimated to be emitted in Europe over the whole life cycle of food that is wasted. The overall environmental impact is at least 170 Mt of CO_2 eq. per annum. The main life cycle environmental impact of food waste is considered to be GHG emissions, predominantly methane.[61] The impacts of food waste on water use are also significant, with WWF and WRAP estimating that producing the food that is wasted in the UK

[60] Best Available Techniques (BAT) in Reference documents (BREFs) within Industrial Emissions Directive 2010/75/EU
[61] European Commission (2010) Preparatory study on food waste

consumers 6,200 million cubic metres of water per year, about six per cent of all water used for food eaten in Britain. Three quarters of this water use occurs abroad.[62] In addition, according to UK estimates, over a quarter of avoidable food waste thrown away is still in its original packaging[63] and the total annual financial loss per household is approximately £480 or 565 Euros.[64]

In order to maximise resource efficiency, waste should avoided – material flows in the food cycle should operate as "closed loops". From most favourable option to least favoured, waste should be: prevented, reduced, reused, recycled, energy recovered through incineration, with disposal being a last option. Bio-waste has been identified by a recent study for the European Commission as one of the three most important waste streams to target in the EU, given its environmental impacts.[65]

Production: While the generation of avoidable food waste in the EU is concentrated at the use/consumption phase, in developing countries by contrast food waste is generated in large volumes at the agricultural production phase. Here, greater availability of packaging presents potential to reduce post-harvest losses, offering protection from spoiling and increasing transportability[66] (although it would not reduce losses in the field from pests, etc.).

Processing: There is evidence that the proportion of foods transformed from raw ingredients is also low for many food groups – although some data include by-products and do not differentiate between edible and inedible wastes.

Retail / distribution: A relatively small amount of food is wasted at this stage.

Consumption: Causes of household food waste have been evaluated to include[67] poor interpretation of labelling ("best before", etc.), storage conditions, packaging, portions, and awareness, knowledge and preferences. According to UK estimates, over a quarter of avoidable food waste thrown away is still in its original packaging.[63]

7.2.2 Packaging waste

Around 81Mt of packaging waste is generated in the EU annually in total (including food packaging). It has been suggested that discarding food waste can generate three times more carbon than discarding packaging by weight.[68]

Packaging provides a protective function throughout the food cycle (preserving the safety, quality and appearance) and increasing longevity (both through increasing shelf life and proving resealable packaging), including packing crops in the field and transporting food products across the supply chain, and provides information to the consumer. Packaging can also make

[62] WWF-UK and WRAP (2011) The water and carbon footprint of household food and drink waste in the UK
[63] WRAP (2008) The Food We Waste
[64] WRAP (2009) Household Food and Drink Waste in the UK. Report prepared by WRAP. Banbury.
[65] European Commission (2010) Analysis of the evolution of waste reduction and the scope of waste prevention
[66] Worldwatch Institute (2011) State of the World 2011: Innovations that nourish the planet
[67] European Commission (2010) Preparatory Study on Food Waste
[68] 'When food packaging can reduce climate change gases' www.independent.co.uk/environment/green-living/marc-bolland-when-food-packaging-can-reduce-climate-change-gases-1684362.html

some food waste difficult to avoid (e.g. grooves and ridges can make it difficult to access the entire product).

The usefulness of food packaging is highly product specific. For fresh produce (e.g. fruits and vegetables), the shelf life of some items is significantly extended by a minimal packaging layer, for other products no benefits are identified. Research on packaging technologies to reduce food waste by increasing product shelf life, showing product lifetimes and warning when end-of-life is imminent is on-going.[69]

One alternative to conventional plastic packaging that could have environmental benefits is bioplastic, as it reduces the use of petroleum for the manufacture of traditional plastic and some types can decompose. However, there are still uncertainties regarding their comparative life cycle impacts, end-of-life treatment and behaviour under different environmental conditions.[70]

Product specific research and investigation of the relative environmental impacts of food waste and packaging waste is needed before specific recommendations can be made.[71] The UK Courtauld Commitment[72], a responsibility deal to reduce the environmental impacts of the grocery sector, launched in 2005 by WRAP and 29 major retailers and brand owners has begun to measure the life cycle impacts of food packaging. Efforts to minimise the environmental impacts of packaging through reduction of its weight, reduction of hazardousness, increased separate collection and recycling should continue to be encouraged.

7.2.3 Bio-waste

Bio-waste can be treated in various ways: composting, anaerobic digestion, landfilling, incineration, or mechanical and biological treatment. Between 118 and 138 million tonnes of bio-waste are generated each year in the EU, and there is significant differentiation between MS in terms of treatment approaches (less than 20% of bio-waste is landfilled in Austria, the Netherlands and Denmark, while more than 80% is landfilled in Ireland, Spain and the UK):[73]

- Countries dependent on incineration of waste diverted from landfills, coupled with a high level of material recovery and strong strategies promoting biological treatment of waste.

- Countries with high material recovery rates and high composting rates, but very little incineration.

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[69] WRAP (2006) Packaging technologies with potential to reduce the amount of food thrown away

[70] Source: DG Environment News Alert Service. Future Brief Issue (Nb. 1; June 2011). Plastic waste: redesign and biodegradability: ec.europa.eu/environment/integration/research/newsalert/pdf/FB1.pdf [Accessed 01/07/2011]

[71] WRAP has produced resource maps for eleven fruits and vegetables that consider the impact of packaging. WRAP (in press) Resource maps for fresh fruit and vegetable supply chains in the UK

[72] Phase 2, from March 2010, moved away from solely weight-based targets and aims to achieve more sustainable use of resources over the entire lifecycle of products: to reduce packaging weight, increase recycling rates and increase the recycled content of all grocery packaging; aim to reduce carbon impact of this grocery packaging by 10%; to reduce traditional grocery (solid/liquid) product and packaging waste in the grocery supply chain by 5%. Source: www.wrap.org.uk/retail_supply_chain/voluntary_agreements/courtauld_commitment [accessed 01/07/2011]

[73] European Commission (2010) Commission communication on future steps in bio-waste management in the European Union

- Countries dependent on landfilling, where a lack of alternatives makes diversion difficult.

In 2008, 17% of waste treated in the EU-27 was composted; between 1995 and 2008 annual increases have been observed in the quantity of municipal waste composted.[74] Bio-waste is expected to increase approximately 10% by 2020. The amounts of landfilled bio-waste are expected to drop by 38% from 35.7 Mt in 2008 to 15.1 Mt in 2020, with diversion to the other forms of treatment.[75]

Anaerobic digestion could have an important role in the context of bio-wastes as it produces biogas and a beneficial soil conditioner/fertiliser. Many member states use the technology to treat municipal bio-wastes, and European countries are world leaders in the technology. The total AD capacity in Europe for municipal waste in 2006 was 6.2 Mt per annum.[76] Figure 7 demonstrates the increasing capacity for AD for municipal waste across Europe, to 2006, and Figure 8 the large differences in capacity across selected Member States.

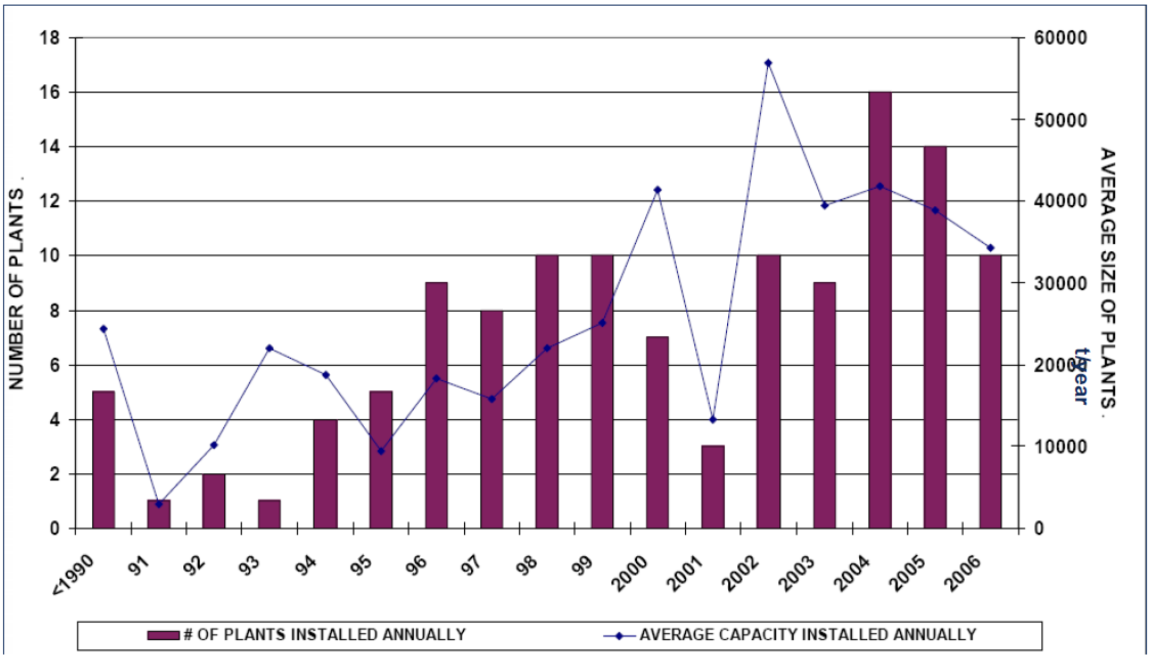

Figure 7: AD for municipal in Europe - annual capacity >3,000 t/a[77]

[74] EC (2011) Commission staff working document on the Thematic Strategy on the Prevention and Recycling of Waste

[75] EC (2010) Commission staff working document on the future steps in bio-waste management in the European Union

[76] Esteves, S. (2008) Anaerobic Digestion – Technology for: Biodegradable Municipal Waste Treatment and Energy Production. The Wales Centre of Excellence for Anaerobic Digestion. Available: walesadcentre.org.uk/Controls/Document/Docs/anaerobic-digestion-s-esteves.pdf [Accessed 04/05/2012]

[77] Sweet, N. (2011) The benefits and barriers for Anaerobic Digestion. WRAP. Figures do not include ~2,000 agricultural plants in Northern Europe mostly fed with manure. Available online: www.rase.org.uk/events/agri-science-events/AD_Walford-Nina_Sweet.pdf [Accessed 04/05/2012]

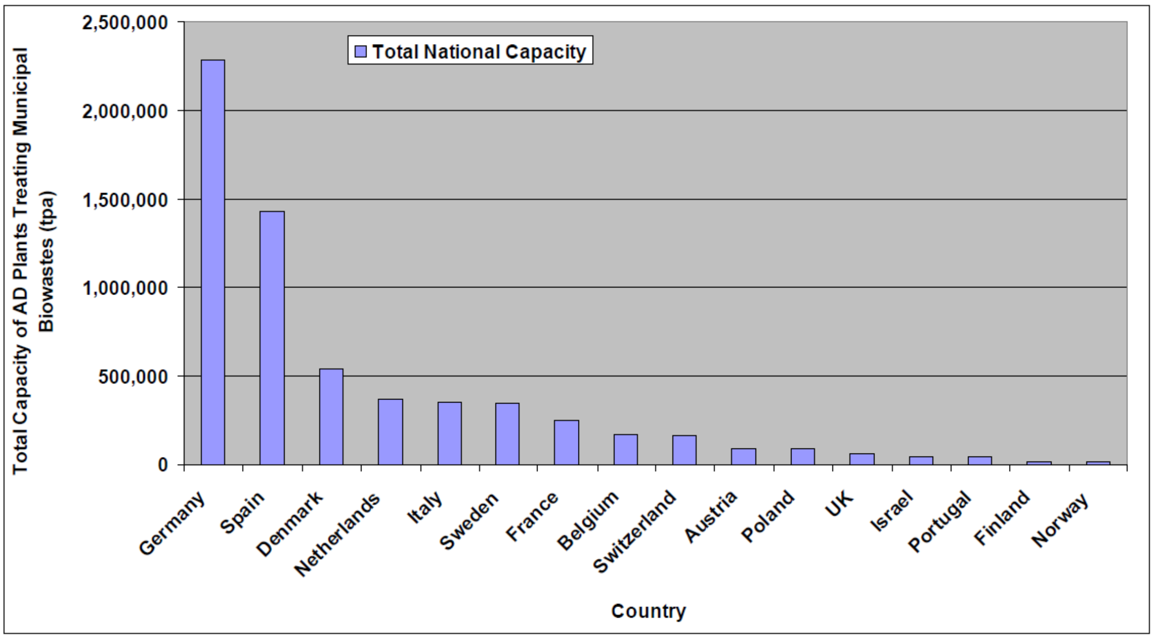

Figure 8: AD Capacity in European Countries in 2006

7.3 Consumption

Accepting that the primary purpose of the food system is to deliver an adequate supply of food to support health and wellbeing, over- and under- consumption in relation to dietary guidelines influences system resource efficiency. In short, food systems characterised by over-consumption of resource demanding foods are less efficient that food systems that provide the same or better nutritional and food-related wellbeing outcomes using more resource efficient foods.

7.3.1 Nutrition and health

A healthy diet for humans is generally considered to be one that includes a balance of products from the major food groups. Studies in the field of nutrition have shown that the diet is a determining factor in numerous chronic illnesses.[78] A number of foods have also been shown to have properties that protect against illness, cancer in particular; hence diets have potential to contribute to human health improvements.[79]

Within food production, protein is pivotal. Food is linked to the nitrogen cycle through protein which is about 16% nitrogen. Nitrogen is also an indispensable constituent of DNA and RNA. Furthermore, eight amino acids are called "essential" for humans because they cannot be

[78] WHO/FAO (2002) Diet, Nutrition and the Prevention of Chronic Diseases Report of a Joint WHO/FAO Expert Consultation. WHO Technical Report Series 916

[79] UK Government Office of Science (2010) Foresight Project on Global food and Farming Futures C8: Changing consumption patterns. Report accessed on the 01/07/2011 at: www.bis.gov.uk/assets/bispartners/foresight/docs/food-and-farming/synthesis/11-628-c8-changing-consumption-patterns.pdf

produced by the human body, and so must be taken in as food, via proteins. Protein sources may be of a vegetal origin or animal origin. Malnourishment is often a case of a lack of protein, rather than a lack of calories, but such malnourishment is extremely rare in Europe. An increasing obesity problem in the EU is evidence of over-consumption in terms of dietary energy.

7.3.2 EU diets

The IMPRO diets study[80] suggested that diets across Europe still reflect classic differences such as Roman and Greek versus Germanic and Celtic cultures. However, the Protein Puzzle study and FAOSTAT data indicate that the major difference in food system consumption from a resource use viewpoint is now between East and West rather than between North and South. Overall, there is a clear trend in commodity consumption: Eastern countries have lower rates of commodity consumption overall and a lower proportion of this consumption is based on livestock products. Figure 9 presents data on the protein intake across the EU27.

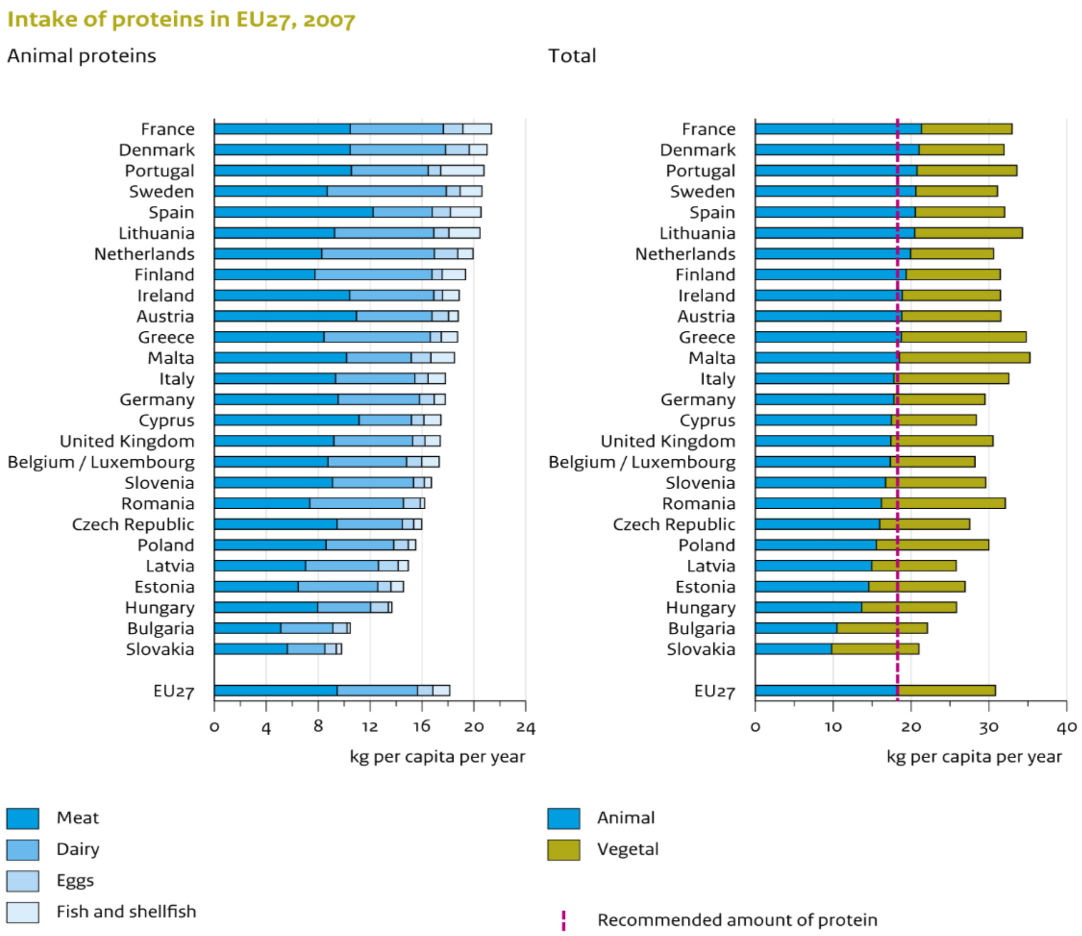

Figure 9: Dietary intake of protein in the EU27, 2007 (kg/capita/year) [81]

[80] JRC-IPTS (2009) IMPRO Environmental Impacts of Diet changes in the EU
[81] Westhoek, H., et al. (2011). The Protein Puzzle. Netherland Environmental Assessment Agency.

Total intake of protein exceeds dietary needs in all EU countries, although there is significant variation. Proportion of animal protein in the total also varies, and is an indicator of differences between national food systems.

Associated with the high intake of livestock protein, intake of saturated fat is also high, exceeding health guidelines in all but two countries (Figure 10).

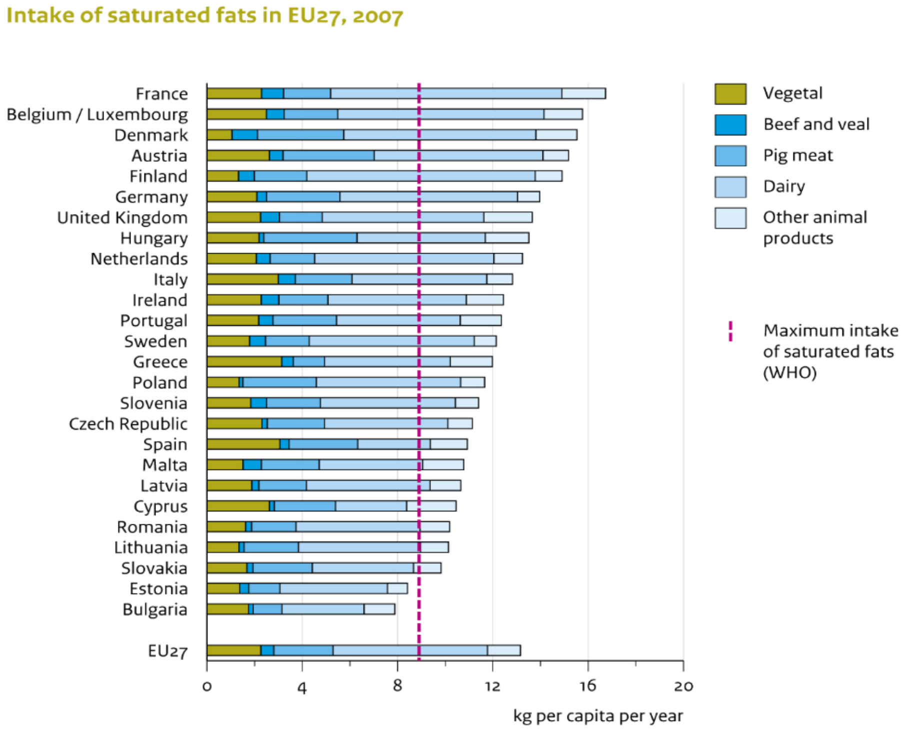

Figure 10: Intake of saturated fats in the EU27, 2007[82]

Since World War II, the proportion of animal proteins and fats have increased dramatically in all countries except France, possibly due to a general homogenisation of food consumption patterns across Europe[83], resulting in a convergence of national food systems in terms of resource use. Under 'Business as Usual' conditions, this process is likely to continue and extend to the newer Member States as incomes grow.

The supply and intake of animal protein in particular is resource intensive and results in unavoidable and large losses of reactive nitrogen to the environment. Many studies have concluded that the protein chain is responsible for an increasing share of environmental pressures.[83,84,85,86] On average, 6 kg plant protein is required to yield 1 kg meat protein. Thus a

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[82] Westhoek, H., Rood, T., van der Berg, M., Janse, J., Nijdam., D., Reudink., Stehfest, E. (2011). The Protein Puzzle. Netherland Environmental Assessment Agency

[83] de Boer, J., Helms, M., & Aiking, H. (2006). Protein consumption and sustainability: Diet diversity in EU-15. Ecological Economics 59: 267-274.

[84] Pimentel, D., Pimentel, M., (2003). Sustainability of meat-based and plant-based diets and the environment. American Journal of Clinical Nutrition 78 (suppl.), 660S–663S.

[85] Aiking, H., De Boer, J., & Vereijken, J. M. (2006). Sustainable protein production and consumption: Pigs or peas? In: Environment & policy, Vol. 45. Dordrecht, The Netherlands: Springer.

[86] Aiking, H. (2011) Future protein supply. Trends in Food Science & Technology 22(2-3): 112-120

large nitrogen input is needed, parts of which are lost during the on farm production phase.[87] Since the production of animal sourced protein is resource intensive and has a major impact on the nitrogen cycle (see section 7.4), total protein intake (and especially livestock protein intake) are strong indicators of the resource efficiency of the food system as affected by consumption.

These trends may lead to scarcity issues[88] and increase the environmental impacts of the EU food cycle; the environmental impacts will depend largely on where the meat is produced. An increased consumption of meat has been met by an increased production in certain areas characterised by high livestock densities.[89] Pig and poultry production especially is concentrated since the production is less coupled to land compared to milk and cattle farming. The direct impacts of the livestock production can be noted through simultaneously increasing ammonia levels as described for example by the ammonia 'hotspot' maps produced through the European Nitrogen assessment.[90]

Data on food commodity supplies in the EU 27 compared with other regions show that European supplies per capita exceed the global average for most food categories. Figure 11 shows the supply of protein in animal sourced commodities used in the EU food system compared with the USA, India and China with predicted trends to 2030. The use of animal protein in EU is relatively high by world standards and there is a rising trend in all regions.

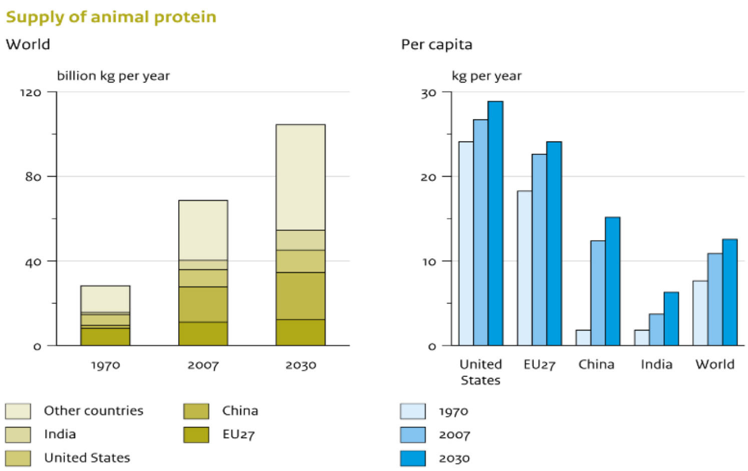

Figure 11: Commodity supply of animal protein in the USA, EU, China and India with estimates to the year 2030[91]

[87] Sources: Pimentel, D., Pimentel, M., 2003. Sustainability of meat-based and plant-based diets and the environment. American Journal of Clinical Nutrition 78, 660S–663S (suppl.) and de Boer, J and Aiking, H. 2011 On the merits of plant-based proteins for global food security: Marrying macro and micro perspectives. Ecological Economics 70, 1259–1265)

[88] Keyzer, M.A., Merbis, M.D., Pavel, I.F.P.W., van Wesenbeeck, C.F.A., (2005). Diet shifts towards meat and the effects on cereal use: can we feed the animals in 2030? Ecological Economics 55, 187-202.

[89] FAOSTAT (2010) FAO Statistical Database. Food and Agriculture Organization (FAO), Available online at: faostat.fao.org/site/573/default.aspx#ancor [Accessed 03/2010].

[90] de Vries, W, et al. (2011)European Nitrogen assessment chapter 15 Geographical variation in terrestrial nitrogen budgets across Europe

[91] Westhoek, H., et al. (2011). The Protein Puzzle. Netherland Environmental Assessment Agency.

Table 7 summarises evidence on resource use and environmental impacts due to livestock production, both within the EU and at the global scale.

Table 7: Figures from studies investigating impacts of livestock production[92, 93, 94]

Issue	Impact	
	Within the EU	**Globally**
Environmental impacts	-Meat and dairy products contribute on average 24% to environmental impacts of total final EU consumption, while constituting only 6% of the economic value - *IMPRO meat and dairy* -Around 10% of EU greenhouse gas emissions are caused by livestock production. Together, the beef and dairy sectors are responsible for two thirds of these emissions - *Protein puzzle*	-Inclusion of CO_2 emissions resulting from UK food-consumption induced land use change increases food's footprint by 50% and increases the contribution made by the food system to overall UK consumption related GHG impacts to 30% - *How law can we go?*
Feed	-For each EU citizen, every *day almost 3 kilograms of feed is consumed by EU livestock, 0.8 kilogram of which in cereals and 0.8 kilogram in grass (dry matter). This feed is converted into 0.1 kilograms of meat and 0.8 kilograms of milk*, being the average EU consumption - *Protein puzzle*	-Around 75% of the protein-rich feed is imported - *Protein puzzle*
Land use	-In the EU, about two thirds of the total agricultural area is used for livestock production - *Protein puzzle*	-
Nutrients	-More than 80% of the nitrogen input to agriculture in the EU is lost - *Protein puzzle*	-
Biodiversity	-	Around 30% of the total human-induced biodiversity loss is related to livestock production.- *Protein puzzle*

7.3.3 Food choices and guidelines

Dietary choice is one of the most important levers for action to reduce the environmental impact of the food cycle, as well as having a significant impact on health. The IMPRO study proposes alternative diets with positive health impacts with low intake of livestock products (dairy and meat).

Consumer preference for local and seasonal produce can support economic growth in the food sector and job creation locally and nationally[95] and may also present local community cohesion benefits. Food choice can also contribute to development goals by supporting markets for certain products, including organics and fair trade. A recent UNEP study[96] shows that organic

[92] JRC-IPTS (2008), IMPRO Environmental Improvement potential of meat and dairy products

[93] Westhoek, H., et al. (2011). The Protein Puzzle. Netherland Environmental Assessment Agency

[94] Audsley, E., et al. (2009). How low can we go? An assessment of greenhouse gas emissions from the UK food system and the scope to reduce them by 2050. FCRN-WWF-UK.

[95] Pretty, J. (2001). Some Benefits and Drawbacks of Local Food Systems. Briefing Note for TVU/Sustain AgriFood Network, November 2nd 2001. Accessed on the 01/07/2011 at: www.sustainweb.org/pdf/afn_m1_p2.pdf

[96] UNCTAD/UNEP (2008) Organic Agriculture and Food Security in Africa

agriculture can raise incomes, build-up natural resources, strengthen communities and improve human capacity, making a significant contribution to food security in areas of Africa.

However, food-related behaviour patterns are complex, habitual and strongly influenced by marketing, budgetary and cultural pressures.[97] It is also suggested that globalization and industrialization have increasingly disconnected places of production from places of consumption[98] and that this allows consumers to overlook the environmental consequences of their consumption patterns. Factors that impact food choices include:

- Price: older consumers are often less likely to pay a premium for environmentally responsible products.[99]
- Income: lower income groups are more likely to consume diets high in fats and sugar (processed meats, pizza, full-sugar soft drinks, fat spreads, etc.) than those with higher incomes[100], and are less likely to consume fruit, vegetables and fibre.[101]
- Socio-demographic aspects, such as age, gender, level of education, the size of the household.
- Beliefs, cultural norms and habits.
- Food safety. For example, children in the household may increase the choice of organic products due to health concerns associated with pesticide use.
- Quality: visual appearance, lack of discolouration, standardised shape, etc.
- Product labelling and information, including certification.
- Commercial marketing.
- Government, health professional and media influence: health and environmental messaging can be an important factor in consumer food-related behaviour[102].
- Available food options in retail outlets and in institutions, such as schools, hospitals, prisons and workplaces.

To date, few guidelines exist that combine health and environmental perspectives and those that exist vary greatly in terms of reporting method, choice of indicators and scope. In a report

[97] Department for Environment, Food and Rural Affairs, UK (DEFRA) (2009) Food Synthesis Review

[98] Kastner, T., Kastner, M., Nonhebel, S. (2011) Tracing distant environmental impacts of agricultural products from a consumer perspective, Ecological Economics 70, 1032–1040. Erb,K-H. (2004) Actual Land Demand of Austria 1926 - 2000: A Variation on Ecological Footprint Assessments. Land Use Policy. 21: 247-259.

[99] OECD (2008) Household Behaviour and the Environment: Reviewing the Evidence

[100] Marmot, M., et al. (2010). Fair Society, Healthy Lives. The Marmot Review, UK, 2010. ISBN 978-0-9564870-0-1

[101] SACN. 2009. SACN Position paper on the low income diet and nutrition survey (LIDNS). Available from: www.sacn.gov.uk/pdfs/sacn_position_paper_on_the_low_income_diet_and_nutrition_survey_lidns.pdf [Accessed 3/9/2010]

[102] Eat Seasonably campaign, UK: www.defra.gov.uk/news/2010/09/24/eat-seasonably/

from the Health Council of the Netherlands[103] 'win-win' guidelines were identified, which, apart from health benefits, deliver environmental benefits in terms of land use and GHG emissions:

- Fewer meat and dairy products and more whole grain products, legumes, vegetables, fruit, and plant-derived meat substitutes. This dietary pattern is associated with a lowered risk of cardiovascular disease; however, there are contra-indications for a diet containing no animal products[104].

- The reduction of energy intake for those with an excessive body weight. This advice would include consuming less sugary drinks, sweets, cakes and snacks. A healthy body weight is associated with a reduced risk of diabetes, cardiovascular disease, and certain forms of cancer. This would reduce the demand for foods, which in turn reduces the ecological impact.

Some health guidelines may be environmentally disadvantageous, such as the common recommendation to eat two portions of fish per week (one of which is oily fish). There are indications that at least one portion of oily fish per week would lower the risk of cardiovascular disease. Since this level of intake is higher than current levels in some countries, this may put increased pressure on marine ecosystems. From an ecological perspective it would be better to focus the recommendation on the health effects unique to fish (e.g. from the oily fish) and recommend the use of fish species not currently overfished or which are farmed with environmentally friendly aquaculture methods.

The on-going TFRN[105] study on the link between consumption and the nitrogen cycle in Europe has already shown that a reduction in the consumption of livestock products would have a major effect on the nitrogen cycle reducing all related emissions, the use of arable land, and the need for imported soy. A 50% reduction in livestock product consumption would reduce the need for soy by 75%. This has very significant direct and indirect consequences for the global demand for cropland.

7.4 Production, processing and supply issues

The EU food system is near self-sufficient in indigenous foodstuffs and provides for large supplies of resource intensive products – particularly livestock products. At the heart of the food system is the production of cereals providing dietary energy for direct consumption and livestock. In certain cases, production had moved away from traditional locations to artificial environments in order to supply certain foods out of season; for example, tomatoes can be produced in heated greenhouses using increased inputs (such as energy for heating) in northern Europe rather than transported from hotter, southern locations.

[103] Health Council of the Netherlands. Guidelines for a healthy diet: the ecological perspective. The Hague: Health Council of the Netherlands, 2011; publication no. 2011/08E.
[104] In children, such a diet has been linked with a raised risk of growth retardation
[105] UNECE Task Force on Reactive Nitrogen – UN webpage: www.unece.org/env/lrtap/TaskForce/tfrn/welcome.htm [Accessed online 20/05/2011]

Environmental impacts per unit weight of produce, and resource efficiency, are very dependent on farm yields. Climate, local conditions and farming practices influence yields. Farming systems can also be heavily dependent on chemical fertilisers and crop protection, and intensification[106] of production can lead to gains in productivity and economies of scale. However, in all farming systems, there is a point where greater inputs do not result in increased yields. There are also the issues of local availability of water and the ability of local ecosystems to support production (and act as a sink to absorb emissions from production).

The use of land, the changes in its use, and the practices followed in its management also have relevance to carbon sequestration and quality of soils. Land-use management is therefore important for GHG budgets, since these can be affected by land use choices (e.g. cropland or pasture), conversions (e.g. forestry replacing cropland), as well as management practices.

On a global scale, land use and forest coverage can be impacted significantly by, for example, consumer demand, cattle raising and crop choice (e.g. palm oil production). [107]

7.4.1 Phosphorus

Cordell et al.[108] have estimated the total phosphorus (P) content in annual global agricultural harvests to be approximately 12 Mt P, of which 7 Mt is processed for feed and food and fibre; 40% of the remaining 5 Mt in crop residues is returned to the land. Regarding past trends in global use of P fertilisers, after a massive increase in the 1940s in the use of phosphate rock (mainly for fertiliser), the use somewhat levelled in the 1980s. The use of P is becoming more efficient, especially in Europe. Farmers in Europe and North America are increasingly avoiding over fertilisation, and are ploughing straw and animal manure into agricultural soils, partly to recycle P. The demand for P is predicted to increase by 50–100% by 2050 with increased global demand for food and changing diets.

Phosphate fertilisers are derived from mined rock phosphate. Current estimates of available phosphate rock reserves equate to up to 20 Gt of P. Existing rock phosphate reserves could be exhausted in the next 30–100 years. Furthermore, it is worth noting that 71% of production comes from mainly three countries where the natural resource is today available (Morocco, China and Israel)[109]. The fertiliser industry recognises that the quality of reserves is declining and the cost of extraction, processing and shipping is increasing.

P loading into water bodies when leaving the food chain is also a problem at different levels, for example, the annual P inflow of the nutrient to oceans due to effluents and loss from

[106] Intensive agriculture we define widely in this context, as agriculture with e.g. high levels of inputs of labour, capital technology, for example high levels of fertiliser. Intensive methods are often put in contrast to extensive methods with e.g. low or no inputs of fertiliser. The definition may vary.

[107] UK Government Office of Science (2010) Foresight Project on Global food and Farming Futures C8: Changing consumption patterns

[108] Cordell, D., Drangert, J.O., White, S. (2009). The story of phosphorus: Global food security and food for thought. Global Environmental Change 19(2), 292-305.

[109] European Commission (2008) Annexes to the Raw Materials Initiative. SEC(2008) 2741. Commission staff working document, accompanying the Communication from the Commission to the European Parliament and the Council: The raw materials initiative, meeting our critical needs for growth and jobs in Europe {COM(2008) 699}

agricultural land is a major problem at the global level[110]. Although this is a global issue, the main sources of loss are associated with developed countries.

It has also been highlighted that the major share of P eaten in food is excreted by humans[111], this is discussed further in section 7.4.3.

7.4.2 Nitrogen

Nitrogen (N), like P, has a crucial role for food production and security. Nitrogen is a major determinant of the growth of green leaves and thus the capture of solar radiation – the foundation of food production. In the past the amount of N that was naturally available (through fixation[112] and application of manures) limited food production. The manufacture of inorganic N using industrial fixation[113] has overcome these limitations: its reliability and cheapness has not only augmented other sources but led to replacement of animal manure as fertiliser (with manure treated as a waste). Figure 12 provides an overview of the flows of N through the EU agricultural sector.

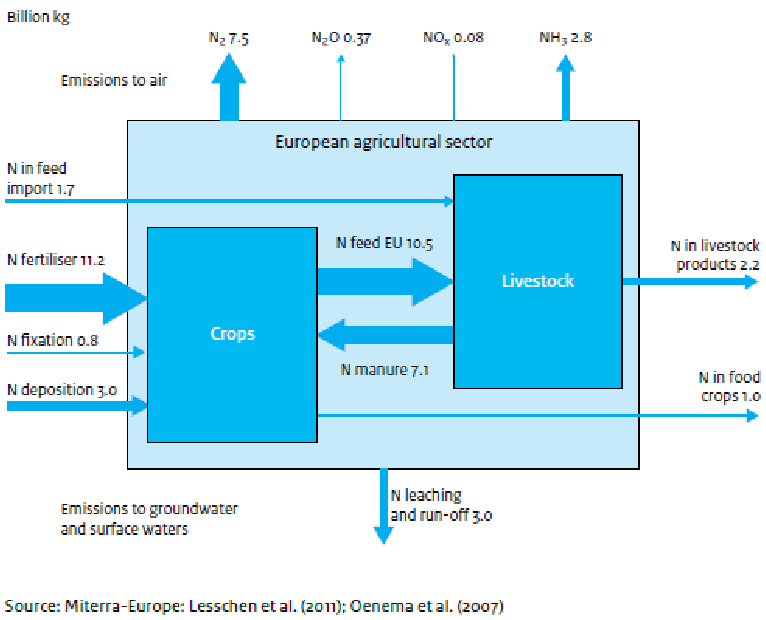

Figure 12: N flows in agricultural sector in EU27, 2005[114]

Investigating how N is transported through the food chain, Galloway et al (2010)[115] concluded that for every 100kg of N entering the animal production chain only about 13 kilos will enter the human food chain.

[110] The authors (Rockström, 2009) suggestion is for extraction not to exceed 10 times the natural background weathering of P.
[111] Jönsson, H., et al. (2004). Guidelines on the Use of Urine and Faeces in Crop Production. EcoSanRes, Stockholm Environment Institute, Stockholm.
[112] Refers to the natural process by which atmospheric nitrogen is converted to ammonia, e.g. via leguminous plants.
[113] Refers to the chemical industrial process by which atmospheric nitrogen is fixed as ammonia
[114] Westhoek, H., et al. (2011). The Protein Puzzle. Netherland Environmental Assessment Agency
[115] Galloway, J.; Dentener, F., Burke, M., Dumont, E.; Bouwman, A.F.; Kohn, R A.; Mooney, A., Seitzinger, S., Kroeze, C., 2010 The impact of animal production systems on the nitrogen cycle. In: Steinfeld, H; Mooney, H., Schneider, F.,

N is less scarce than P, but also more easily lost to air and water bodies (surface water and ground water). Differences in N loss patterns can be observed between different farming systems (arable vs. livestock, conventional vs. organic, etc.). Livestock farming presents particular problems with large potential N losses[116]; there is evidence that intensive animal farming, especially on certain (e.g. sandy) soils, increases N losses to water.[117]

N that is lost pollutes local water bodies, and at a global scale N has been ranked as one of the top 3 threats to biodiversity.[118] The use of reactive N also leads to emissions of nitrous oxide, contributing to global warming.[119] Furthermore, significant amounts of energy are needed as input for nitrogen fertiliser production; the related level of GHG emissions depends on the energy source used for production (e.g. natural gas or coal).[120]

Due to its significant impacts, sustainability boundaries related to the global use of N have been proposed.[121]

7.4.3 Nutrient management and recovery

When available, manure is a source of N and other nutrients; manure can be stored and applied in many different ways, resulting in different levels of nutrient efficacy. In terms of use of animal manure, in some regions it may be difficult to access without increasing transport networks[122], and the nutrient content and release may be more difficult to handle (which involves a risk of leaching).

Recycling of food waste and animal manure to agricultural soil is also preferable from a nutrient and soil structure perspective. Both N and P can be recovered from the food production and consumption system and reused as a fertiliser either directly or after intermediate processing. These recovery measures on the farm include integration of crop residues into the soil, compost application, and using human and animal excreta. Nutrient recycling from human wastewater is illustrated in Figure 13. Cordell et al (2009) estimated that every year the global population

Neville, L., (eds.) Livestock in a Changing Landscape. Volume 1. Drivers, Consequences and Responses. Washington, USA, Island Press, 83-95, 13pp.

[116] Jarvis, S. Contributing authors: Hutchings,N., Brentrup,F. Eivind Olesen, J. and van de Hoek , K. (2011) Nitrogen flows in farming systems across Europe. Chapter 10. In: The European Nitrogen Assessment, ed. Mark A. Sutton, et al. (2011) Published by Cambridge University Press., with sections authors/ European Union.

[117] For example: Oenema J, et al. (2010) Multiscale effects of management, environmental conditions, and land use on nitrate leaching in dairy farms. J Environ Qual. Nov-Dec; 39(6):2016-28.

[118] Townsend, A.R. and Howarth, R.W. (2010) Fixing the Global Nitrogen Problem, Scientific American Magazine; February, 8 Page(s).

[119] de Boer, J and Aiking, H. (2011) On the merits of plant-based proteins for global food security: Marrying macro and micro perspectives. Ecological Economics 70, 1259–1265

[120] Worrell, E. and Blok, K. (1994), Energy savings in the nitrogen fertiliser industry in the Netherlands Vol. 19, Issue 2, pp 195-209, AND Kahrl, F., et al. (2010) Greenhouse gas emissions from nitrogen fertiliser use in China Environmental Science & Policy, Volume 13, Issue 8, December, Pages 688-694

[121] The authors (Rockström) suggestion: regarding biogeochemical nitrogen (N) cycle, the industrial and agricultural fixation of N_2 should be limited to 35 Tg nitrogen yr-1

[122] Morari, F. Lugato, E. Berti, A. Giardini, L.(2006) Long-term effects of recommended management practices on soil carbon changes and sequestration in north-eastern Italy, Soil Use and Management Volume 22, Issue 1, pages 71–81

excretes around 3 million tonnes of phosphorus in urine and faeces. However, infrastructure and distribution systems need to be place to enable its collection and delivery to farms.[123]

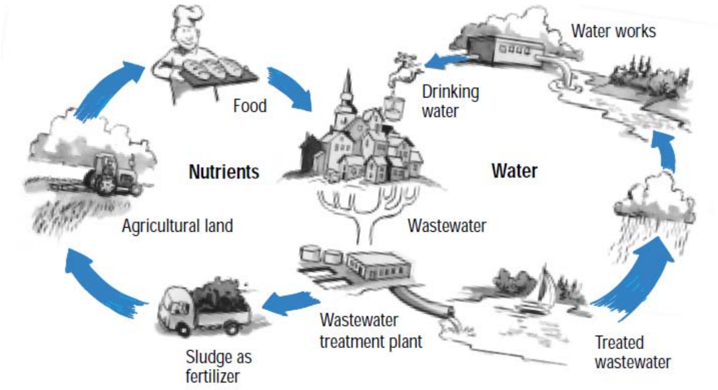

Figure 13: Wastewater nutrient and water cycling[124]

However, organic (waste) nutrient sources may be polluted (by e.g. heavy metals in wastewater) or carrying bacteria or viruses. The balance between nutrients in the substrate may also not be optimal. Lastly, they are typically bulkier than inorganic fertilisers due to their lower concentration and there may be a need to develop infrastructure for collection, treatment and distribution networks (particularly for reuse of solids from wastewater).

There may also be alternative feedback loops for nutrients into the food cycle. For example, cultivation of mussels in waters polluted by agriculture could filter excess nutrients (P and N), reducing eutrophication[125]. The mussels could then be sold to the consumer market or used as a feed (for livestock or fish). Institutional and attitudinal barriers are likely to be encountered, hence further research is required.

7.4.4 Farming systems

Each farm is unique due to the combination of production factors available, so there is as many farming systems are there are farms. However, there are broad categories.

'Conventional' farm businesses, i.e. non-organic, seek economic optimal use of resources and support payments while meeting legal requirements. Organic farms exclude certain key technologies and thereby constrain production, but optimise economic returns through higher prices and additional support payments. Mixed farms can be either conventional or organic. They use a combination of plant and animal based resources (particularly to recycle nutrients and support more diverse rotations) to optimise economic returns. More than one third of

[123] Cordell, D., Drangert, J.O., White, S. (2009). The story of phosphorus: Global food security and food for thought. Global Environmental Change 19(2), 292-305.
[124] Swedish Water & Wastewater Association (2000) Facts on water supply and sanitation in Sweden. Stockholm.
[125] Baltic Sea 2020 project webpage: www.balticsea2020.com/index.php?option=com_content&view=article&id=150%3Amusselodling-som-miljoeatgaerd&catid=53%3Apagaende-projekt&lang=en [Accessed online 20/05/2011]

European farms are mixed in some way. Mixed farms have potential to be particularly resource efficient.[126] [127]

Some conventional farms participate in schemes that certify that they operate fully to legal and other industry standards. These schemes enable them or their customers such as retailers to label produce accordingly (e.g. the 'Red Tractor' scheme). Farms that practice so-called 'integrated farm management (IFM)' are conventional farms that have special auditing practices to document production processes. Despite the name 'integrated' they do not necessarily engage in practices that integrate and conserve resource flows, but they combine practices such as the use of disease resistance and pesticides within the given system to optimise farm economic returns. 'Conservation production' is practiced on conventional farms with some additional resource protection measures, especially for biodiversity.

A great deal of attention is paid to 'branded' farming systems such as 'organic' or 'integrated (IFM)'. The only branded farming approach which involves practices that deviate significantly from conventional production is 'organic'. This is due to the effects of withdrawal of key technologies – especially synthetic fertilisers and pesticides, some animal welfare related measures, and a forced link to the land resource base in livestock production. Some advocates of 'integrated' farming system brands suggest that 'conventional' unbranded production is based on high use of inputs within fixed production blueprints. This is misleading as very few farm businesses operate in this way.

The resource efficiency and environmental impact of a farm is largely determined by the resource management system used. Integrating resource flows between crop and animal production in particular has a great potential to improve efficiency. The implementation of branded systems (e.g. 'IFM') and private standards within conventional production ensure good production practice and reduce the risk of errors in production affecting the supply chain, but have on their own little effect on the wider system factors determining the resource use and environmental performance of the farm beyond that achieved by adherence to legal requirements.

Improving the intrinsic resource efficiency of farming systems will vary greatly across regions and existing farming structures. Some policy instruments that could be used to improve farming systems with respect to key resource flows and impacts are already in place or well developed, e.g. the Nitrates Directive, nutrient balancing (e.g. in Denmark) or support for rotations. Using these in a way that drives changes in resource flows and improves environmental performance would result in winners and losers. Incentives to have better farm gate nutrient balances will penalise farming systems that generate large nutrient surpluses. However, overall the food output of European agriculture will not be affected.

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[126] Murphy, D.P.L., Roever, M. and Heinemeyer, O. (Editors) (1998). Bewertung der Verfahren der ökologischen und konventionellen landwirtschaftlichen Produktion im Hinblick auf den Energieeinsatz und bestimmte Schadgasemissionen. Evaluation of the conventional and organic agricultural production in terms of primary energy consumption and pollution gas emissions. Landbauforschung Völkenrode ISBN 3-933140-33-1(Refereed monograph, 206pp)

[127] Oomen, G.J.M., Lantinga, E.A., Goewie, E.A., Van der Hoek, K.W., 1998. Mixed farming systems as a new way towards a more efficient use of nitrogen in European Union agriculture. Environmental Pollution 102, 697-704.

7.4.5 Intensification

Intensification of agriculture is considered one way of using land more efficiently to produce more food without using more land (and thereby avoiding land use change impacts). However, the increasing pressure associated with intensification needs to be taken into account. Bearing in mind the differences of soil type, farm type, climate, crop selection and other factors across the different regions in the EU and that the environmental impact of farming intensity is very dependent on such factors. Deciding what management practice is the most beneficial for EU production from an environmental sustainability point of view is not straightforward. To develop methods of intensification, which yield the benefits of high productivity and avoid at the same time the associated detrimental effects[128], is a central challenge for agriculture.[129]

The capacity of the individual farmer or farming enterprise to manage the systems will affect its impacts (e.g. nutrient efficacy and emissions), leading to large differences between farms. In addition, some farming systems can be certified and their products labelled to provide assurance to consumers that a certain quality level in farming practice has been met.

In an LCA of 18 grassland farms in three different farming intensities (intensive, extensive, and organic) in southern Germany, extensive and organic farms were shown to reduce environmental impacts (in the categories of energy use, acidification and eutrophication potential) when compared with intensive farms, mainly by avoiding use of inorganic N fertilisers, as described in Table 8.

Table 8: Comparison of environmental impacts of farming systems in Germany, 2001[130]

Impact category	Energy consumption		Acidification SO2-equivalents	Eutrophication potential, PO4-equivalents,	Farm gate balances for N	Farm gate balances for P
Unit	GJ ha−1	GJ t−1 milk	kg SO2 ha−1	kg PO4 ha−1	kg ha−1	
Intensive farms	19.1	2.7	136	54.2	80.1	5.3
Extensive	8.7	1.3	119	31.2	31.4	4.5
Organic farms	5.9	1.2	107	13.5	31.1	−2.3

In a recent LCA on Swiss arable cropping and forage production systems, researchers found that the overall extensification of an intensively managed system reduced environmental impacts, both per unit area and per product unit. However, depending on the land use type, extensive farming did not always result in the highest possible eco-efficiency. In arable cropping systems, medium production intensity gave the best results per product unit. In grassland systems, a combination of intensively and extensively managed plots was preferable.[131]

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[128] Matson, P.A., et al. (1997). Agricultural Intensification and Ecosystem Properties. Science, 277, 504-509.

[129] Tilman, D., et al (2002). Agricultural sustainability and intensive production practices. Nature, 418 (6898), 671-677

[130] Haas, G., Wetterich, F., and Köpke, U. (2001) Comparing intensive, extensified and organic grassland farming in southern Germany by process life cycle assessment Agriculture, Ecosystems & Environment, Volume 83, Issues 1-2, Pages 43-53

[131] Nemecek, T., et al. (2011) Life cycle assessment of Swiss farming systems: II. Extensive and intensive production. Agricultural Systems, Volume 104, Issue 3, Pages 233-245

Studies indicate that extensive systems are better for biodiversity; nevertheless, as the overall land demand of extensive systems is higher, less land is available for other uses such as nature conservation or protection.[132] This relates to the so-called "land-sparing – land-sharing" debate on whether protecting some land and farming the rest intensively saves biodiversity more effectively than protecting less land (but farming the remainder with wildlife friendly techniques). While some argue for the benefits of the land-sparing effect of intensive use, others draw attention to uncertainty about the realisation of the land-sparing benefits, which often are overcompensated by e.g. rebound effects which translate efficiency gains in increased absolute production.[132,133] A recent meta-analysis[134] illustrates that under certain conditions and for some products, organic systems can nearly match conventional yields. In addition, this meta-analysis identifies important trade-offs resulting from the many social, environmental and economic benefits of organic farming systems. Furthermore plant protein crops (such as peas) are useful in crop rotations, a farming practice which is considered to provide environmental benefits. The 1999 CAP reform encouraged development of single crop farming practices. The decreased production of plant protein crops could thus have an impact on the environmental effects of farming systems.

Information, advice and guidance is supplied to farmers, from various sources, about how to optimize their practices (e.g. in the UK[135]). Programmes of providing advice to farmers are useful in ensuring that good management practice and the most beneficial available technologies are taken up, for example methods for calculating the nutrient budgets for the farm, to help track and manage nutrient use, or adopt new technology that may increase efficiency, while maintaining yield and quality.[136] Farm-scale nutrient flow models (including simple cycles and farm budgets) can be used to represent gross flows of nutrients into and from farms. The continued development of these models could provide important insights for farm practice as well as policy development.

7.4.6 Livestock production

Figure 14 shows the density of livestock in relation to agricultural land across the EU 27. It shows an important characteristic of European agriculture: concentration in livestock production.

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[132] Green, R.E., et al. (2005) Farming and the Fate of Wild Nature. Science 307, 550-555.

[133] Several sources: Erb, K.-H. (2012) How a socio-ecological metabolism approach can help to advance our understanding of changes in land-use intensity. Ecological Economics 76, 8–14; Fischer, J., et al. (2011) Conservation: Limits of Land Sparing. Science 334, 593–593; Lambin, E.F., and Meyfroidt, P. (2011) Global land use change, economic globalization, and the looming land scarcity. Proceedings of the National Academy of Sciences 108, 3465 – 3472; Phalan, B., et al. (2011) Reconciling Food Production and Biodiversity Conservation: Land Sharing and Land Sparing Compared. Science 333, 1289–1291; and Rudel, T.K., et al. (2009) Agricultural intensification and changes in cultivated areas, 1970–2005. Proceedings of the National Academy of Sciences 106, 20675 –20680

[134] Seufert et al. (2012) Comparing the yields of organic and conventional agriculture. Nature online. doi:10.1038/nature11069

[135] Department for Environment, Food and Rural Affairs, UK (DEFRA) (2010) Fertiliser Manual (RB209) 8th Edition, Available online at: www.defra.gov.uk/publications/files/rb209-fertiliser-manual-110412.pdf [Accessed 11/05/2011]

[136] Jarvis, S. Contributing authors: Hutchings,N., et al. (2011) Nitrogen flows in farming systems across Europe. Chapter 10: The European Nitrogen Assessment, ed. Mark A. Sutton, et al. (2011) Published by Cambridge University Press., with sections authors/ European Union.

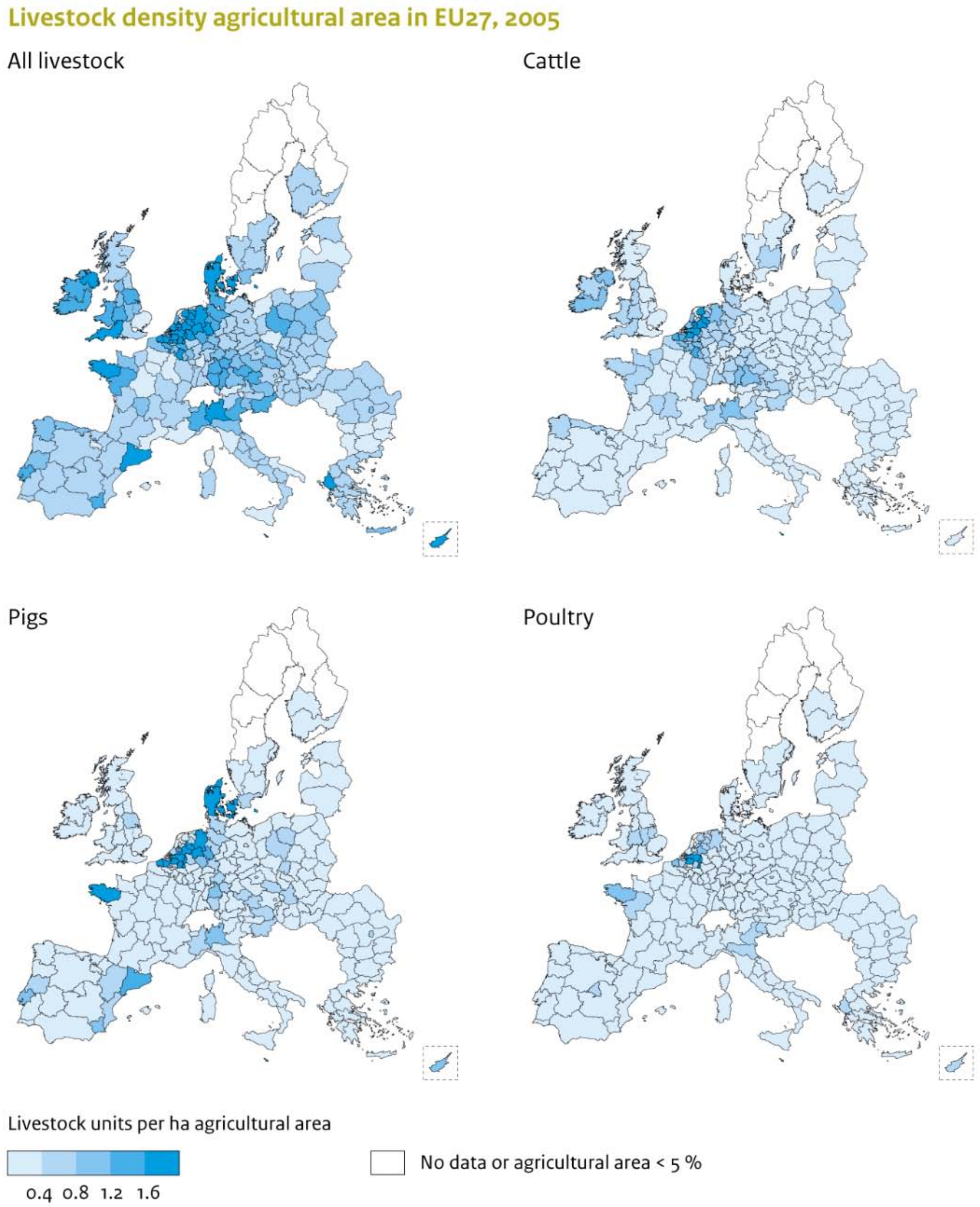

Figure 14: Livestock densities on agricultural land in EU27, 2007 [137]

European agriculture is characterised by high levels of livestock production in the North and West, with particularly high levels of pig and poultry production parts of in Belgium, Netherlands, Germany and Denmark. This concentration in pig and poultry production is driven by advantages in scale and the existence of the supporting technical infrastructure that concentration brings. Ruminant meat production is widespread, based mostly on beef. Milk production is also widely distributed, and most beef production is linked to milk production. However, even with cattle-based production, there is a tendency to concentrate. This includes concentration in regions not strongly characterised by grassland. Production systems are

[137] Westhoek, H., et al. (2011). The Protein Puzzle. Netherland Environmental Assessment Agency

particularly diverse for ruminant in terms of feeds used, scale of production, and links between milk and beef production.

Detailed study of Lower Saxony in north-west Germany provides a clear illustration of the consequences of livestock concentration. [138] In Lower Saxony, pig and poultry production is concentrated on the west, supported by intensive production of maize and imported soy and other feedstuffs. The result is the production of livestock manure is concentrated in these regions (Figure 15). While data illustrated in Figure 14 and Figure 15 show the general problem at the national and international level, examinations on a small local scale are required to fully appreciate the effects of concentration.

Figure 16 shows the nitrogen and phosphorus content of animal manures in relation to the farmed area at the district and municipality level in an area where there is a particularly high concentration of pigs and poultry in the Landkreises of Vechta and Cloppenburg in Germany. The municipality of Damme shows that organic nitrogen loads net of emissions to air exceed 400 kg /ha locally. Studies show that transport of a large proportion of the manure from these areas over distance of about 100 km is required to bring local manure use in line with regulations.

The example set out above is not unique. Similarly high local concentrations occur in the Netherlands, Belgium, Denmark, northern Italy and western France (Brittany). These illustrate a global challenge to reconnect animal production to the resource base thereby enabling better recycling of nutrients and closer of nutrient cycles.[139]

[138] Warnecke, S., Biberacher, M., Brauckmann, H-J., and Broll, G. 2012. Nachhaltige Verwertung von Nebenprodukten aus der Erzeugung tierischer Nahrungsmittel durch Initiierung eines regionalen Stoffstrommanagements. Final report of the Forschungsverband Agrar- und Ernährungswissenschaften Niedersachsen

[139] Naylor, R., Steinfeld, H., Falcon, W., Galloway, J., Smil, V., Bradford, E., Alder, J., Mooney, H. Losing the links between livestock and land. Science 310:1621-1622.

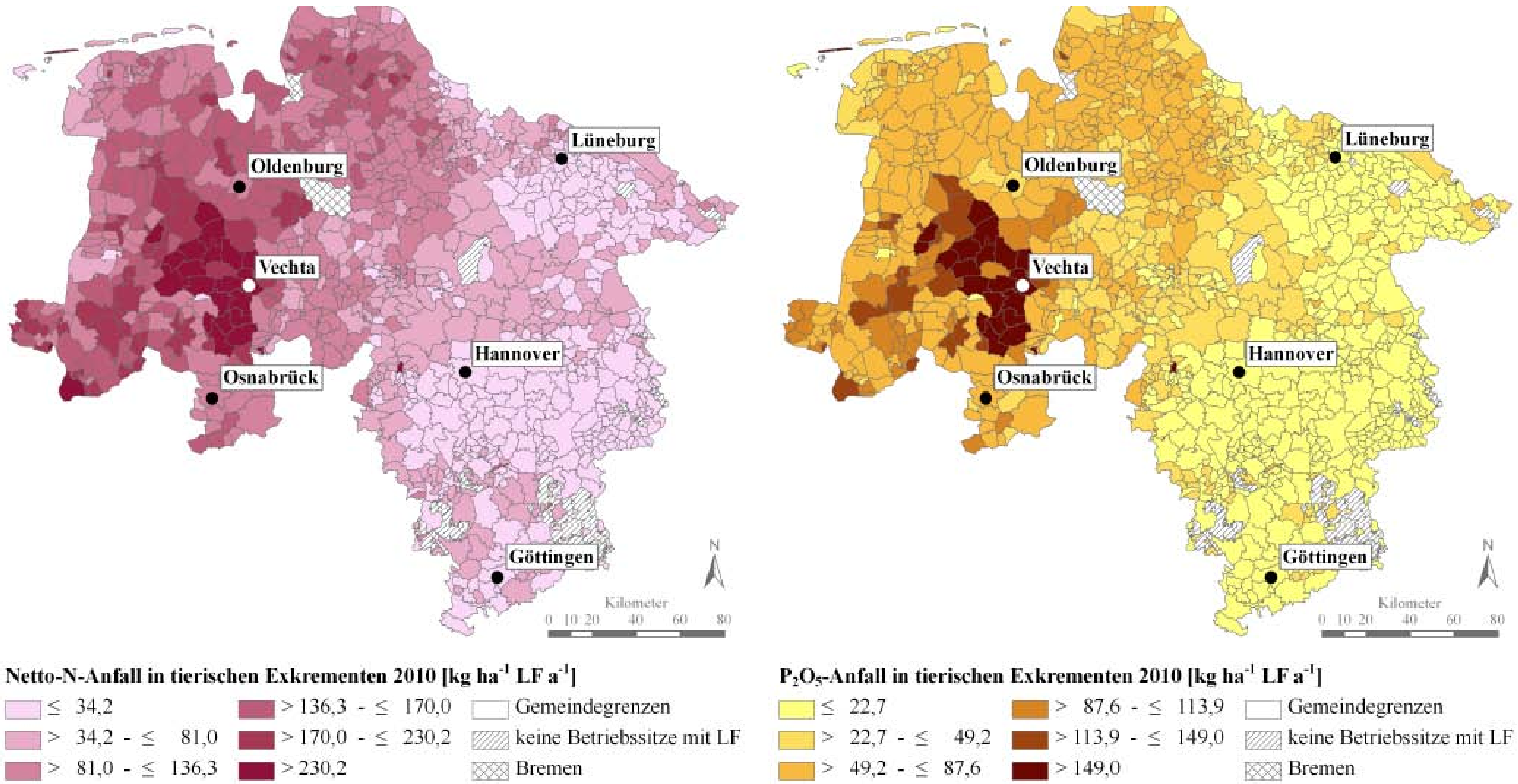

Figure 15: Maps of phosphorus and nitrogen in animal manures (net of emissions to air) for each administrative district across Lower Saxony (Germany)

Figure 15 shows that the organic nitrogen burden in manures exceeds 170 kg/farmed ha over a large proportion of the districts Vechta and Cloppenburg.[140] Large amounts of excess phosphorus are also present.

[140] Warnecke, S., Biberacher, M., Brauckmann, H-J., and Broll, G. 2012. Nachhaltige Verwertung von Nebenprodukten aus der Erzeugung tierischer Nahrungsmittel durch Initiierung eines regionalen Stoffstrommanagements. Final report of the Forschungsverband Agrar- und Ernährungswissenschaften Niedersachsen

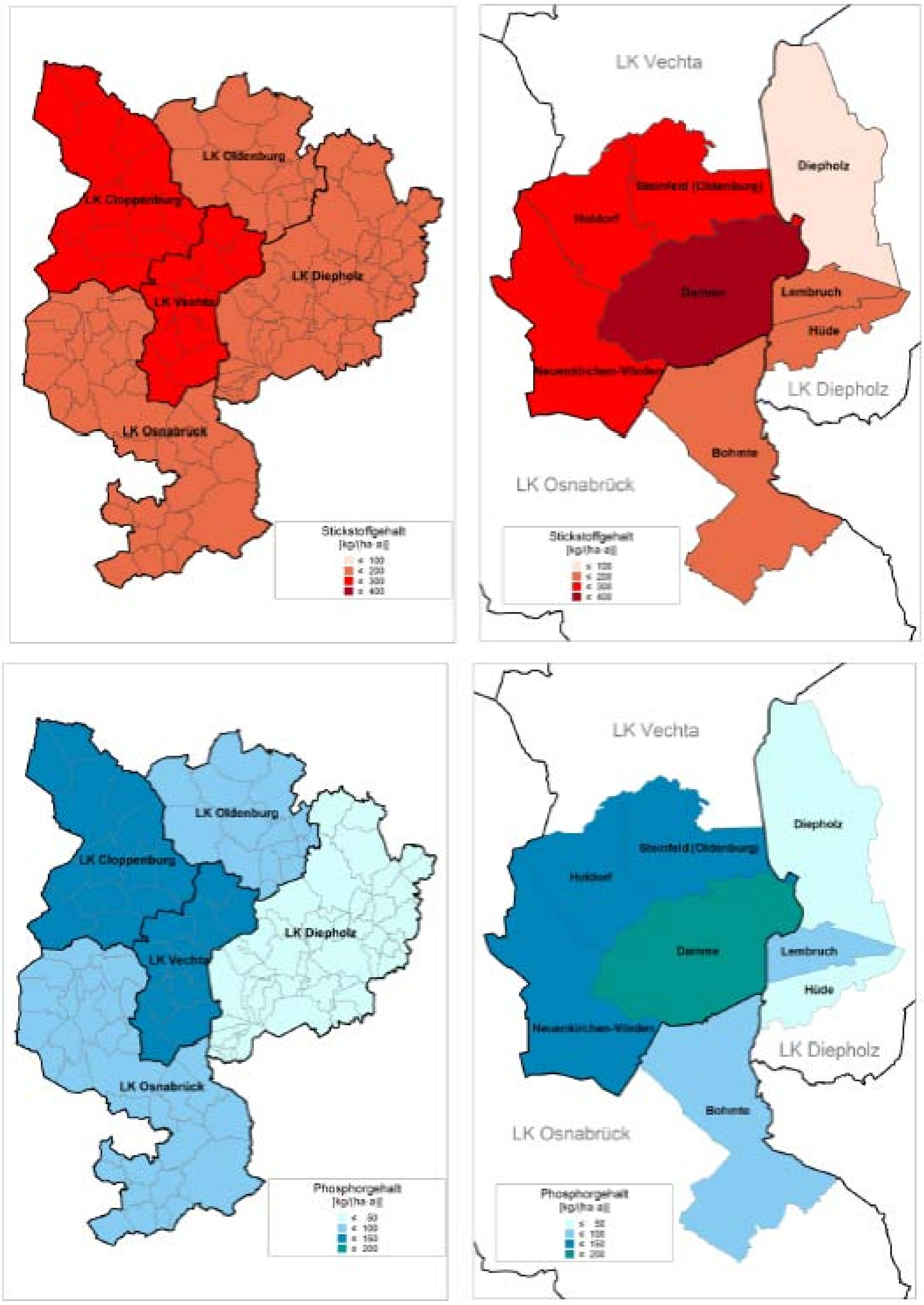

Figure 16: The nitrogen (at top of figure) and phosphorus (at bottom) content animal manures (in kg/ha) at the district (on left of figure) and municipality level (on right) [141]

[141] Wetter C, Brügging E & Baumkötter D (2010) Bioenergiepotentialstudie für die Stadt Damme. Deutschland. accessed at: www.spd-damme.de/IPC/downloads/Biogaskonzept.pdf in March 2012.

7.4.7 Animal welfare

A substantial body of European and national legislation has built up over the last 30 years aimed at improving and protecting the welfare of farmed animals, including fish. This legislation recognises that animals are sentient beings and should be protected from avoidable pain and suffering and should be raised using welfare standards. The Five Freedoms compiled by the UK Farm Animal Welfare Council have been instrumental in developing legislation and are adopted by the Directorate General 'Health and Consumers' of the European Commission as a basis for the European animal welfare standards. They are: freedom from hunger and thirst, freedom from discomfort, freedom from pain, injury or disease, freedom to express normal behaviour, and freedom from fear and distress.

A cornerstone of this body of legislation is the Protocol on Protection and Welfare of Animals in the Treaty of Amsterdam.[142] The Protocol provides that in formulating and implementing the Community's policies on agriculture, transport, the internal market and research, the Community and the Member States 'shall pay full regard to the welfare requirements of animals'. Backed by this, EU legislation has prohibited what are regarded as the three most inhumane rearing systems: veal crates, sow stalls and battery cages for laying hens.[143] On the dairy and beef production side, the use of tethered stalls is now the focus of debate. Tethered stalls for cattle are still common in Europe. About one third of German dairy farms use tethered stalls and these are mostly small farms[144] showing that animal welfare concerns arise in all farming systems: intensive and extensive, traditional and modern.

In general, current animal welfare regulations have little direct effect on the environmental impact or resource use of the relevant parts of the food cycle. Increased space in housing for animals may lead to increased potential emissions of ammonia as the total area of emitting surfaces increases, but these effects are generally small, and may be eliminated when they involve general modernisation of the production facilities. Reflecting this lack of direct impact, the literature on animal welfare legislation is characterised by a lack of reference to environmental impacts.

However, general animal welfare measures can have indirect implications for the environment and vice versa. Voluntary welfare measures that for example require the use of straw bedding increase the proportion of manure in solid form, which has implications for the efficiency of manure use, depending on manure management systems. However, this effect is small. Of more relevance are the effects of production intensity on animal welfare and the associated potential trade-offs with resource use efficiency.

Potential trade-offs are evident in dairy production where increased production intensity is claimed to raise resource use efficiency. High yields of milk per cow mean fewer cows are

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[142] Treaty of Amsterdam amending the Treaty on European Union, the Treaties establishing the European Communities and certain related acts. Official Journal C340, 10.11.1997 p. 0110. CIWF 2009. EU legislation on the welfare of farmed animals on-farm.

[143] CIWF 2009. EU legislation on the welfare of farmed animals on-farm. www.ciwf.org.uk/includes/documents/cm_docs/2009/e/eu_legislation_welfare_farmed_animals.pdf

[144] Animal Angels 2009. Tie stall housing systems on dairy farms. www.fao.org/fileadmin/user_upload/animalwelfare/TieStalls.pdf

required for a given supply. However, this raises questions about animal welfare standards. Continuous housing in very dairy intensive systems is claimed to be particularly resource efficient. [145] With these systems, animals are housed most or all of the time and milk yields are high supported by a combination of dairy cow genetics, intensive feeding using a high proportion of concentrate feedstuffs, and indoor production. In addition, the absence of grazing means that losses of nutrients, particularly nitrogen and the associated emissions of ammonia, nitrous oxide and nitrate are reduced.

If it is assumed that indoor housing to achieve high yield compromises welfare, there is a trade-off between resource efficiency and welfare. However, there is increasing evidence that at the agricultural systems level, the farm-level resource efficiency and emissions benefits of these intensive systems are offset by wider system disbenefits.[146] For example, such intensive systems are characterised by poor longevity of cows in the herd (also an indicator of poor welfare standards), which raises overall emissions from the raising of the increased number of replacement stock required. In particular, these specialised intensive dairy production systems are poor in supporting the beef sector. As a result, Weidema et al report[147] that:

"… improvement[s] at the specialised dairy farm is offset by the concomitant increase in feed requirement and reduction in beef output (30% less beef produced, due to a smaller number of calves born and a smaller number of cows slaughtered), leading to increased emissions from feed production and from the induced additional beef production from suckler cows necessary to keep meat output unaltered. The net effect for methane emissions is a mere 4% of the emissions from the dairy farms, and this is further counteracted by a net increase in CO_2 emissions, so that the net effect on global warming is negligible.

In an exploration of the relationship between productivity of dairy production and greenhouse gas (GHG) emissions on a global scale, Gerber et al. [148] showed that the benefits of increased dairy cow yield in terms of minimising the level of GHG emissions per litre milk produced are most striking at about 2000 l/cow/year. Above about 5000 l/cow/year, the benefits (in terms of minimising GHG emissions per litre of milk produced) of increasing yields further are very low. Since average commercial dairy cow yields in most of Europe are well above 5000 l, this indicates that, for many areas of Europe, any further intensification of dairy production that might compromise welfare, for example through selection for higher annual milk yield potential, may not be justified by reduction in GHG emissions.

In conclusion, there are few direct trade-offs between higher animal welfare standards and individual animal performance. Animal welfare legislation has little direct effect on resource use efficiency in the food system. However, trade-offs may occur at the herd or flock levels as increased provision of space increases emissions. Increased animal performance in the dairy

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[145] Place S.E., and F.M. Mitloehner., 2009. Contemporary Environmental Issues: A review of the dairy industry's role in climate change and air quality and the potential of mitigation through improved production efficiency. J. Dairy Sci. DOI: 10.3169/jds.2009-2719.
[146] O'Brien, D., Shalloo, L., Grainger, C., Buckley, F., Horan, B., Wallace, M., 2010. The influence of strain of Holstein-Friesian cow and feeding system on greenhouse gas emissions from pastoral dairy farms. Journal of Dairy Science 93, 3390-3402.
[147] Weidema, B., Wesnæs, M., Hermansen, J. and Kristen, T. (2008) Environmental improvement potentials of meat and dairy products. European Commission JRC.
[148] Gerber, P., Vellinga, T., Opio., C., and Steinfeld., H. 2011. Productivity gains and greenhouse gas emissions intensity in dairy systems. Livestock Science 139: 100-108.

sector that may have negative animal welfare implications. Recent and more holistic life-cycle based assessments indicate that intensive systems have reached a point where systems level resource trade-offs eliminate benefits of further increases in performance at the animal level. This presents fundamental challenges to the argument that technical improvement in efficiency can make a significant contribution to reducing emissions and resource efficiency in western Europe where systems are already intensive.

7.4.8 Livestock feed

Figure 17 presents data on the consumption of different feeds for six types of livestock, most of which require significant inputs of crops for feed. About 60% of EU cereal production is used in animal feed.[149] This is complemented by the use of grassland, particularly in north-western Europe for cattle and sheep production, and also depends heavily on external supplies of protein rich soy meal. This underpins a weakness in the EU food system from a resource efficiency viewpoint.

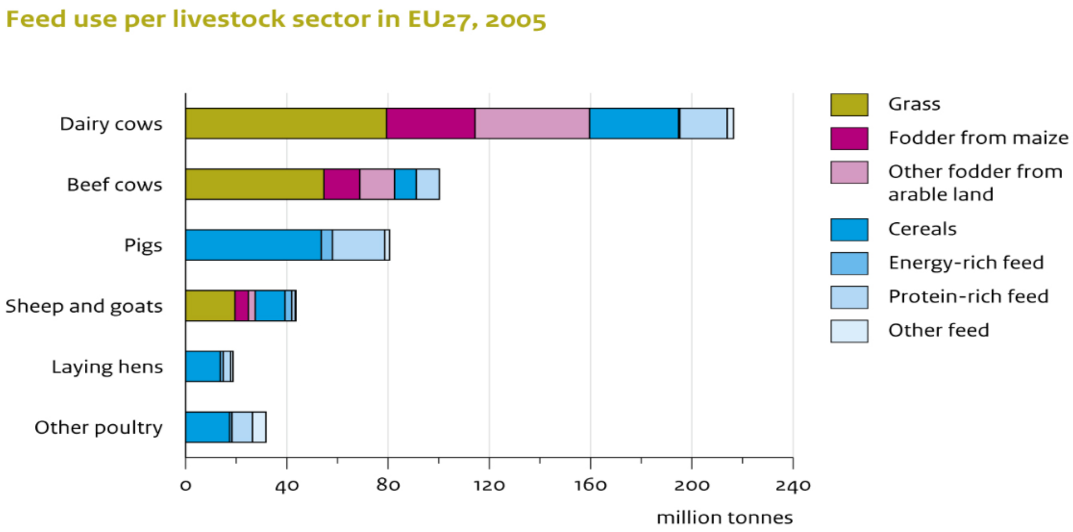

Figure 17: Volumes of types of feed used (in Mt) for different livestock groups in the EU27, 2005

The European livestock sector is responsible for the use of approximately 79 million ha of arable land, 67 million ha of which within Europe (hence the area of arable land used to feed livestock is greater than the area used for crops directly consumed) and 12 million ha outside Europe.

Alternatives to soy products in fodder include by-products from food processing, such as brewery by-products[150]. There are substantial supplies of protein-rich rapeseed residues. Compared to about 40 Mt of soy meal used, some 9 Mt of rapeseed meal is used yearly, and the

[149] Westhoek, H., et al. (2011). The Protein Puzzle. Netherland Environmental Assessment Agency
[150] Audsley, E., et al. (2009). An assessment of greenhouse gas emissions from the UK food system and the scope to reduce them by 2050. How low can we go? FCRN-WWF-UK.

production of oilseed crops in the EU shows an increasing trend[151]. It is notable that rapeseed meal is a by-product of biodiesel production.

A recent study of the relationship between livestock product consumption and the nitrogen cycle in the EU identifies the profound implications of Europe's large livestock sector.[152] Using a combination of models, it showed that a halving of livestock product consumption would reduce the need for soy meal by 75% and release 10 - 15 million hectares of arable land from feed production (net of land required for substitutes). It also indicated that all nitrogen emissions to air and water would be reduced very significantly – by 43 and 35 % respectively. A striking feature of these dramatic savings in resources is they arise from consumption scenarios that would bring European consumption in line with health guidelines.

7.4.9 Global land use

Trade of agricultural commodities is a driver for land use and land cover changes.[153,154] Over the past decade there has been a decline in the use of EU land for agricultural commodity exports and an increase in land used outside EU borders ('global land use') for imports.[155] The EU imports of raw agricultural products (not including processed food and meat) result in global land use of 14.1 million ha[156]. This is a conservative measure since the amount is predicted to increase if processed products are taken into account, possibly to double the original estimate.[157] Other studies suggest that the total EU global land use is 34.9 million ha.[155]

A limited number of raw agricultural products are responsible for a large amount of EU virtual land use (more than 60%)[156,171]; in particular due to imports of wheat, coffee, soy and cocoa beans. The EU27 imports nearly one quarter of the global soy crop and the meal output of 22 million ha. These imports, mainly from the USA, Brazil and Argentina are showing a rising trend.[158] The importance of EU livestock feed in EU global land use is highlighted above and in

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[151] FAOSTAT (2010) FAO Statistical Database. Food and Agriculture Organization (FAO), Available online at: faostat.fao.org/site/573/default.aspx#ancor [Accessed 03/2010].

[152] TFRN 2012. Nitrogen on the table. www.clrtap-tfrn.org/epnf

[153] Scheidel, A. Krausmann, F. (2011) Diet, trade and land use: a socio-ecological analysis of the transformation of the olive oil system, Land Use Policy 28, 47–56

[154] Erb, K-H, et al. (2009) Embodied HANPP: Mapping the spatial disconnect between global biomass production and consumption. Ecological Economics. 69: 328-334. Bennett,EM, Balvanera, P (2007) The future of production systems in a globalized world. Frontiers in Ecology and the Environment. 5: 191-198.

[155] von Witzke, H., Noleppa, S.(2009) EU agricultural production and trade: Can more efficiency prevent increasing 'land-grabbing' outside of Europe?. Note: Report for Agripol network at Humboldt University Berlin for policy advice and OPERA (stakeholders in the agri food sector).

[156] van der Sleen, M (2009) Trends in EU virtual land flows: EU agricultural land use through international trade between 1995-2005, In cooperation with Rijksuniversiteit Groningen & the European Environment Agency. A Report to the European Environment Agency

[157] The calculations were bases in FAOSTAT and EUROSTAT data on extra EU imports and exports, Yield per hectare (country and product specific) and production in mass units. This type of calculation may not give the right import values for individual EU countries, since one assumption is that products are produced in the country they are imported from. Thus sequential imports/exports and intra EU trade is not taken into account.

[158] Westhoek, H., et al. (2011). The Protein Puzzle. Netherland Environmental Assessment Agency

other studies.[159] Palm oil is another product largely imported to the EU, similarly used in a multitude of processed foods (it is also used to make biodiesel).

Global trade is potentially problematic since the spatial separation of material production (including resource exploitation) from consumption eliminates the direct negative feedback that normally occurs when people dependent on local ecosystems degrade those ecosystems[160], and may lead to food scarcity at the source of production.

It is also problematic because of the link between land use change and global climate change. In some non-EU regions the market for certain agricultural products drives an increasing need for agricultural land, which drives land use change. For example in Brazil and Argentina, forest and savannah removal are linked directly and indirectly in part to the growth in soybean and beef production for exports[161]. Deforestation leads to drastic C-emissions. Hence, the land use changes overseas due to EU consumption of imported food entail carbon emissions attributable to the EU food cycle.[162]

Although agricultural land demand is a driver of deforestation, other contributing factors include rural poverty and the commercial value of timber.[163] The potential for and effects of global land use changes need to be carefully considered in policy making. Accounting systems for these global land use effects are needed to measure the impacts of EU imports.

7.4.10 Land use competition

Assessing the amount and spatial distribution of land that would be suitable as cropland is a difficult task. The FAO forecasts[164,165] cropland area change and crop yields, and has estimated a cropland expansion of 9% to 2050.[166] Global studies of land suitable or potentially available for cropland[167,168,169] suggest that cropland potentials are considerably larger than those estimated

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[159] Bringezu S., Schütz, H., Arnold, K. Merten, F. Kabasci, S. Borelbach, P. Michels, C. Reinhardt, G.A. , Rettenmaier, N. (2009) Global implications of biomass and biofuel use in Germany – Recent trends and future scenarios for domestic and foreign agricultural land use and resulting GHG emissions. Journal of Cleaner Production 17, S57–S68

[160] Kissinger, M., Rees, W.E., (2010) Importing terrestrial biocapacity: The U.S. case and global implications, Land Use Policy 27, 589–599

[161] Smaling, E.M.A., et al. (2008) From forest to waste: Assessment of the Brazilian soybean chain, using nitrogen as a marker. Agriculture, Ecosystems and Environment 128: 185–197

[162] Gavrilova, O., et al. (2010) International trade and Austria's livestock system: direct and hidden carbon emission flows associated with production and consumption of products. Ecological Economics. 69: 920-929

[163] Audsley, E., et al. (2009). An assessment of greenhouse gas emissions from the UK food system and the scope to reduce them by 2050. How low can we go? FCRN-WWF-UK.

[164] Bruinsma, J., (2003). World agriculture: towards 2015/2030. An FAO perspective. Earthscan, London.

[165] FAO (2006) World agriculture: towards 2030/2050 - Interim report. Prospects for food, nutrition, agriculture and major commodity groups. Food and Agricultural Organization (FAO), Rome.

[166] Erb, K.-H., et al. (2009) Eating the planet: Feeding and fuelling the world sustainably, fairly and humanely - a scoping study. Report commissioned by Compassion in World Farming and Friends of the Earth, UK. [116], 1-132. Vienna, Potsdam, Institute of Social Ecology and PIK Potsdam. Social Ecology Working Paper. 19-4-2010.

[167] Fischer, G., Heilig, G.K., (1997). Population momentum and the demand on land and water resources. Philosophical Transactions of the Royal Society B: Biological Sciences, 352 (1356), 869-889.

[168] IIASA, FAO, (2000). Global Agro-Ecological Zones 2000. International Institute for Applied Systems Analysis (IIASA) and Food and Agriculture Organization (FAO), Rome, Italy.

[169] Ramankutty, N., et al., (2002) The global distribution of cultivable lands: current patterns and sensitivity to possible climate change. Global Ecology and Biogeography, 11 (5), 377-392.

by FAO. These results, however, have been severely criticized.[170,171] In general, most of these assessments are based on a 'land balance' approach that involves identifying cultivable areas and subtracting areas already cultivated. In summary, there is no consensus on the amount land available for expansion of agriculture.

Future global demand for food and growth in production of biofuels[172] may lead to increasingly limited availability of suitable cropland to meet these increased demands. In this case, the EU's current reliance on global land for imports may pose risks to supplies of plant proteins for livestock feed and the EU's food security.

Different future land use scenarios under the generally accepted assumptions of increasing demand for food to 2050 have been compared, suggesting that there could be land enough to feed a global population of 9.2 billion in 2050, depending on the interplay of technological change, dietary developments and demand for non-food commodities. One scenario calculates that the use of organic agriculture only worldwide would be able to feed a population of 9.2 billion in 2050, delivering a diet that is sufficient in terms of nutritional energy (2,800 kcal/capita/day), protein and fat. However, the scenario includes significant requirements: adoption of specific dietary choices, a growth in global cropland area by approximately 20%[173] (as compared to 2000 level), and a high level of equality in food distribution in order to avoid malnutrition, and would be paired with a significant reduction of subsistence agriculture, with unclear socio-ecological consequences. In such a scenario, however, the potential for bioenergy production would be low if deforestation were to be avoided. The scenarios indicate that the share of animal products in human diets significantly influences environmental impact and also determines the feasibility of producing animal products humanely (or using organic rearing methods) and is thus a major parameter relating to land competition.[174]

The spatial aspect is of importance in terms of where productive land (e.g. correct climatic and soil properties) is situated and whether it is socioeconomically advantageous to use the land for the different types food production. In some areas the most efficient use of land may be grazing, while other areas may be more suited to wheat production.

[170] Young, A., (1998). Land Resources: Now and for the Future. Cambridge University Press, Cambridge, UK.

[171] Young, A., (1999). Is there Really Spare Land? A Critique of Estimates of Available Cultivable Land in Developing Countries. Environment, Development and Sustainability, 1 (1), 3-18.

[172] Promoted by the Renewable Energy Directive's (2009/28/EC) Renewable Energy Roadmap: it has been estimated that production of biofuel for transport and energy may lead to use of from 17.5 million ha arable land (the equivalent to approximately 15% of total current EU arable land) (source: DG AGRI (2007) Impact assessment of the Renewable Energy Roadmap) to approximately 30 million ha (source: Eickhout, B., et al. (2008) Local and global consequences of the EU renewable directive for biofuels. Testing the sustainability criteria), increasing competition for land and potentially incentivising further land use change.

[173] This is due to the fact that the productivity of organic agricultural production is considered to be lower than conventional production.

[174] Erb, K.-H., et al. (2009) Eating the planet: Feeding and fuelling the world sustainably, fairly and humanely - a scoping study. Report commissioned by Compassion in World Farming and Friends of the Earth, UK. [116], 1-132. Vienna, Potsdam, Institute of Social Ecology and PIK Potsdam. Social Ecology Working Paper. 19-4-2010.

7.4.11 Land use efficiency

Agricultural systems can be optimized for different parameters, such as productivity or a range of environmental impact indicators (i.e. economically-optimized compared to ecological-optimized resource efficiency). There may be trade-offs between these different efficiency objectives. For example, production efficiency measured as yield per ha is likely to be highest for intensive farming systems. In contrast, energy efficiency, measured as energy output per unit energy input (EROI), as well as N use efficiency, measured as yield per unit of applied N, may be higher in less intensive farming systems.[175,176] Labour efficiency has increased due to mechanization, reducing human labour but increasing other resource inputs (e.g. fossil fuels). Consideration of different indicators is needed.

When looking at the overall efficiency of the food cycle, upstream conversion efficiencies and consumer choices are important. For instance, intensive production systems that include a livestock conversion pathway will be less area efficient (in terms of land per calorie provision for human consumption) than more extensive systems that supply vegetal calories to consumers[177]. The Human Appropriation of Net Primary Production (HANPP) framework[178,179] provides an indicator to measure this type of efficiency[180], and therefore a way to link pressures on ecosystems (through the appropriation of ecosystems' primary production of biomass) to consumption choices, and production and processing efficiencies. . Minimizing HANPP per unit of final consumption (Figure 18) would indicate greater efficiency in the use of land to produce food for human consumption.

[175] Pimentel, D., Pimentel, M. (2008). Food, Energy and Society, 3rd ed. CRC Press, Boca Raton.

[176] Dobermann, A.R. (2005). Nitrogen use efficiency–state of the art. Paper presented at the IFA International Workshop on Enhanced-Efficiency Fertilisers, Frankfurt, Germany, 28-30 June, 2005.

[177] Gerbens-Leenes, P.W., Nonhebel, S. (2002). Consumption patterns and their effects on land required for food. Ecological Economics 42, 185-199.

[178] Haberl, H., et al. (2007). Quantifying and mapping the human appropriation of net primary production in earth's terrestrial ecosystems. Proceedings of the National Academy of Sciences 104, 12942-12947.

[179] Erb, K.-H., et al. (2009). Analyzing the global human appropriation of net primary production -- processes, trajectories, implications. An introduction. Ecological Economics 69, 250-259.

[180] HANPP traces upstream biomass requirements from final consumption of goods (e.g. meat, grain products) and establish a link to human impact on ecosystem energy flows. It considers several conversion steps, such as productivity changes due to land conversions (i.e. the difference in NPP between actual and potential vegetation), biomass flows in ecosystems associated with harvest events (including harvest and felling losses), the amount of biomass that enters socioeconomic processes (used extraction), and conversion losses associated with processing. A typical perspective of resource efficiency would take only the latter conversion losses into account.

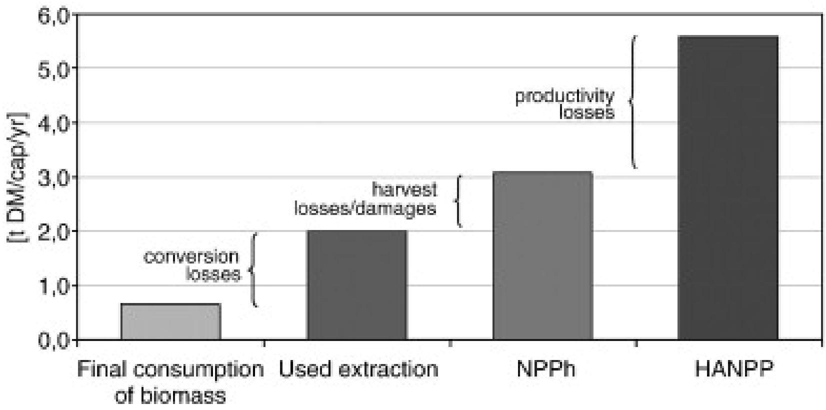

Figure 18: Comparison of final consumption (left hand column) to primary production of biomass (HANPP in right hand column) and identification of losses during stages of production, harvesting and processing ("conversion") (NPPh: Net Primary Production harvested; unit: global biomass flows in t dry matter (DM) per capita in the year)

Geographically and historically, densely populated areas in general show much smaller losses of biomass per unit of final consumption then sparsely populated areas (i.e. smaller HANPP per unit of final consumption). In addition, historical increases in biomass production per unit land area and efficiency of biomass appropriation from that land (i.e. increase in NPPh per unit HANPP) due to industrial agriculture, mainly input-driven, have compensated for surges in biomass demand due to increases in consumption and increases in the share of animal protein in human diets.

As a general pattern, land use intensification increases the efficiency of production from that land (i.e. reduces HANPP per unit of available output for consumption). On the other hand, land use intensification is strongly associated with increases in pressures on ecosystem processes and functioning[181,182,183]. Thus, it is necessary to complement the HANPP framework with indicators of input intensification (e.g. fertiliser use efficiency) in order to gain a sound and robust insight into land use efficiency.

7.4.12 Fish production

Fish are important to food security, particularly in the poorest developing countries. In 2002 fish products provided more than 2.6 billion people with at least 20 per cent of their average per capita annual protein intake.

- **Wild fisheries**

The main concern with wild fisheries is the overexploitation of fish stocks and the impacts on marine ecosystems. Reduced fish stocks have raised the issue of the sustainability and profitability of the fishing industry, and placed it at the top of the international fisheries agenda. Sustainable stock management is important to ensuring that fish resources are able to replenish

[181] Matson, P.A., et al. (1997). Agricultural Intensification and Ecosystem Properties. Science 277, 504-509.
[182] Tilman, D., et al. (2002). Agricultural sustainability and intensive production practices. Nature 418, 671-677.
[183] Kiers, E.T., et al. (2008). ECOLOGY: Agriculture at a Crossroads. Science 320, 320-321.

themselves and maintain a consistent stock.[184] The catches by EU fisheries are declining, partly due to fisheries policies. Catches in the major fishing areas have dropped by a third since the early 1990s, while fishing today takes place over larger distances and in deeper waters than previously.[185] Climate change may increasingly become a risk to the EU fish fleet. For example, changing sea temperatures may affect the distribution of fish species.[184]

By-catch (species caught unintentionally in fisheries) furthermore causes significant disturbance of certain populations of seabirds and marine mammals, declining marine biodiversity. Techniques have been developed for reducing by-catch from fishing, for example for tuna fishing.[186]

For many developing countries, fisheries are crucially important to food security. Despite this, the European Commission has acknowledged that the external dimension of the Common Fisheries Policy is "partly responsible for overexploitation of the fishing grounds of some third countries", which may therefore pose a threat to the food security of certain developing nations.

Total Allowable Catches (TACs) are now set as limits to fishing for each fish stock, and are shared out between the Member States of the EU according to a fixed allocation key based on their historic catches. Limiting the days which vessels can spend at sea is also a systematic element in all long-term plans. It has been suggested that European fisheries policies today address the issue of overfishing, but that broader environmental and development issues continue to be marginalized. Reasons for this includes limitations in access to fishing waters as well as impediments to EU market access for many less developed countries.[187]

- **Aquaculture**

EU aquaculture currently represents only 2 % of world aquaculture production. EU 27 in 2007 produced 1307 kt live weight from aquaculture, and the 3 largest producers were Spain, France and Italy, producing more than 50% of the fish, the five largest more than 75% (also including UK and Greece)[188].

Despite great progress in aquaculture techniques, the EU output from aquaculture has been constant since 2000, far from the 30% increase observed in the rest of the world. Feed is a limiting factor, since the large part of fish produced in EU aquaculture is carnivorous[189], requiring wild fish (and the energy to catch it). In comparison, the consumption of herbivorous fish is larger in many Asian countries; even if for such production methods, there is a need for feedstuffs (e.g. soy and cereals), requiring resource inputs and agricultural land.[185]

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[184] AEA Technology (2010). Review of the Future Resource Risks Faced by UK Business and an Assessment of Future Viability

[185] Westhoek, et al. (2011). The Protein Puzzle. Netherland Environmental Assessment Agency

[186] Gilman, E. (2011). By-catch governance and best practice mitigation technology in global tuna fisheries. Marine Policy. 35: 590-609.

[187] Bretherton, C. and Vogler, J. (2008) The European Union as a Sustainable Development Actor: the Case of External Fisheries Policy, Journal of European Integration, 30:3, 401-417

[188] EUROSTAT database available at epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database [Accessed online 28/02/2011]

[189] Audsley, E., et al. (2009). An assessment of greenhouse gas emissions from the UK food system and the scope to reduce them by 2050. How low can we go? FCRN, WWF-UK.

While aquaculture could reduce the pressure from overharvested wild fish stocks, it can have a harmful effect on aquatic environments, such as conversion of coastal ecosystems and pollution of coastal and inland waters (nutrient pollution contributing to eutrophication or pollution through the use of disease control chemicals[190]).

Other barriers to the growth of European aquaculture include:

- limitations to access to space and water required for production;
- need for authorisations, or environmental restrictions or regulations;
- insufficiency of medicine and vaccines; and
- pressure from imports and wild catch competition, etc.[191]

7.4.13 Storage and the cool chain

Chilling and refrigeration equipment (CRE) takes many forms reflecting the scale of a particular commercial operation. For example, distribution warehouses use large walk-in chiller rooms to store large quantities of goods. Small shops use almost domestic scale fridges and chilled cabinets. Such equipment finds use in a number of other environments including: supermarkets, restaurants, hotels, cafes, pubs and bars.

The stock of CRE is growing. Energy using Product Preparatory Studies[192] estimate the present EU stock as being 25.0 million units with annual sales of around 3 million units / year. CRE is a significant energy consuming sector (service cabinets alone are estimated to consume 10.3 TWh per year). Globally, it is estimated that 40% of all food requires refrigeration and that 15% of the electricity consumed worldwide is used for refrigeration[193]. Direct emissions (leakage) of refrigerant gases are significant and in terms of CO2 equivalent, estimated to be 40% of world total refrigerant emissions (calculated as CO2-equivalents).[194]

Actions to address the issue:

Such is the scale of CRE EU energy consumption, that the European Commission has completed two Preparatory Studies for the specific purpose of identifying technology development for reducing energy consumption. Options include improved insulation, lighting, compressors and high efficiency fan blades. Estimates for service cabinets suggest that a 76% improvement in

[190] AEA Technology (2010), Review of the Future Resource Risks Faced by UK Business and an Assessment of Future Viability

[191] European Commission (2009) Building a sustainable future for aquaculture: A new impetus for the Strategy for the Sustainable Development of European Aquaculture. Available at: europa.eu/legislation_summaries/maritime_affairs_and_fisheries/fisheries_resources_and_environment/pe0007_en.htm

[192] ENTR Lot 1 "Refrigeration and Freezing Equipment" and TREN Lot 12 "Commercial Refrigerators and Freezers"

[193] James, S. J., & James, C. The food cold-chain and climate change. Food Research International (2010), doi:10.1016/j.foodres.2010.02.001. Available at: www.frperc.com/FRPERC.com/News/Entries/2010/11/5_New_publication__Category-Based_Food_Ordering_Processes_files/SJ_CJ%20FdResInt%20Climate%20change%202010.pdf

[194] IPCC 2005, Special Report on safeguarding the Ozone Layer, Chapter 4, Refrigeration

energy efficiency is possible by 2015. Various options for driving this improvement are proposed in the studies including; labelling, development of test standards/methods, self-regulation and provision of information to consumers.

The potential environmental benefits are significant. Potentially the upgrade to manufacturers' production lines could require investment beyond that ordinarily required. Additional warranty claims due to sales of new technology might arise. Consumers on the other hand would, from a life cycle cost perspective, see cost savings due to lower energy consumption.

7.4.14 Distribution and transport

Transporting food (distribution transport (air, road or rail)[195], transport for food shopping by consumers, etc.) from its production place to reach the consumer plays a vital role in the food chain. The most important impacts are contribution to climate change, to local air pollution, to noise levels, to biodiversity loss and natural resources depletion. With global trade, the miles food travels increases and leads to changes in delivery patterns, the increase in processed and packaged foods and making more trips to the supermarket. Main environmental impacts (GHG emissions) arise from transport used (car using) for food purchase or transport (air, road, rail) for delivery of not locally-produced products. An increase in land use for transport infrastructure would generate increased pressure on biodiversity and ecosystem services due to direct damage linked to construction, habitat fragmentation and degradation and disturbance. The increase in traffic would lead to increase of noise related external costs.

The total transport use for household food shopping trips and distribution sector (especially) is increasing; at an EU level freight transport is projected to increase by around 80% by 2050 compared to 2005, while passenger traffic should grow by 51%, and air freight is forecast to increase by 125% by 2020.[196] Transport is responsible for about a quarter of the EU's greenhouse gas emissions. In 2004, by weight, agricultural products and live animals, foodstuffs and animal fodder, and fertilizers constituted the following proportions of EU freight: 19.29% road, 10.84% rail (2002) and 11.09% inland waterways[197].

With processed foods made of many different ingredients, it is very complicated to calculate the CO2 emissions from transport by multiplying the distance travelled of each ingredient, by the carbon intensity of the mode of transport (air, road or rail), etc. The environmental impacts associated with transport (car use by consumer) for food purchasing are also difficult to quantify, but general shopping by car contributes for example more than 10 % of photochemical ozone during a product's life cycle.

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[195] Transport is responsible for about a quarter of the EU's greenhouse gas emissions. 12.8% of overall emissions are generated by aviation, 13.5% by maritime transport, 0.7% by rail, 1.8% by inland navigation and 71.3% by road transport (2008) [European Environment Agency, ec.europa.eu/transport/strategies/facts-and-figures/putting-sustainability-at-the-heart-of-transport/index_en.htm]

[196] Appendix 5 of the Impact Assessment accompanying the White Paper, SEC(2011) 358 final

[197] EEA (2008) Beyond transport policy — exploring and managing the external drivers of transport demand: Illustrative case studies from Europe. Available at: www.eea.europa.eu/publications/technical_report_2008_12

Actions to address the issues:

There are no EU policy initiatives with a direct focus on addressing the environmental impacts of transporting food. However, there is a series of initiatives that can contribute indirectly to addressing the issue. Such policy initiatives mainly focus on the improvement of efficiency and sustainability of freight transport:

- *Transport White paper 2011* (Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system) aims to achieve key goals by 2050 including: 40% use of sustainable low carbon fuels in aviation; at least 40% cut in shipping emissions; 50% shift of medium distance intercity passenger and freight journeys from road to rail and waterborne transport; and monitor the environmental performance of transport based on 10 indicators, including Modal split of freight transport (the achievement of a balanced shift towards environmentally friendly transport modes for freight); Modal split of passenger transport (achievement of a balanced shift towards environmentally friendly transport modes for passengers), etc.

- Pointing the way to a European freight transport policy, *package of measures to support freight transport* aims to make it more efficient and sustainable, including Freight Transport Logistics Action Plan with its main orientations: innovation, simplification, quality, green corridors and updating of the regulatory framework.

- *Marco Polo* incentives aim at reducing or avoiding road transport by switching to the modes of rail, sea and inland waterways distribution that may well be greener, cleaner and even cheaper over time. Through co-funding (grant) the projects aimed at such switch, it aims to free Europe's roads of an annual volume of 20 billion tonne-kilometres of freight.

- The *Easyway project* aims to improve the situation on European roads, concerning safety, mobility and environmental impact, by deploying harmonised ITS services for the European traveller and haulier.

Considering the environmentally beneficial potential of 'road to rail and inland waterways transport' food delivery shift[198], enabling greater access to rail by for example improving communications to identify synergies/networks/backloads and to generally make the rail freight industry more flexible could be strengthened.

Although consumers are relatively well aware of 'food miles' concept (energy input during food delivery), awareness-raising campaigns can be still reinforced to guide consumers to making pro-environmental choices. Providing alternative distribution systems is an option for reducing car driving for shopping. Delivery services offered by supermarkets may replace at least some of

[198] The share of road transport in intra-EU long distance freight transport is around 33%, while rail and inland waterways jointly contribute less than 20%. The poor environmental performance of the transport system is linked to the fact that the generally greener rail and inland waterways transport have failed to exploit their potential in medium to long distances. [Appendix 5 of the Impact Assessment accompanying the White Paper, SEC(2011) 35]

the shopping trips by private car, if combined with remote ordering (e.g. through Internet). To attract consumers to such services, the high quality service can be strengthened through a requirement to participate in a quality scheme (like the Danish 'Smiley' scheme or the setting up of a competing public delivery service. Another option to strengthen the acceptance is to require delivery services to be offered for free (limited to customers within a certain distance from the shop and, for example, to purchases over a certain value or for a maximum number of deliveries within a period).

A larger capacity utilisation of the delivery vehicle leads to a net result of fewer kilometres driven per consumer. As an achievable target, if suitable incentives are put into place, it is assumed that 25 % of customer trips can be replaced by a delivery service, taking into account that some consumers, a saving of 18 % is obtained on all shopping kilometres by car, and a reduction in public transport for shopping of 25 %. Emissions from car driving are larger for short trips with a cold engine than for longer trips, which means that reductions in shopping by car will mean not just the proportional reduction in kilometres, but also - reduction in cold engine emissions. In addition, if home delivery is widespread, this may also involve a reduction in retail space, as warehouses can replace some shops. Also, deliveries can be made more frequently than private shopping, without significant increase in vehicle-kilometres, which may contribute to reduce storage loss in households.

7.5 Pre-farm: inputs to production and processing

7.5.1 Water

The main impact of water use in the food system arises from the abstraction of water. Abstraction of water for irrigation accounts for 24% of total water abstraction in Europe.[199] The energy sector accounts for the largest amount of water but this is only temporarily abstracted for cooling. Agriculture therefore accounts for over half of European longer term water abstractions, and dominates abstraction in Mediterranean countries. Outside the Mediterranean, abstraction for agriculture has increased significantly in France, the Netherlands and the United Kingdom where local impacts are significant. The majority of the water abstracted for agriculture is consumed and not returned to the source water bodies adding to the overall impact.

The quantity of water used for irrigation depends on crop types, soil and irrigation infrastructure and methods. Techniques such as drip irrigation reduce the volume of water abstracted and decrease the investment in water sourcing, storage and transfer. They also reduce the problems associated with soil erosion. However some of the efficiencies at the field level reduce aquifer recharge or transfers to downstream users. Where salt accumulates under arid conditions, drip irrigation may be constrained because this precise use of water reduces the leaching of salt from the rooting zone.

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199 European Environment Agency (2009). Water resources in Europe – confronting water scarcity and droughts. Report No 2/2009.

Irrigation is used widely across Europe to secure and protect the yield and quality of valuable horticultural crops in particular. However, in recent years irrigation has been extended to traditionally rain-fed crops, notably olives. Strosser et al. provide an overview of the development of irrigated area in the EU 15 over the last 40 years.[200] In addition to highlighting expansion in the Mediterranean, that report shows expansion in other countries, notably France, the Netherland and the UK. In France, irrigation is now widely used for grain crops such as maize, even though maize is well adapted to drought conditions.

Impacts:

Abstracting freshwater from surface waters and aquifers gives rise to most of the impacts. In addition, desalination is now used to supply irrigation water in Mediterranean countries, inside and outside the EU. Spain is now a world leader in the use of desalinated water for agriculture, and this is driven by European markets for fresh produce. Although abstraction for desalination has fewer direct impacts compared with abstraction from fresh water bodies, the desalination process itself is energy demanding leading indirectly to greenhouse gas emissions. Desalination requires 1.5 – 2.5 kWh electricity/m^3. Scenarios to 2030 indicate that total energy use from desalination and transport of this water in the EU ranges from an equivalent of 3 to 7% of total power production in 2030, with equivalent proportions of CO2 emissions, ranging from 23 to 114 Mt annually[201]. In addition, the brine returned to the sea has local ecosystem impacts, as salt concentration in discharge is high. Larvae and small organisms are vulnerable close to poorly designed desalination plant inlet pipes. However, evidence is currently limited and requires further research.[202]

While the hydrological cycle is entirely closed in that all water used is eventually returned to the cycle, abstraction impacts arise because of distortion of local hydrological cycles. The irrigation of crops results in the evapo-transpiration of the water via the crop which exceeds background transpiration rates in natural rain-fed vegetation. The net effect is sinking water tables or reduction in surface water flows with consequences for natural vegetation and surface water flows fed by ground water via springs.

In the case of abstraction for purposes other than irrigation, for example food processing, the water used in the process is usually transferred after use out of the area of abstraction to the local water treatment system and from there to the surface water (rivers etc.). This results in a local net loss of water from the aquifer, with perhaps a gain for the water course receiving the treated water. The overall impact depends largely on the capability of the aquifer to recharge and compensate for the localised abstraction loss.

Impacts of local abstraction for processing can be significant in all parts of Europe as centralised processing localises a large demand for water. Use for processing is constant throughout the year, which adds to the recharge challenge.

The impact of abstraction from surface waters is easy to appreciate. Abstraction reduces river flow rates at the time when water levels are already low due to the dry weather necessitating

[200] Strosser, P., Pau Vall, M., and Plöscher, E. Water and agriculture: contribution to an analysis of a critical but difficult relationship. ec.europa.eu/agriculture/envir/report/en/eau_en/report.htm

[201] Ecologic (2008) Potential impacts of desalination development on energy consumption. Available at: ec.europa.eu/environment/water/quantity/pdf/desalination.pdf

[202] Dickie, P. (2007). Desalination: option or distraction for a thirsty world. WWF

irrigation. The impact of abstraction from aquifer is less obvious but can be more profound in the long-term. There impacts are also counter-intuitive. The largest impacts on vegetation from ground water abstraction may be where ground water resources are naturally close to the surface, and can be particularly significant in areas where water appears plentiful. In these circumstances, the impacts are greatest on the most deep rooted vegetation – for example mature beech and oak woodland. Mature trees root deep enough to tap these relatively shallow water reserves. In these circumstances, the woodland is particularly vulnerable to sinking of the water table. Mature vegetation does not extend its root system to follow a sinking water table and so local abstraction can cause damage and loss of tress, especially the mature trees.

The European food cycle and the Mediterranean – Spain as an example:

Spain exemplifies the consequences of expansion of irrigated agriculture most. Spain is a world leader in the export of fresh horticultural produce with exports to northern European countries dominating. To meet north European demand, Spain has invested heavily in all aspects of water exploitation: dams, boreholes, irrigation infrastructure, and desalination. Spain has the largest desalination capacity in the world[203] and about 22% of the desalinated water is used for agriculture, for example for horticulture in Almeria. Irrigated intensive agriculture is frequently associated with practices that remove vegetation cover leading to soil erosion. There has been widespread conversion of extensive farming with high landscape and biodiversity value to intensive olive and fruit plantations.

Public debate about water use in the Mediterranean is usually focused on the well-known irrigated crops – soft fruit and vegetables. These crops drove the expansion of irrigation in the 1980s. Less well known is the increase in the use of irrigation to support what was previously the domain of dry land agriculture, particularly olives, with serious consequences for the environment.[204] Crops such as wheat, maize and sugar beet also draw on significant quantities of irrigation water in the Mediterranean, for example in the Ebro Basin.

Actions to address the issues:

The maximum yield per unit area of most crops depends on absence of water stress, i.e. maximum evapo-transpiration. This leads to low yield per unit water used. Increasing water use efficiency involves a degree of deficit irrigation – that means restricting water supply so that evapo-transpiration is constrained and yield per unit water used is increased. The yield per unit area decreases. Deficit irrigation can reduce water use to 60% of that required for maximum yield without reducing profit.[205]

The economic benefits of deficit irrigation depend on water pricing policy. Water for agriculture is widely under-priced[206] and even free or illegally abstracted in many situations.

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[203] Dickie, P. (2007). Desalination: option or distraction for a thirsty world. WWF

[204] Beaufoy, G. (2001). EU policies for olive farming. WWF.

Bellamy P.H., Loveland P.J., Bradley R.I., Lark R.M. & Kirk G.J.D. (2005) Carbon losses from all soils across England and Wales 1978-2003. Nature 437, 245-248.

[205] Ferres, E. and Soriano, M.A. 2006. Deficit irrigation for reducing agricultural water use. Journal of Experimental Botany 58 147-159.

[206] European Environment Agency (2009). Water resources in Europe – confronting water scarcity and droughts. Report No 2/2009.

Water abstracted for processing can be returned to the aquifer using artificial water recharge. The feasibility and success of this depends on the quality of the discharged waste water. It also depends on willingness of the processing sector to invest in water treatment so that used water can be safely returned to the aquifer.

In the past, the focus has been on the supply side with investment in reservoirs, for example in Spain. Actions now centre round the full implementation of the Water Framework Directive and the implementation of a user pays principle linked to the local scarcity of water. If enforced (not a given due to widespread illegal abstraction in some regions), this inevitably leads to either increased investment in water saving and recycling technology or constraints imposed on water use. Water pricing may put some water users in agriculture out of business and could lead to changes in processing.

Changes in food consumption are required to facilitate structural changes in the food cycle that reduce pressure on water supplies. Reversing the trend away from rain-fed systems to irrigated systems will require reconsideration of some recent demand patterns, for example olive oil, and the increased location of fresh produce production in the Mediterranean.

7.5.2 Fertiliser manufacture

The major impacts from fertiliser production are associated with nitrogen, phosphorus and potassium.

Nitrogen

78% of the atmosphere is comprises nitrogen and the nitrogen cycle is conservative so fundamental scarcity is not an issue. The issue is the energy required to convert the unreactive N2 to reactive forms of nitrogen that support plant growth – ammonium and nitrate.

The anthropogenic input of reactive nitrogen has been increased ten-fold since 1860 to more than 150 million tonnes, with two thirds (100 million tonnes) of this due to fertiliser manufacture.[207,208,209] About a further 32 million tonnes is added in the cultivation of legumes. Overall, the fixation of N in synthetic fertiliser equals the background natural fixation.

The main issue with the manufacture of nitrogen fertilisers is the consumption of energy, mostly as natural gas, for all synthetic nitrogen fertilisers. In addition there are emissions of nitrous oxide from the manufacture of nitric acid for the production of nitrate. [210]

Phosphorus

Phosphorus is abundant in the Earth's crust but concentrations that can be exploited for fertiliser are confined to 'rock phosphate'. Rock phosphate is the raw material used in the manufacture of most commercial phosphate fertilisers. Due to low plant availability of P in rock

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[207] Enquete Commission (1994). Protecting our green earth. Enquete Commission of the German Bundestag. Economica Verlag

[208] UNEP and WHRC 2007. Reactive nitrogen in the environment.

[209] Jenssen, T.K. and G. Kongshaug (2003) Energy consumption and greenhouse gas emissions in fertiliser production, Proceedings No. 509, International Fertiliser Society, York, UK, 28 pp

[210] Patyk A, Reinhardt G A. (1997). Dungemittel - Energie- und Stoffstrombilanzen. Braunschweig: Vieweg

phosphate, use of rock phosphate is largely confined to organic farming as an alternative to processed fertiliser P which is not permitted. Most commercial phosphate fertilisers are based on the production of phosphoric acid. Reactions with phosphoric acid produce a range of phosphorus fertilisers, some combined chemically with nitrogen delivering highly concentrated fertiliser products.

Estimates of available reserves of rock phosphate vary depending on assumptions about the accessibility of resources. There is consensus that current consumption gives us reserves that will be depleted in less than 1000 years.[211] Assuming today's technology and rates of use, the current economic reserves may be depleted in as little as 100 years. Even if technical change increases the life of the exploitable reserve, the decline of a finite reserve leads to price increases long before there is acute scarcity meaning that increasing phosphorus prices due to actual or anticipated scarcity may occur in the much nearer future.

In addition to scarcity, these rock phosphate reserves are concentrated in just a few places, notably north Africa, the USA and China. Depending on quality, rock phosphate contains toxic heavy metals, notably cadmium and uranium. Scarcity is likely to lead to the use of lower grade rock phosphate with higher metal concentrations leading to increases in the transfer of these metals to agricultural soils.

Potassium

Potassium fertiliser is based on potassium chloride, which is manufactured directly from mined potassium salts.[212] Such salts are plentiful and the production processes are similar in impact terms to other large-scale mining operations.

Impacts:

The major impacts of fertiliser manufacture are energy use in ammonium production, nitrous oxide emissions from nitric acid production, and depletion of rock phosphate reserves.

The fixation of dinitrogen[213] in air to reactive nitrogen in ammonia is an energy intensive process requiring large quantities of natural gas in particular. Nitrogen fertiliser manufacture, based mostly on natural gas as a source of hydrogen, accounts for 1.2% of global energy consumption and 94% of energy used in fertiliser production overall. Nitrogen fertiliser production also releases nitrous oxide where nitrate is produced. Use of energy is higher in urea production than ammonium nitrate production, but nitrous oxide emissions are lower.

Patyk and Reinhardt[214] provide detailed LCAs of fertiliser production for German agriculture and these data are generally representative of Europe. They estimated that nitrogen fertiliser used in Germany has a primary energy consumption of 49 MJ/kg N and a greenhouse gas emission of 7.5 kg CO2 eq./kg N. The data come from the 1990s and some improvement may have been made since then, but the general picture remains.

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[211] Syers JK, Johnston AE, Curtin D (2008) Efficiency of soil and fertiliser phosphorus: Reconciling changing concepts of soil phosphorus behaviour with agronomic information. FAO Fertiliser and Plant Nutrition Bulletin **18,** 108. (FAO: Rome).
[212] Garret, D. (1996): Potash: Deposits, processing, properties and uses. Chapman & Hall, London,
[213] Two atoms of nitrogen (as part of some other compound).
[214] Patyk A, Reinhardt G A. (1997). Dungemittel - Energie- und Stoffstrombilanzen. Braunschweig: Vieweg

The principle impact of phosphorus fertiliser manufacture is the use of a finite resource. The scarcity of the resource is debated and predictions of depletion rates vary depending on assumptions. It is sometimes assumed that the efficiency of phosphorus fertiliser use in agriculture is low because its use does not result in immediate concurrent increases in crop uptake. However, in the long term, the fertiliser phosphorus is efficiently used, especially where soil phosphorus reserves are not allowed to rise to high levels.

The manufacture of potassium fertiliser has low impacts and confined to the immediate impacts of mining, simple chemical processing, and transport.

Fertiliser manufacture is linked to all issues related to plant nutrient use. It is also strongly linked to the processing of post-consumer waste, particularly for phosphorus.

Actions to address the issues:

The manufacture of fertilisers is driven by demand, which in turn depends on agricultural activity and the efficiency of nutrient use. Within the nitrogen fertiliser manufacturing process, production systems are generally well optimised, particularly in Europe. Modern nitrogen fertiliser factories are approaching the theoretical minimum energy requirement. Alternatives to the use of natural gas to generate the required hydrogen include the use of renewable or nuclear electricity for hydrolysis. In the longer term, nitrogen fertiliser will be manufactured from such energy sources.

The obvious alternative to phosphorus fertiliser from rock phosphate is phosphorus from food and human waste streams thereby closing the phosphorus cycle. In addition, the efficiency of use of phosphorus from animal manures could be increased especially in areas with high animal populations.

With the exception of some Scandinavian countries, the focus of wastewater treatment is to reduce the nutrient related hazard of discharged water and sludge rather than to recover nutrient to conserve resources. There is a case for a systematic examination of Europe's wastewater treatment infrastructure and municipal waste treatment (e.g. incineration) in relation to the goal of using waste streams for phosphorus and nitrogen recovery.

Taking the longer term view, the recovery of phosphorus from the food cycle is essential to the sustainability of the food cycle. This raises a number of issues around the use of nutrients from waste stream, particularly sewage, linked to the contamination from heavy metals and persistent organic compounds. ´Technological innovation in waste treatment may overcome these constraints.

The major impact will be cost, especially if the risks associated with conventional sludge disposal on land are to be avoided.

7.5.3 Plant protection products

Plant protection products (PPP) are used to protect plants from pests, weeds and diseases. About 200,000 tonnes of PPP active ingredient is used in Europe each year (FAOSTAT). The trend in recent years is towards reductions in the total weight of active ingredient used, but many of these newer pesticides are more potent materials and so the total quantity required for a given effect is less. The major pre-farm issues centre round manufacture and registration/marketing.

Manufacture: The manufacturers of pesticides are either pharmaceutical companies or use manufacturing facilities that are similar in terms of emissions and safety. Most pesticides are carbon-based compounds and therefore fossil carbon such as oil and gas are the major raw material resources used. In addition, the processes are energy demanding. As a result, the depletion of fossil carbon reserves and the associated emission of CO_2 are the major impacts from manufacture.

The production of PPPs is estimated to consume 370 MJ/kg active ingredient.[215] This is equivalent in energy terms to about 8 kg of crude oil. The use of pesticides accounts for about 9% of primary energy inputs into arable crop production and about 3% of GHG emissions from crop production. Other impacts are in line with other manufacturing of this type. As PPP production is increasingly concentrated, it could be argued that manufacturing has become safer. This increased safety is due partly at least to the enforcement of the Seveso Directive which was prompted by an industrial accident in the PPP industry.

Regulation: In the European Union, no plant protection product can be used unless it has first been scientifically established that it has no harmful effects on consumers, farmers and local residents and passers-by, that it does not cause unacceptable effects on the environment, and that it is sufficiently effective in protecting the crop.

The regulation system is based around two European instruments which are the Regulation (EC) 1107/2009[216] is focused on the authorisation of active ingredients for inclusion in PPPs in Europe and Directive 2009/128/EC establishing a framework for the sustainable use of pesticides.[217] While Regulation 1107/2009 governs what active ingredients may be marketed, the actual sale of products containing these is subject to Member State approval. This governs the information on the pesticide label. The use-phase is the subject of Directive 2009/128/EC. This aims to reduce the risk linked to the use of pesticides, improving the quality and efficacy of pesticide application equipment, ensuring better training and education of users and developing integrated pest management schemes.

Impacts:

Economic: Without PPPs, the yield of many crops would be halved. The yield levels achieved in organic farms are generally indicative of those that would prevail without the use of PPPs. The current regulatory system costs about 200 million Euros per active ingredient approved in Europe.

Public health and environmental safety: The system specifies **strict criteria for approval** of substances to ensure a high level of protection for human and animal health and the environment.

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[215] Audsley, E., Stacey, K., Parsons, D.J. and Williams, A.G. (2009) Estimation of the greenhouse gas emissions from agricultural pesticide manufacture and use. A report to the Crop Protection Association. Cranfield University. https://dspace.lib.cranfield.ac.uk/bitstream/1826/3913/1/Estimation_of_the_greenhouse_gas_emissions_from_agricultural_pesticide_manufacture_and_use-2009.pdf

[216] Regulation (EC) No 1107/2009 concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414/EEC

[217] Directive 2009/128/EC establishing a framework for Community action to achieve the sustainable use of pesticides

Constraints: The current regulatory system represents a significant tightening of the approval process. In particular it provides that carcinogens, mutagens, endocrine disruptors, substances toxic for reproduction or which are very persistent will not be approved, unless exposure to humans is negligible. It also establishes a mechanism for the **substitution of more toxic pesticides** by safer (including non-chemical) alternatives.

This means that the previous system which was based around risk – i.e. hazard and exposure is replaced with a system that sets minimum standards on hazard. As a result, substances are removed from the market or not approved because of their hazard regardless of the risk arising from exposure. The result is the range of PPPs is increasingly restricted. It is predicted that many minor crops, for example carrots, onions, peas, lettuce and beans, will experience severe if not total yield failures due to losses of herbicides. A greater reliance on non-EU imports; fruit and vegetables will become more expensive or unavailable, affecting a move towards more healthy eating.[218]

Directive 2009/128/EC includes provision for promoting non-chemical control measures and supporting integrated pest management. The wording of the directive is not particularly specific and therefore not necessarily a driver for changes in farm practice. It can be expected that it will result in a general raising of awareness in Europe of good practice.

The availability of PPPs enables in some situations intensive and less diverse farming practices. It therefore affects rotations and crop choices. There is a close link with farm biodiversity. There is a strong link with the regulation of the sale of new cultivars.

Actions to address the issues :

The recently revised regulatory system is still relatively new, introduced only two years ago. It appears from the industry bodies that the system could severely restrict the range of plant protection options in some situations. There is no case at this stage for suggesting that the system needs further tightening.

In any case, the system envisages a process of continuous improvement based in principle on comparative risk assessment. This is laudable.

The regulatory system still addresses the efficacy of PPPs. PPPs must be proven to be effective against target organisms. This seems sensible at first sight, but it means that materials that are not lethal may not meet efficacy criteria. The result is the EU pesticide regulatory system hinders the introduction of environmentally benign and resource efficient products for biological control.[219] Such products are less lethal or non-lethal and therefore may not pass conventional efficacy tests. Testing can account for up to 50% of registration costs compared with 10% for agrochemicals. Furthermore, the low market value of biological control agents compared with conventional pesticides is hindering the development of biological control. Consequently, for example the UK regulatory authority has initiated a scheme to reduce regulatory and financial hurdles.[220]

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[218] Parliamentary Office of Science and Technology (2009) POSTNote Number 3336. Crop protection
[219] Ehlers, R-U. (2011) Regulation of biological control. Springer.
[220] www.pesticides.gov.uk/guidance/industries/pesticides/user-areas/biopesticides-home

For resource efficiency and reduced impacts, effective crop protection must be combined with reduced impacts on non-.target flora and fauna, increased in-field floral diversity, and reduced emissions of harmful substances to air and especially water. In the long term, the solution is the integration of measures using host plant resistance, biological control agents and the targeted use of synthetic pesticides. It remains to be seen if the new system will achieve this. In particular, the measures in the Sustainable Use Directive 2009/128 are rather weak.

7.5.4 Plant breeding

Plant breeding to provide improved crop cultivars is a key technology with implications for the resource efficiency and environmental impact of the food system. With the exception of food captured from the wild, the entire food system is based on the genetic resources in cultivated crop plants, including forage grasses and other forage plants. Breeding allows traits to be introduced that increase yield, increase resistance to diseases and pests, and increase the efficiency of the use of nutrients. Breeding can also improve quality and can increase the suitability of minority crops thereby increasing crop diversity.

The process of breeding and delivering new cultivars (varieties) into use involves three distinct stages: the generation of new variability within a species, the selection and multiplication of improved germplasm from this variability for desirable traits, and the registration and marketing of the new cultivar. The breeders' return on the investment in this demanding process depends largely on Plant Breeders Rights (PBR), which is a form of time-limited copyright on new cultivars. Holders of plant breeders' rights receive a fee when the new cultivar is sold or reproduced. This fee, which is a tiny proportion of the value of the crop grown, maintains the private breeding system.

The patenting of genes and gene sequences is a second mechanism for getting returns from the market. For the most part, this is only directly relevant to the seed market where recombinant DNA technology (GM) is used. It is however relevant to the whole market where patenting is used to protect genes or processes, rather than specific varieties.

Regulation of conventional plant breeding: PBRs are awarded by national authorities or by the European Community Plant Varieties Office (CVPO). To obtain rights, the variety must be shown to be Distinct from other varieties, Uniform in itself, and Stable through generations. This is established through DUS testing. In addition, varieties for food production are usually required to demonstrate Value for Cultivation and Use (VCU) in that the new variety represents progress over existing varieties.

Regulation of genetically modified crops, feeds and foods: Genetically modified organisms (GMOs) can be defined as organisms in which the genetic material (DNA) has been altered in a way that does not occur naturally. This means that the breeder uses GM technology to introduce variability into the species that is not present naturally in the species genome or is not possible to introduce by natural means of reproduction. GM technology opens opportunities to produce plants with new traits and also to breed these with greater precision than can be done with conventional breeding.

Because this is a break with the thousands of years' experience with conventionally bred crops, the introduction of GM crops is subject to special controls. These centre on the regulation of the release of the crops into the environment, i.e. their cultivation, and on the regulation of crop products for food and feed. The procedures for evaluation and authorisation of GM foods are laid down in Regulation (EC) No 1829/2003 on GM food and feed, which came into force in April 2004, and in Directive 2001/18/EC on the release of GMOs into the environment, which came into force in March 2001.

The **Directive 2001/18/EC for the deliberate release of genetically modified organisms into the environment** authorisation process includes an environmental risk assessment which comprises a very comprehensive set of tests of the potential effect of the widespread use of the trait on the environment.

The use of GM plant products for food or feed is governed by separate EU regulation (1829/2003)**.** This regulation covers foods that are GMOs as well as processed foods derived from a GMO (e.g. cornstarch) that are no longer organisms themselves. This regulation applies to food and feed and addresses health, safety, and labelling.

The authorisation process for release has consequences for the resource efficiency of the EU food system. In some respects, the GM risk assessment approach that has been used in for example the UK Farm-scale Evaluations (FSEs)[221] is a rare example of a systems approach to testing the introduction of a new technology. It examines the effects of the widespread adoption of the trait in question, beyond its immediate impact.

Impacts and their causes:

Impacts of regulating conventional plant breeding: The regulatory system outlined above is the foundation of PBRs and thus the economic viability of the plant breeding sector. PBRs are a relatively weak form of copyright – they apply only to the variety in question and not to new varieties bred from it. Consequently breeders find it difficult to get a return on investment in new traits, particularly for traits in in-bred crop such as wheat, relevant to the resource efficiency of the crop grown – e.g. disease and pest resistance or nutrient use efficiency. This gap is the cause of profound market failure in the investment in plant breeding for environmental benefits.[222]

The use of Value for Cultivation and Use (VCU) testing may add to the burden on testing and constrain the introduction of varieties that have traits important to the resource use efficiency but which do not perform well in these tests. VCU is essentially about the conventional commercial use of the variety and it is questionable if it should be the subject of a public regulation at all. In contrast, traits that may be of public interest such as nutrient use efficiency are not tested. However, farm industry groups favour support VCU testing as it provides a form of standard screening of new cultivars for traits of direct interest to farmers.

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[221] Defra. The Farm Scale Evaluations: webarchive.nationalarchives.gov.uk/20080306073937/www.defra.gov.uk/environment/gm/fse/

[222] Defra research report ST0158. The role of future public research investment in the genetic improvement of UK grown crops: sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=10412

Regulation of genetically modified crops, feeds and foods: Very few GM crops are grown in the EU. In effect, the regulatory system outlined has prevented GM technology making a significant impact (positive or negative) on the resource efficiency and environmental performance of the EU food system. The safety tests go well beyond those used in conventional crops. Until now, the effect of this on the food system has been minor as most of the traits (so-called first generation GM traits) at stake are input traits such as herbicide resistance. These traits have little overall effect on the resource efficiency of the crop although they can reduce pesticide inputs and thus related impacts.[223]

Actions to address the issues:

The harnessing of the power of plant breeding for resource efficiency is a neglected area. The privatisation of public breeding programmes in the 1990s in particular put plant breeding outside the public sphere.[224] There is a case for revitalising public-good plant breeding in Europe, perhaps through the research programme. There are examples of such research-based development in the UK.[225]

The regulation of GM crops and products is an extremely controversial area. A discussion on how to progress this to improve the resource efficiency of the EU food system is worthy of a study in of its own. The introduction of GM crops is likely to have internal benefits for farmers and external effects for the environment, but the net effect will vary on a case-by-case and regional basis.[226] Some significant on-farm benefits are reported but these would be out-weighted by off-farm costs associated with segregation under current EU regulations.

The benefits of public investment in plant breeding are widely regarded as positive. In financial terms returns on public investment are well in excess of public financial thresholds are expected, with returns in excess of 20% pa expected.[227]

7.5.5 Energy use

Energy use is a significant source of greenhouse gas emissions within the food cycle and leads to depletion of scarce mineral fuels (and to climate change). Reducing energy consumptions can improve resource efficiency.

The main uses are natural gas for fertiliser production, gas for heating greenhouses, diesel for mobile machinery and fuel for transport. Lang et al. (2009: p. 193) state that nitrogen fertiliser accounts for 37% of all energy used in USA agriculture. The European situation will not be far different.

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[223] R., Phipps, R., Strange, A. (2006) Potential environmental and human health impacts of growing genetically-modified herbicide-tolerant sugar beet. Journal of Environmental Planning and Management. 49(1): 59-74.

[224] Dale, P.J. Public-good plant breeding: what should be done next? Journal of Commercial Biotechnology (2004) 10, 199–208; doi:10.1057/palgrave.jcb.3040075

[225] The Defra Wheat Genetic Improvement Network. www.wgin.org.uk/

[226] Gómez-Barbero, M. and Rodríguez-Cerezo, E. (2006) Economic impact of dominant GM crops world-wide: a review. European Commission Joint Research Centre.

[227] Defra (2007) The rationale for Defra investment in R&D underpinning the genetic improvement of crops and animals: randd.defra.gov.uk/Document.aspx?Document=IF0101_6236_EXE.doc

Energy use is of great concern within fisheries, due to both associated environmental effects and the cost of fuel to fishermen.[228] LCAs of fisheries indicate that the production and use of diesel fuel while fishing accounts for more than half of the total impacts.[229]

However, there are cases (herring, mackerel and mussels) where the fuel use in the processing stage is more important, due to energy intensive packaging materials. Future scenarios indicate that energy consumption will remain one of the most important environmental aspects in the fishing stage. This is partly due to regulations banning anti-fouling biocides, which are used to remove biotic growth on ships (biotic growth on ships' hulls or fishing gear can reduce the fuel efficiency of the vessel due to increased drag). It is also due to the forecast increase in effort (and hence fuel consumed) required to maintain catches during a period of continued depletion of fish stocks.[230]

Fishing fuel efficiency and fishing effort are linked. Specific fuel use ranges from 20 l/tonne to about 3000 l/tonne of fish catch. In general, demersal and shellfish fisheries require large fuel inputs in relation to catch. Fishing accounts for about 1% of fuel oil use worldwide.[231]

<u>Actions to address the issues:</u>

- As discussed in section 7.5.2, nitrogen fertiliser production systems are generally well optimised in Europe; modern nitrogen fertiliser factories are approaching the theoretical minimum energy requirement. Alternatives to the use of natural gas to generate the required hydrogen include the use of renewable or nuclear electricity for hydrolysis.

- Regarding energy use for mobile equipment and greenhouse heating: energy use is already subject to optimisation measures to reduce costs; further reductions could be achieved from reduced tillage, use of CHP, and reduced greenhouse cropping.

- See section 7.4.14 for recommendations for actions transport, such as the Marco Polo initiative, aiming to reduce or avoid road transport by switching to the modes of rail, sea and inland waterways.

- Use of renewable energy sources to replace non-renewables.

- Reviewing scope of Ecodesign Preparatory Studies to identify whether other products associated with the food cycle can be brought within scope and reviewing existing Ecodesign Preparatory Studies and the resulting implementation policies to gauge the scope for these to be enhanced still further.

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[228] Erwin M. Schaua, Harald Ellingsen, Anders Endal, Svein Aa. Aanondsen (2009) Energy consumption in the Norwegian fisheries. Journal of Cleaner Production Volume 17, Issue 3, Pages 325–334: The Sustainability of Seafood Production and Consumption

[229] This is true in six of the seven impact categories analysed. Fisheries Research Volume 76, Issue 2, November 2005, Pages 174–186 Life cycle environmental impacts of Spanish tuna fisheries Almudena Hospidoa, Peter Tyedmersb, 1,

[230] Mikkel Thrane (2006) The International Journal of Life Cycle Assessment, Volume 11, Number 1, 66-74, LCA of Danish Fish Products. New methods and insights (9 pp)

[231] Tyedmers, P.H., Watson, R. and Pauly, Daniel (2005). Fuelling global fishing fleets. Ambio 34(8): 635-638.

- Bringing more equipment within scope of the EU Energy Label. The energy label has been in place for more than 10 years and caused a shift in the market leading to a review and the introduction of new categories (A+ to A+++).

- If product standards are enhanced there may be additional costs for manufacturing industry. Costs to those using the equipment would be reduced across the life cycle with improved energy efficiency equipment.

<u>Actions to address fisheries:</u>

On a macro level, fuel efficiency of fleet and capacity could be addressed, though this is not the top priority as gains are expected to be moderate. It is worth noting that marine fuel today is not taxed. The expected effects of an introduction of such a tax could be further investigated.

The perspective of existing fishery regulations could be broadened to increase the focus on fishing gear and energy in the primary production (fishing stage).[232]

Policy options may include further regulations regarding fishery management or the gear used. Scenario studies indicate that fisheries management decisions can influence energy demands. For example, for herring fishery, because of the five-fold lower fuel intensity of purse seining, relative to midwater trawling (21 l/ton versus 108-118 l/ton), a seasonal ban on midwater trawling has the potential to markedly reduce overall fuel use. [233]

Large reductions in fuel intensity[234] can be obtained by changing the type of fishing gear – particularly in flatfish fisheries. Trawls energy efficiency is greatly affected by the drag, as well as by the swept area regarding pelagic trawls and by the swept width for bottom trawls. There are examples of tools for automatic optimisation of the trawl design which show a 43% increase in energy efficiency regarding the pelagic trawl case and 27% for the bottom trawl one[235]. For coastal trawlers full-scale trials on trawl vessels show that potential increases in the net cash flow of up to 27% over a range of operational navigation and trawling speeds, partly due to reduced fuel consumption.[236]

A key feature of fishing is the increase in fuel use as stocks decline. Energy consumption increases as boats range further to hunt down depleted stocks. In most natural hunter–prey systems, the increased cost of predation reduces the intensity of predation allowing prey stocks to recover. In fisheries, however, stock depletion leads to higher fish prices, propped up by consumer preferences (e.g. for cod) sending a signal to hunters (i.e. fishers) to intensify hunting further. The overall effect of this is increased investment by fishers in power and fuel as stocks decline. The other side of this phenomenon is the expected benefits of the recovery of depleted stocks. The recovery of depleted stocks represents a rebuilding of the capital base of the system, the sustainable fish yield of which represents the interest earned. A reduction in

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[232] Mikkel Thrane (2006) The International Journal of Life Cycle Assessment, Volume 11, Number 1, 66-74, LCA of Danish Fish Products. New methods and insights (9 pp)
[233] John Driscoll, Peter Tyedmers (2010) Fuel use and greenhouse gas emission implications of fisheries management: the case of the new England Atlantic herring fishery Marine Policy Volume 34, Issue 3, Pages 353–359
[234] Fuel consumption per kg caught fish.
[235] Daniel Priour (2009) Numerical optimisation of trawls design to improve their energy efficiency, Fisheries Research Volume 98, Issues 1–3, Pages 40–50
[236] Joaquim Parente, Paulo Fonseca, Victor Henriques, Aida Campos (2008) Strategies for improving fuel efficiency in the Portuguese trawl fishery. Fisheries Research, Volume 93, Issues 1–2, 1 September 2008, Pages 117–124

fishing will allow stocks to recover to the point where a much reduced fishing effort will be sufficient to harvest the sustainable catch, thus generating multiple benefits. This reduced effort may comprise more operations with wider multifunctional social benefits such as inshore fishing.[237]

Previous barriers observed for the efficiency of the CFP is the great diversity of the sector along with a difficulties to obtain full compliance with rules and regulations (non-compliance problems) which may have been caused by a (feeling of, or actual) lack of involvement of stakeholders in the policy making process.[238] Other barriers include the price instability and low elasticity of the fishing industry and difficulties to obtain coherence in technical measures. Commission inspections have been used to obtain better compliance with existing regulations.

[237] Murphy-Bokern, D. (2010). Environmental impacts of the UK food economy with particular reference to WWF Priority Places and the North-east Atlantic. WWF UK.

[238] Ali El-Agraa,Brian Ardy The Common Fisheries Policy The European Union: Economics and Policies

7.6 Overview of influencing factors on resource use

Table 9 sets out the factors and processes influencing resource use which are assessed as being significant drivers of resource efficiency and/or environmental impacts (these do not cover specific emissions, as these are driven by the use of resources).

Table 9: Factors or processes influencing resource use across the food cycle

<table>
<tr><th rowspan="2">Food group</th><th rowspan="2">General</th><th colspan="10">Stage in food chain</th></tr>
<tr><th>Pre-production</th><th colspan="3">Primary production</th><th>Processing</th><th>Packaging</th><th>Storage and retail</th><th>Transport</th><th>Use/ maintenance</th><th>End of life</th></tr>
<tr><td>Crops</td><td rowspan="3">Energy
Water
Waste
Wastewater (sewage)
Scale of operations affects impacts</td><td rowspan="3">Water supply
Energy supply
Fertiliser production
Breeding technology</td><td rowspan="3">Management of production:
Choice of location of production: climate and local conditions
Yields
Intensive farming/ overfishing
Land use change</td><td colspan="2">Fertiliser management: application technique and dosage
Crop protection management: application technique and dosage
Management of water: particularly in water scarce areas
Soil management: (e.g. by-products left on field)
Energy management: Heating for greenhouses (i.e. for fruit and vegetables)</td><td rowspan="3">Energy management: refrigeration storage, lighting, heating
Water management
Waste generation: product losses (e.g. in batch processing)</td><td rowspan="3">Packaging design: Choice of material (e.g. plastic, metal); size or volume of packaging; reuse- and recycla-bility</td><td rowspan="3">Energy management: refrigeration, lighting, heating
Choice of refrigerants
Waste generation (product losses, e.g. stocking practice and sell-by/best-by dates)</td><td rowspan="3">Distribution: mode of transport, distance, how filled are the vehicles
Consumer: mode of transport, distance</td><td rowspan="3">Purchase and consumption: Catering and hospitality - serving sizes, menu choices; Household: diet, overconsumption, choice of food types (e.g. out-of-season)
Energy and water use: Storage and preparation – choice and use of equipment (e.g. size and energy efficiency of appliances)
Waste generation: Product losses during preparation and food waste(e.g. correct storage, serving sizes, sell-by/best-by dates)</td><td rowspan="3">Management of waste: Choice of waste management practices (e.g. composted, incinerated, landfill)
Management of wastewater: Choice of wastewater (sewage) treatment</td></tr>
<tr><td>Livestock</td><td>Rearing method: pastures, free range
Energy management: heating, lighting
Water management
Manure management</td><td rowspan="2">Feed selection: type, composition and source (i.e. for livestock and aquaculture)
Veterinary care: antibiotics, etc.</td></tr>
<tr><td>Fish</td><td>Wild: Fuel efficiency of fleet, by-catch management, fishing gear and practices
Aquaculture: effluent</td></tr>
</table>

Chapter 8: Environmental sustainability criteria

Sustainability criteria are requirements that, if met, indicate that a process, product or service respect the environment or other sustainability goals. The study focuses on environmental sustainability criteria. Such criteria can help policymakers to define environmental standards and targets, and to measure progress in meeting goals. In addition, they can assist producers and processors, through defining standards, and consumers and other purchasers, through provision of information and raising awareness, towards sustainable production and consumption.

8.1 Existing thresholds, targets and criteria

Thresholds, targets and criteria have been developed by various entities, as part of policy measures, or as part of other schemes (examples are provided in Table 10 and detailed background data on the environmental sustainability criteria is provided in Appendix C).

Table 10: Examples of existing environmental sustainability thresholds, targets and criteria

Entity	Specific criteria (thresholds, levels, targets)
GLOBAL LEVEL (thresholds and targets)	
Stockholm Resilience Centre (2009)	Planetary boundaries proposed for safe operating space: Nitrogen and phosphorus: Limit amount of N_2 removed from the atmosphere for human use to 35 million tonnes/year; Limit quantity of phosphorus flowing into the oceans to 11 millions of tonnes/year. Land system change: Limit percentage of global land cover converted to cropland to 15%
World Business Counci for Sustainable Development	According to Vision 2050 agenda, targets[239] for agriculture: 2 to 10% increase of highly efficient irrigation; producing the same yield with at least 50% less fertiliser; 80% of crops planted on unploughed land
lobal Footprint Network	World Ecological Footprint[240] (resource accounting tool): global footprint should not exceed ecological carrying capacity
EU LEVEL (mainly environmental sustainability policy and certification measures)	
EU Organic label	Organic label indicates that the product has been grown with restrictions to cultivation systems, such as banning of certain chemical inputs and banning of "landless" livestock rearing
EU Green Public Procurement	Requirement for public authorities to choose goods/services with lower impacts on the environment: criteria on aspects such as proportion of organic certified food purchased
EU biofuels criteria	Prohibiting use of certain land types from production. Biofuels must ensure at least 35% GHG savings; by 2017 - at least 50%; by 2018 - at least 60%

[239] Completed by "must haves" by 2020: Agriculture (Training of farmers, Freer & fairer trade, Yield gains, Water efficiency, More agri R&D, New crop varieties); Materials (Landfills phased out, Closed loop design, Value chain Innovation, Energy efficiency in production); People's values (Deeper local & environmental understanding, Incentives for behavior change); Mobility (Energy awareness, Tough energy-efficiency rules, Biofuels standards, Integrated transport solutions, Innovation with consumers)

[240] Mekonnen, M.M. and Hoekstra, A.Y. (2011) National water footprint accounts: the green, blue and grey water footprint of production and consumption, Value of Water Research Report Series No.50, UNESCO-IHE.

Entity	Specific criteria (thresholds, levels, targets)
NATIONAL LEVEL (Member States targets)	
Sweden	Climate certification for food based on requirements: requirement to calculate nitrogen balance of the farm; specifications on feed; minimum energy efficiency of greenhouses
France	Land use (organic farming): Switching 6% of farmland to organic farming by 2010, 15% by 2013 and 20% by 2020; doubling the number of hectares under pulses cultivation by 2020
Denmark	Land use (organic farming): A doubling of the organic farming area by 2020

Many initiatives pertaining to environmental sustainability cover several issues, but not always directed at main issues and not always covering issues in an effective way. Gaps remain in the coverage of criteria for a holistic approach to food sustainability – such as criteria addressing land use change. Relevant criteria have been applied to crops for biofuels production under EU regulation, hence could be considered for crops used for food. Some criteria within a certification scheme, for example, may be important, but others may not be relevant – i.e. to meet them, one must meet all of the criteria within the scheme, and they may not all be necessary for sustainability.

However, the difficulty in achieving them all in order to comply could be acting as a barrier to entry – e.g. as an example, one criteria for organic certification is that it must not use a 'landless' system for livestock: however, it may be necessary to retain certain aspects of intensive systems, such as landless systems, perhaps in order to supply sufficient quantities of food – but other criteria within organic certification may be crucial. Therefore the relevant criteria to address the main issues must be examined separately.

8.2 Implementing criteria

Types of criteria

In regards to the use of resources, four perspectives have been identified in the context of criteria setting for resource efficiency, which are useful to consider. These are:

- imitations to the resource base;
- limitations to absorption capacities of the earth's ecosystems;
- efficient and equitable resource supply for people; and
- efficient and equitable resource supply for economies.

In principle, environmental sustainability criteria should be determined by the planet's carrying capacity and thresholds.[241] Environmental Management Systems can have interesting terminology of relevance, such as that set out in ISO 14031 for various indicator types:

[241] BIO Intelligence Service, IEEP, IFF and Umweltbundesamt (2010) Preparatory study for the Review of the Thematic Strategy on the Sustainable Use of Natural Resources.

- Operational Performance Indicators (OPI) – flows of materials (e.g. consumption of energy)

- Management Performance Indicators (MPI) – management actions (e.g. number of employees trained in environmental management skills)

- Environmental Condition Indicators (ECI) – site conditions (e.g. waste water quality)

MPI may be unique to a firm and ECI are site specific. However, these can still be aggregated, for example by counting the number of sites that meet their targets.

Table 11 sets out a proposed categorisation for the environmental sustainability criteria.

Table 11: Categorisation of environmental sustainability criteria

Scale	Description	Target stakeholder(s)	Sources	Example indicators
Product	Criteria for specific food product characteristics	Retailers, caterers and consumers	Often based on certification schemes	-Organic -Water / carbon footprint
Process	Criteria for specific processes, such as input-based	Food and beverage (processing) industry	Standards, or other sources of best practice	-Energy consumption per kg output -Amount of food losses along the food chain
Organisation	Criteria at the farm, such as practice, or processing installation level	Farmers, fisheries, food and beverage (processing) industry	Standards, or other sources of best practice	-Farm nitrogen balance -Amount of wild-caught fish in fish feed
Macro	Used for tracking progress at EU / national / regional levels (scalable)	Policy-makers, NGOs, etc.	Policy and other global initiatives	-Gross Value Added (GVA), national nutrient balance -Level of nutrition education

The environmental sustainability criteria themselves are based around pre-defined maximum or minimum levels of indicator(s) (and/or qualification(s)), such as thresholds or minimum requirements.

Practice-based criteria prescribe or ban certain practices (e. g. *EU organic label* - indicating that the product has been grown with restrictions to cultivation systems, such as and banning of "landless" livestock rearing). *Input-based criteria* set limits on, or ban the use of, certain inputs (e.g. *EU biofuels criteria* - prohibiting use of certain land types from production; *EU organic label* - banning of certain chemical inputs). *Output-based criteria* assess the resource efficiency through productivity or environmental performance.

Existing environmental food labels mainly employ input- or practice-based criteria. The disadvantages of such criteria are that they can lead to a shift of environmental burdens when practices or ingredients are substituted, and can hamper innovation. Output-based criteria may be more economically efficient and provide a clearer link to environmentally positive results.[242]

[242] Sengstschmid, H., et al. (October 2011) EU Ecolabel for food and feed products – feasibility study. Available at: ec.europa.eu/environment/ecolabel/about_ecolabel/pdf/Ecolabel%20for%20food%20final%20report.pdf

Considerations when setting criteria

The stakeholder[243] to whom the criteria are addressed is an important consideration and the point in the "decision chain" at which the criteria is applied has significant effect on its potential impact. For example, in regards to the decision chain linked to meat consumption, the following sequential actions may take place:

- A consumer decides to increase their consumption of meat.
- There is a need to increase production to meet this demand, and may lead to a decision to intensify production.
- The decision to intensify production leads to a change in management practice (e.g. related to livestock manures or change in feed type).
- The change in management practice leads to a change in the environmental impacts at local level (due to increased emissions of manure and/or at the site of the production of the feed due to increased production of feed crops).

Sustainability criteria need to be measureable, and should allow the stakeholder at whom the criteria is aimed to act upon it – for example, regarding land management, at the local authority level an indicator such as urbanisation is relevant, whereas for a farmer the criteria might be based on proportion set-aside. Operability, feasibility and impact relate to both to the ability or motivation of the stakeholder to act on the criteria (e.g. consumer understanding of complex trade-offs when making food choices), and the strength of "enforcement" of the criteria (i.e. means through which it is implemented such as voluntary or mandatory policy measure).

A balance should be found between potential synergy and trade-offs of criteria. A number of criteria simultaneously can lead to improvements for some issues (synergies) or aggravation of others (trade-offs). For example, there are synergies between reduction in the demand for animal products or increased feed efficiency that would reduce nitrogen and greenhouse gas emissions, and benefit biodiversity and human health. On the other hand there is a potential trade-off between increased animal welfare and livestock productivity, as improving animal welfare may require more space or outdoor access. In turn, this may lead to higher feed demand per unit output and therefore increase environmental impact.

Implementing measures

Choice, technology, and the economy, for example, form part of the drivers for possible resource efficiency gains in the food cycle and can therefore be used to implement environmental sustainability criteria (i.e. labelling, best available technology solutions, pricing, etc.). The means to implement the environmental sustainability criteria vary from regulatory, to economic, to information tools. These can be implemented as either mandatory or voluntary measures. Mandatory measures could, for example, include bans on the use of certain type of

[243] For example: Member States, local authorities or other food cycle actor (farmer, fisherman, retailer, consumer, waste disposal, etc.)

fertilisers (using a regulatory tool), environmental taxation (using an economic tool), or the extension of the EU Ecolabel to the food, drinks and feed sector (using an information tool).

As the processes of implementation, administration and verification of compliance to criteria require significant resources (that may not be available in the EU and/or Member States), careful consideration on method of implementation is required. The costs of application may also be a burden for SMEs.

Voluntary policy measures are of important, as they can place responsibility on the industrial/commercial stakeholders and reduce regulatory burden. A recent analysis investigating the development of a climate certification label assessed the interaction between traditional economic and sustainability discourses during its development. It concluded that voluntary initiatives may struggle to change established views associated with the traditional economic discourse and hence lead to weak reforms, but that in the long-term they can help to mobilise actors, influence discourse, broadly facilitate change in practice, and ultimately may help to increase acceptance for stricter regulation[244]. Well-resourced communications campaigns would significantly benefit implementation of environmental sustainability criteria.

[244] Bonnedahl, K.J., and Eriksson, J., The role of discourse in the quest for low-carbon economic practices: A case of standard development in the food sector, European Management Journal (2010), doi:10.1016/j.emj.2010.10.008

Chapter 9: Improvement options and recommendations

There is a need to ensure a sustainable supply of food to the EU, decouple productivity from unsustainable use of resources and negative environmental impacts, and care for the ecosystems on which food production depends, in the context of increased global demand for food. A number of options for reducing certain negative effects simultaneously lead to improvements for other issues; however, some options may lead to the aggravation of others (trade-offs).

Table 12 describes improvement options, derived from the literature, to increase resource efficiency or reduce environmental impacts. Sections 9.1 and 9.2 summarise food cycle issues and improvement options or actions to address these.

Table 12: Improvement options for the stages of the food cycle

General	*Primary production*	*Processing*	*Packaging*	*Storage and retail*	*Transport*	*Use/maintenance*	*End of life*
-Improve processes -Best practices -New technology -Match supply and demand -Reduce, reuse, recycle -Avoid/ Substitute	- Finding alternative renewable sources[245], using catch[246] crops[247], and integrated pest management - Improving manure handling and livestock housing types[248] - Sustainable feeds - Minimising by-catch (selective trawl), use and waste of bait , less energy-intensive fishing gear[249] - Reduction of nutrient emissions from fish farming[250].	- Using less harmful cooling media and efficient equipment - Dry cleaning, maintenance of equipment, improved work systems, process controls[251]. - Less product losses optimising processing (reduced impact up to 30%)[252]	- Recycling /energy recovery[253] - Optimising pack material and weight (could half the life cycle energy use)	- Collaboration in an upstream /downstream chain of environmental responsibility, (timing optimisation, etc.)	- Internet shops, electric cars, optimizing transport chain - Ship freight instead of flights - Eating seasonal fruits/veg	- Consumer choice policy: Reducing meat intake and Mediterranean diet (reduces overall impact by about 8%[254]) - Stimulating proactive businesses, GPP incentives via healthcare or insurance systems - Reducing product losses in preparation/storage in household	- Segregation of outputs, also minimise waste water contamination. - Non product outputs may be used as animal feed - Anaerobic digestion[255] - Optimising supply chain , particularly for fresh produce

[245] Sanjuán N., Úbeda L., Clemente G. and A. Mulet (2005) LCA of integrated orange production in the Comunidad Valenciana (Spain) Int. J. Agricultural Resources Governance and Ecology, Vol. 4, No. 2, 2005 (Sanjuán_2005)
[246] Crop that stops nutrient leaching during non-growth season
[247] Claudine Basset-Mens, Hayo M.G. van der Werf (2005) Scenario-based environmental assessment of farming systems: the case of pig production in France. Agriculture, Ecosystems and Environment 105, 127–144
[248] Williams, A.G., Audsley, E. and Sandars, D.L. (2006). Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra. (Williams_2006)
[249] Ziegler F., Nilsson P., Mattson B. and Walther Y. (2002) Life Cycle Assessment of Frozen Cod Fillets Including Fishery-Specific Environmental Impacts, LCA Methodology with Case Study, Frozen Cod Fillets, Int. J LCA 2002 (OnlineFirst) (Ziegler_2002)
[250] Foster et al. (2006) Environmental impacts of food production and consumption: a report to the Department for Environment, Food and Rural Affairs. Manchester Business School. Defra, London (Foster_2006)
[251] European Commission (2006) Integrated Pollution Prevention and Control Reference Document on Best Available Techniques in the Food, Drink and Milk Industries.
[252] Defra (2008), Hospido A., M.T. Moreira, G. Feijoo (2003) Simplified life cycle assessment of galician milk production, International Dairy Journal 13 (2003) 783–796 (Hospido_2003)
[253] Berlin Johanna (2002) Environmental life cycle assessment (LCA) of Swedishsemi-hard cheese, International Dairy Journal 12 (2002) 939–953 (Berlin_2002)
[254] Cederberg and Magnus Stadig (2003) System Expansion and Allocation in Life Cycle Assessment of Milk and Beef Production, Int. J LCA 8 (6) 350 – 356.
[255] JRC-IPTS (2008), IMPRO Environmental Improvement potential of meat and dairy products

9.1 Improvements to address horizontal issues

9.1.1 Food waste

Issues description	Improvement options (actions)
At the **production stage**, high purchasing standards force waste in production.	Reduce/eliminate standards that are not related to food safety.
Waste from **processing** can have uses; if disposed it is a source of resource inefficiency.	Encourage the use of these wastes, highlighting opportunities for co-product uses such as animal feed or for energy using anaerobic digestion.
Waste at **distribution and retail stage** due to commercial sales practices .	Move away from a wide choice of foods available all the time and encourage consumers to react to supply. More flexible in-store pricing policies to sell surplus perishable stock.
High levels of waste in food services (**catering**). This links to all consumption related issues.	Reduce choice for late diners, reduce over-supply at buffets etc.
Consumer confusion on existing date labelling schemes leads to waste at **consumption stage.** Unstructured shopping practice can lead to a mismatch between planned meals and items purchased, increasing the probability of food being wasted.	Change date labelling schemes and use public information campaigns to improve understanding of date labelling. Education on use of leftovers. Home delivery of groceries and household meal planning can contribute to the avoidance of waste.

9.1.2 Food choices and diet

Sector	Issues description	Improvement options (actions)
Consumers	Lack of knowledge on portion sizes/ healthy diet/ reduced environmental impact. The consumption of resource intensive products (esp. meat) is higher than dietary guidelines. This links to all supply chain issues, especially primary production. A reduction would have profound effects through the food system. Despite this, public	Sustainable food and health agendas should be developed in parallel and integrated: a potential 'win-win' opportunity for the environment (reducing the GHG emissions) and for public health (improvements in cardiovascular health) by reducing intakes of meat and dairy products.[256] Shift to a healthier diet and a 50% reduction in the consumption of animal products would lead to an actual

[256] Dualine by INRA (2011) Setting the Table: Advice to Government on Priority Elements of Sustainable Diets

Sector	Issues description	Improvement options (actions)
	bodies responsible for health and food standards have scarcely addressed this in public information.	reduction in, or avoided expansion of total arable area of 45 million hectares and avoided expansion of grassland use outside the EU of around 60 million hectares.[257] Promote fish from sustainable stocks and aquaculture, as well as consumption of fish from a wider variety of species.
	The planning / mode of purchase (how people buy their food, e.g. subscription, local produce, etc.) has an impact. For example, the expectations of consumers to have all fresh foods available all the time everywhere increases waste. This links to all supply chain issues, especially primary production.	Discourage the purchase of fresh produce from out-of-season production. Integrating preparation and cooking of fresh produce reduces energy use
Catering (Restaurants / Canteens)	The **food options** for consumers are important. Menus may not be promoting a balanced and sustainable diet.	Green public procurement. Re-design of menus to promote more sustainable diets, such as a wider variety of fish species.
	Catering (esp. restaurants) is strongly focused on meat/fish based dishes. More sustainable menu choices can be proposed. This links to all consumption related issues.	Restaurants and canteens offering more food products that serve as alternatives to meat and fish and or smaller portions of animal products. Promotion of GPP: making the GPP criteria for Food and Catering services mandatory, or setting an EU-wide target.

9.1.3 Food chain equipment and the cool chain

Issues description	Improvement options (actions)
Storage, processing and cooking equipment can be inefficient (in terms of use of energy or water), as well as potentially being more costly to run compared to new equipment/technology. In addition, bad practice during use of equipment can lead to unnecessary and significant waste (of energy or water).	Increased plant /machinery efficiency. Reduced consumption of certain products – esp. from the cool chain. The **best practices** on optimal fridge temps, freezing options, processing method and cooking techniques could be promoted by public authorities to companies/catering professionals, emphasising the opportunities for reduced wastage and potential cost savings.
The cool chain (**chilling and refrigeration**) is a major cause of energy use and trace GHG emissions from the coolants. This links to retail activities and consumer preferences.	Reduce energy consumption of chilling and refrigeration equipment. Improvement options include improved insulation, lighting, compressors and high efficiency fan blades. Reduce consumption of products from cool chains, more fresh product consumption. Use of alternative, lower impact refrigerants. Reduce leakage of refrigerants.

[257] Westhoek, H. et al. (2011), The Protein Puzzle. The consumption and production of meat, dairy and fish in the EU, The Hague: PBL Netherlands Environmental Assessment Agency

9.1.4 Distribution / transport

Issues description	Improvement options (actions)
The choice of **mode of transport** for food distribution can have significant environmental impacts.	'Road to rail and inland waterways transport' food delivery shift has environmentally beneficial potential. Improve infrastructure.
Distance: The availability of products such as tropical fruits and fresh herbs (not locally produced) can lead to increased energy input during food delivery. In addition, the total transport use for household food shopping trips (car use) and distribution sector (especially air freight) is increasing.	In regards to "food miles", awareness-raising and life cycle impact quantification and labelling could help guide consumers to making sustainable choices. Provide alternative distribution systems (e.g. home deliveries) to reduce car driving. To attract consumers to such services, the quality and accessibility of delivery services could be strengthened, through a requirement for service providers to participate in an assurance scheme, or via provision of a publicly available delivery service, or requirement of free delivery services from retailers.
Poor planning for **logistics / not filling distribution vehicles** can lead to an inefficiency of resource use and higher impacts per unit of product transported.	Help to improve communications/sharing logistics best practice within retail supply chains and between distributors, for example to identify synergies/networks/backloads.

9.1.5 Research and innovation for sustainable food

Issues description	Improvement options (actions)
Lack of technological developments that support a sustainable food cycle	Support through funding, particularly aspects related to the production stage of the cycle such as: - Investment in plant breeding, which can provide traits that reduce resource use and impacts - Choice of crop and cropping sequence: varieties with better pest resistance may reduce inputs (pesticides). - Assessing potential resource efficiencies: e.g. crop cascade utilisation potentials, feed strategies, benefit of aquaculture products compared to other protein sources, nutrient and water recycling, and other sustainable management - Pilot projects: technologies to reduce by-catch and enable energy efficiencies (e.g. fishing gear, trawling methods, etc.)
Lack of consistent/harmonised measurement methodologies, for example one that would enable direct comparisons of environmental performance of products.	Cross-sectoral research initiatives to develop criteria to distinguish between sustainable and less sustainable food and drink products. Intensifying cooperation between policymakers and the statistical offices or research institutes responsible for producing resource efficiency indicators[258]. Communicate clear messages on sustainable food and monitor the progress.

[258] Several accounting methods (e.g. material flow accounting, NAMEA and environmentally extended input/ output analysis, lifecycle assessment, ecosystem capital) offer the potential to produce a coherent indicator package of this sort.

9.1.6 International

Issues description	Improvement options (actions)
Market barriers and inequalities: **Trade, food security and food prices** are interconnected. National subsidy systems influence trade patterns between developing and developed countries. Improving the access to markets, by subsidizing agricultural production may result in higher incomes and decreased food prices for low income earners. Prices of imported goods can have an impact on small-scale farmers with no market access as these are only sold in cities or where farmers have access to the market. Countries without subsidy payments can suffer disadvantages from free-trade agreements.	Connecting small-scale farmers with markets can be strengthened by contract farming, building co-ops or by the establishment of niche markets. Low price of agricultural commodities can improve food security for consumers in developing countries. Internalising externalities (to include costs of environmental damage and value of ecosystem services in prices) and better pricing of products to account for resource scarcity. Taking into account resources 'embedded' in global trade (i.e. resources indirectly utilized in the production of globally traded goods). EU could play an important role in defining strategic objectives, targets or provisions for setting targets at a later date, or discussion on aspirational targets on resource efficiency at global level.
Lack of proven/evidenced-based **environmental criteria** (including environmental footprint, standards and labels) that support/enhance broader sustainability objectives	Support for research to examine the trade-offs and synergies with other social and environmental goals, notably with animal welfare and biodiversity[259].
Lack of **international cooperation** (including international agreements) – actions to be initiated at the global level.	International agreements, such as Rio + 20 - The EU should set an example by developing an environmentally sustainable food cycle plus initiate actions to be taken at the global level.
Food insecurity and inequality of distribution as a barrier to **development** (including food aid)	Reducing food waste worldwide to increase food security

9.1.7 Biofuels

Issues description	Improvement options (actions)
The net-effects of **biofuels (BF)** on GHG emissions are highly disputed (net energy return is low due to processing to liquids, destruction of natural sinks, deforestation and prohibitively large carbon depths). BF are linked to all issues related to agricultural production and to food security and trade issues. BF production / demand can have strong effects on agriculture: competition for land. BF expansion can have the negative effects of intensive agriculture. It might also increase pressure on natural or semi-natural ecosystems, directly or by displacing food production. Price effects might lead to price surges in food commodities and affect food security.	Focus biofuels development on resources that do not compete with food production – wood from non-agricultural land and waste. Cascade utilization potentials should also be better explored. Link subsidies to GHG benefits and to invest equally in transport energy conservation and new transport systems. Reducing impacts of production requires methods of intensification which yield the benefits of high productivity and avoid detrimental impacts in order not to enhance area demand.

[259] Audsley, E., et al. (2009). How low can we go? An assessment of greenhouse gas emissions from the UK food system and the scope to reduce them by 2050. FCRN-WWF-UK.

9.2 Improvements to address food chain stages

9.2.1 End of life (waste management)

Aspect	Issues description	Improvement options (actions)
Wastewater	N and P recovery is rare. European **water treatment** uses denitrification reducing post-consumer N emissions. In the long term, recovery of P from human waste is essential to the sustainability of the food cycle. This issue links to nutrition of crops, greenhouse gas emissions.	Reactive nitrogen and phosphorus could be captured from waste water and used as a safe fertiliser using more advanced treatment.
	Loss of resources where sewage sludge is not used as a resource – problems with heavy metal and persistent organic compound contamination (soil contamination). This links to soil degradation, N and P cycle.	More systematic support for higher quality sludge – removal of heavy metals at source, removal of POPs
Solid waste	Management of organic materials (reuse of safe waste as feed, anaerobic digestion and composting) can be optimised. Organic waste streams are generally not effectively used – dominated by landfill and aerobic digestion (composting). Post-consumer waste feeding subject to strict controls, support of biogas from waste not adequate – lower than biogas from crops. This links to N and P cycle, energy.	Reduced demand for animal feeds, reduced landfill and landfill gas emissions, energy recovery, with recovery of N and P in biogas digestate.
	Reuse and recycling of packaging can be improved. Packaging waste increases with increased use of processed foods, read-to-eat meals etc. Landfill still dominant disposal route in some countries. This links to energy in processing and retail, consumer choices.	Reduced landfill, increased energy recovery, increased 'recycling' sector but with related transport and other costs.

9.2.2 Retail

Aspect	Issues description	Improvement options (actions)
Purchase (contractual production standards)	High private standards not connected to nutrition or safety cause increased waste – esp. in fresh produce.	Relax standards and/or offer optically lower grade produce
Product range and availability	Retailers' conditioning of consumers to expect all fresh produce to be available all the time increases waste.	Reduced consumption of fragile and out-of-season produced produce. Increase awareness of consumers of the consequences of their expectations. Increase emphasise on in-season produce, change offer and price to match seasonal availability. Using 'choice editing', removing endangered fish species from stores

Aspect	Issues description	Improvement options (actions)
		or food service operations.[260]
Packaging	Packaging is used not only to display the final product for sale and consumption, but used throughout the food cycle to transport raw materials, and in processing. This links to consumption, labelling, end of life, distribution/transport.	Further reductions in packaging weight (10%) is considered to be achievable (WRAP unpublished work). Full life cycle assessments should be identified where possible to find quantifiable examples of efficiencies in packaging products. Using retail transit packaging, or shelf ready packaging, can reduce material handling costs and use of raw material.
Labelling	Current **labelling** (best before, conserved until ('*haltbar bis')* not properly understood and may lead to unnecessary waste.	Change (or abolishing) of labelling can be considered.

9.2.3 Processing and manufacture

Aspect	Issues description	Improvement options (actions)
Water use	Processing of some commodities and manufacture of some foods and drinks requires large quantities of high quality water, esp. abattoirs and meat processing, vegetable processing, and drinks production.	Process optimisation, internal recycling, on-site waste water processing with return via the soil to the aquifer. Measuring/metering water use (benchmarking) and setting targets for water reduction (or the introduction of key performance indicators).
Energy use	**Energy use** is the source of the key impact: greenhouse gas emissions. Plant /machinery efficiency can be increased.	Reduced consumption of certain products – esp. from the cool chain will impact the food chain equipment and the cool chain.
Use of by-products	Food production creates **by-products**, with different high or low value uses including recovery. This links to waste, production, end of life.	If beverage by-products were increasingly used for AD and other alternatives, financial implications of sourcing alternative animal feed may be significant, with knock on impacts on land use. Producer responsibility for waste in the food industry could impose obligations on food 'producers' to report on their wastes and achieve prescribed levels of waste minimisation, recovery and recycling
Wastewater management	Waste water can carry significant nutrient loads. **Wastewater management** is important for processing, land-spreading and irrigation	Water use, N, P.

[260] Westhoek, H. et al. (2011), The Protein Puzzle. The consumption and production of meat, dairy and fish in the EU, The Hague: PBL Netherlands Environmental Assessment Agency

9.2.4 Production

Aspect	Issues description	Improvement options (actions)
Crop and forage production	Agriculture has a major impact on biodiversity, releases **nitrate, nitrous oxide** and **ammonia.** This links to water and energy use, phosphorus in animal manures and in waste water.	Improvement possible throughout the cycle from improved varieties to recovery of reactive nitrogen in waste water.
	All crops rely on **phosphorus** which is a limited resource. Phosphorus emissions, esp. from livestock, usually linked to nitrogen emissions, pollute water.	Improved recycling of phosphorus is essential to long-term sustainability. The first target is better use of manures through better distribution of the manure resource in relation to crop production. The second target is systematic recovery of phosphorus post consumption – from sewage.
	Soil management covers a diverse range of issues: erosion, contamination, loss of organic matter, compaction, salination, loss of agricultural and forest land to urban development. In farm practice, soil management is focused on crop residue management, tillage practices, grazing management. This links to crop nutrition, choice of crop and rotation, biodiversity, irrigation.	Improvement requires a broad range of measures. Reducing cultivation intensity to leave crop residue on the surface can protect soils from erosion but claimed benefits for soil organic matter are disputed. Leaving crop stubble and residue over-winter has the same effect and improves biodiversity. Improvement requires a broad range of measures, including halting the loss of top soil.
	Water use for irrigation is essential to increase production in water stressed environments, but water resources are depleting. This links to soil management, because more precise use of irrigation water reduces soil erosion and nutrient loss..	More precise irrigation (e.g. drip irrigation) produces more crop per drop.
	The main **energy uses** are gas for fertiliser production, heating of greenhouses and diesel for mobile machinery. This links to oil protection (tillage), consumption change.	Energy use can be a subject to further optimisation measures to reduce costs from reduced tillage, CHP, and reduced greenhouse cropping.
	Choice of crop species/varieties –The choice of crop strongly depends on consumption, markets (e.g. consumer preferences and price) and subsidies etc. Some products leave more options in the choice of crops than others: e.g. if fodder crops are demanded, many cultivars are possible. Specific varieties are required for many food crops. Related topics	More diverse crop cover improves farm biodiversity, reduces pesticide and fertiliser use. Certain plants with high soil nutrient depletion effects Nutrient enrichment (e.g. legumes) By-products can be used for feed or soil improvement (straw) Erosion protection-endangerment (soil degradation prevention)

Aspect	Issues description	Improvement options (actions)
	Monocultures vs. diversified cropping. **Rotation – cropping sequence.**[261] The cropping sequence (rotation) depends on the crop types and of the technology/availability of means of production, and on the choice of crops. Strongly depends on climate-soil conditions. *Related topic:* *+ Ratio primary crop – by-product* *+ soil fertility, fertiliser demand*	Water availability improvements (vegetation cover conserves soil moisture) Varieties with higher content of vitamins etc. can have favourable health effects. Varieties with better pest resistance may reduce inputs (pesticides) Crop rotations systems can also be optimized for carbon mitigation (reduced emissions from soil)
	Land use and land use change (LULUC) encompasses changes in land cover as well as changes in management. In Europe, cropland area is shrinking (stagnating in Western Europe), built-up land is expanding, forests are growing, grazing areas are declining in the long-term (decades) trend. For Europe, changes in intensity are the prevailing changes, much more pronounced quantitatively than land cover changes; large geographic variation in this trend is observable, as well as a slowing of the rate of intensification. Outside Europe, in particular in tropical regions, deforestation for commodity production, esp. soy, palm oil and beef, prevails. A considerable fraction of these commodities are consumed in Europe. Thus, Europe's consumption system can be regarded a driver of these changes. *Related sectors: food production and livestock.*	Land use change in Europe (in particular grassland to arable land) is a major source of C emissions. It is also a major cause of biodiversity loss. Overall, the return of the forests in Europe causes a large carbon sink. Globally, the forest area is declining. Deforestation causes more GHG emissions than carbon absorbed in re-growing forests (particularly in the northern hemisphere). Land use change is the most important driver for terrestrial habitat loss and thus pressures on biodiversity. Globally, agricultural intensification often leads to degradation of soil and vegetation (e.g. overgrazing, salination) Impacts in Europe: habitat loss, soil erosion, reduced water recharge (due to increased drainage). Global impacts: habitat loss, social consequences of land management change.
	Farmland biodiversity strongly depends on the land use pattern at the landscape scale: corridors, even when small, can potentially counteract diversity losses. Intensification of crop and forage production has reduced the value of farmland as a habitat and reduced feed supply in the farm ecosystem. Agriculture has a major impact on biodiversity by releasing nitrate, nitrous oxide and ammonia and pesticides. This links to PPP regulation and use, land use change, plant breeding.	This is the major underlying cause of decline in farmland as a habitat. It is driven by technology, especially PPPs, tillage enabling winter cropping, simple rotations, harvest technology – especially for forage. To remedy farm biodiversity loss, less intensive farming practices, habitat conservation/restoration, organic farming (pesticide-free) can be developed.
Livestock	**Feed production** – grass, forage crops and grain and oilseed crops has the greatest impact in the product lifecycle. A large proportion of EU arable land is devoted to livestock feed. This links to almost all other issues especially land	Reduced livestock production, more efficient feeding, more precise nutrition, greater use of co-products.

[261] BIO Intelligence Service (2010) Environmental Impacts of Different Crop Rotations in the European Union. Available at: ec.europa.eu/environment/agriculture/pdf/BIO_crop_rotations%20final%20report_rev%20executive%20summary_.pdf

Aspect	Issues description	Improvement options (actions)
	use change, nutrients, biodiversity loss.	
	Manure management is important. More than 80% nitrogen and phosphorus (usually more than 90%)[262] consumed by the animal is excreted representing an important resource and posing a major risk to air and water. This links to P and N, feed production, crop rotation, animal welfare.	Reduced local/regional concentration of livestock production and/or advanced manure processing.
	Animal welfare legislation is a major consideration in livestock technologies. This links to N, P, land use change, biodiversity, soil erosion.	The impact of animal welfare measures on resource use and emissions is overall relatively small, but specific measures can be positive or negative.
Fishing	**Fisheries management** (controlling catches, e.g. quotas)	Reduce consumption of marine fish.
	Use of certain types of **fishing gear** is environmentally damaging.	Promote/enforce development/use of technologies that reduce environmental damage.
	The fish **by-catch** can sometimes be used for feed/food but is often wasted, which can also be seen as a resource use inefficiency.	Reducing by-catch could be a priority, and better use should be made of that which remains (e.g. as feed). Options to reduce wasteful discarding include improved technology, e.g. better fishing gear, different trawling methods, selective gear, area closures, discard bans and data enhancement. Better monitoring, reporting and standards could be a means to reduce by catch of seabirds in fisheries. Best practice guidance could be disseminated. Demand side measures include giving value to by-catch to reduce wasteful discarding
	Biodiversity loss/ loss of ecosystem services	Promote fishing of a wider variety of fish species and sustainable fish catches.
	Fishing **fuel efficiency**[263] and fishing effort are linked. Demersal and shellfish fisheries require large fuel inputs in relation to catch. Fishing accounts for about 1% of fuel oil use worldwide. Specific fuel use ranges from 20 l/tonne to about 3000 l/tonne. This links to biodiversity loss.	Stock recovery allows more efficient fishing creating a virtuous circle – provided fishing intensity is controlled. Allow stocks to recover, reduce capacity, remove tax exemption.
Aquaculture	**Feed** production is the major impact in the life cycle of aquaculture fish production. Industrial fishing has profound implications for marine ecosystems. This links to fisheries management	Move to herbivorous species, plant breeding (GM) for plant oils that reduce the need for fish in feeds.
	Farming methods (incl. stocking density)	Reduce consumption of farmed fish fed on feed produced from other fish

[262] Galloway, J.; Dentener, F., Burke, M., Dumont, E.; Bouwman, A.F.; Kohn, R A.; Mooney, A., Seitzinger, S., Kroeze, C., 2010 The impact of animal production systems on the nitrogen cycle. In: Steinfeld, H; Mooney, H., Schneider, F., Neville, L., (eds.) Livestock in a Changing Landscape. Volume 1. Drivers, Consequences and Responses. Washington, USA, Island Press, 83-95, 13pp.
[263] Tyedmers, P.H., Watson, R. and Pauly, Daniel (2005). Fuelling global fishing fleets. Ambio 34(8): 635-638.

Aspect	Issues description	Improvement options (actions)
		species (e.g. salmon, trout, bass).
	Antibiotics, chemicals	Closed systems, improved hygiene, fish breeding, and use of biological control approaches.
	Effluent/wastewater management can be improved. Closed recycling systems allow recovery of nitrogen and especially P. This links to animal welfare, animal health products, feed.	Closed recycling systems are more efficient but require more energy inputs.
Farming system	Farm businesses vary hugely due to the range of production factors available. However, **farm businesses** are often categorised according to the approach to production taken: organic, conventional, 'conservation farming', mixed (both crops and animals). The approach to production provides the framework for the individual practices that use resources and determine impacts. Conventional farm businesses seek economic optimal use of resources and output constrained by legal requirements and regulations governing support payments. Organic farms exclude certain technologies and constrain production. Mixed farms use a combination of plant and animal based resources (particularly to recycle nutrients and support more diverse rotations) to optimise economic returns. Many 'conventional' farms are mixed in some way. Most 'organic' farms mix crop and livestock production. Some conventional farms are members of schemes that certify that they operate to legal standards (e.g. the 'Red Tractor' scheme). So-called 'Integrated Farm Management' uses special auditing measures to ensure compliance of conventional farms with legal standards and to document production processes. Farms using 'conservation management' are conventional farms with some additional resource protection measures that are compatible with economic optimal production, especially for biodiversity.	What matters is not the brand the farm business might have on the entrance sign (e.g. 'Bioland', 'IFM', etc.) but the practices and interactions between the practices that the farm uses. Some advocates of farming system brands suggest that 'conventional' production is based on maximum inputs and fixed production blueprints in which case any alternative is an improvement. This is misleading as very few farm businesses operate in this way. 'Organic' is the only branded farming system which requires use of methods that deviate significantly from 'conventional' (i.e. economically optimised) methods. This is due to the effects of withdrawal of key technologies – esp. synthetic fertilisers and pesticides, some animal welfare related measures, and a forced link to the land resource base in livestock production. Farm system improvements can be achieved through the use of key inputs and practices. Integrating resource flows between crop and animal production has the greatest potential. Depending on the situation, this requires change at all scales – for example, from methods used by farmers 'on-field' to European-level policy and infrastructure.

9.2.5 Pre-production

Aspect	Issues description	Improvement options (actions)
Water supply	**Water abstraction and desalination** are associated with reducing reserves locally (including for processing), energy consumption (desalination).	Water recycling and use of waste water from processing for aquifer recharge (feasibility and success of this depends on the quality of the discharged waste water and willingness of the processing sector to invest in water treatment), more precise irrigation, pricing of water, reduced consumption of water-demanding crops
Energy supply	In addition to energy efficiency gains in the cycle, sustainability of supply should be improved.	*Not within scope of study*
Fertilisers (manufacture of inorganic)	Safe and efficient **manufacture of fertilisers**, esp. nitrogen. Sourcing of phosphorus fertilisers with increasing risks of heavy metal contamination. The issue reflects the long-term challenge to sustainability of phosphorus supply – its use cannot be addressed at the mining stage	Nitrogen fertilisers are now manufactured efficiently and can be manufactured from alternative energy sources (renewable or nuclear electricity for hydrolysis). Alternative to phosphorus fertiliser from rock phosphate is phosphorus from food and human waste streams thereby closing the phosphorus cycle. In addition, the efficiency of use of phosphorus from animal manures could be increased, especially in areas with high animal populations. Plant breeding can be used to reduce the soil P levels needed for high yields.
Plant protection products	Safe production, storage and marketing are important. Production has local impacts. Consumption of energy and fossil resources is lower than commonly claimed in popular debate.	While PPP manufacture has been the cause of major incidents in the past (e.g. Bhopal, Seveso), recent legislation has reduced risks (including the Seveso Directive)
Plant breeding: Registration of cultivars on the common catalogue, regulations controlling the introduction of GMOs.	Crop breeding and seed production does not pose special risks. The regulation of new crop cultivars has implications for the use of crop genetic improvement to reduce impacts. The regulation of GMOs (herbicide tolerant crops) in Europe based on system-level environmental impacts is one of the few examples of regulation based on the systems level impacts.	Investment in plant breeding can provide traits that reduce resource use and impacts. GMOs have in the medium term the potential to reduce resource use and impacts

9.3 Recommended actions

When considering improvement potentials, system-level innovation could provide the greatest benefits, as shown in Figure 19; Figure 20 presents examples of system level approaches.

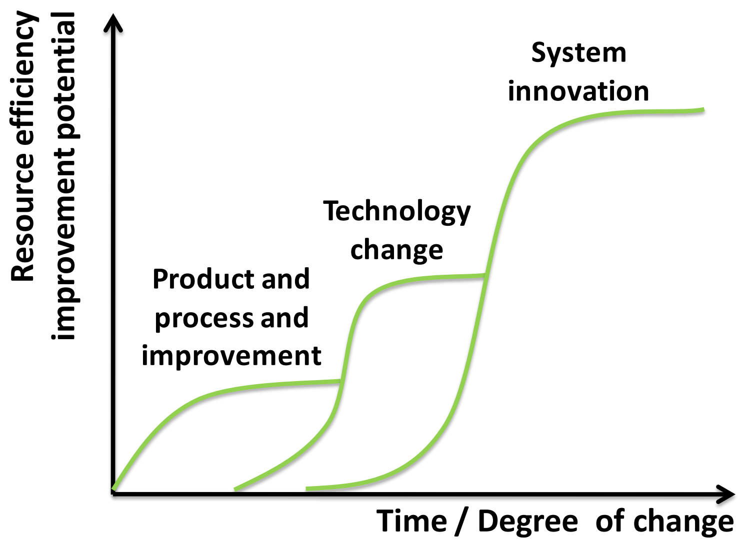

Figure 19: Resource efficiency improvement potential at different levels

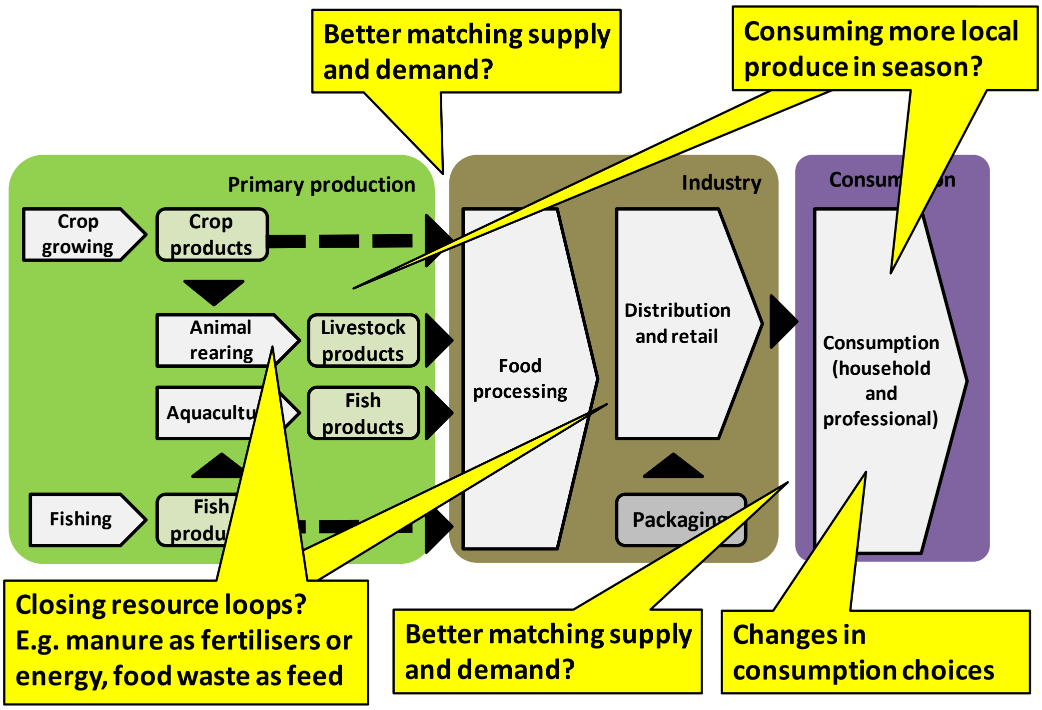

Figure 20: Resource efficiency options at the system level

It is important to note that there are many potential points of intervention at which negative effects of different stages of the food cycle on the environment, resource efficiency and human health could be addressed, as several problems are interlinked.

Priority options for improving resource efficiency include:

- **Reducing waste and closing resource loops** (though better or new management structures)**:** Reduce nutrient loss and GHG emissions, and increase supply security as wastes become a resource as fertilisers or energy.

- **Diets and food choices:** Define a human diet which is both healthy and sustainable. **Reduction meat and dairy intake** is an option to consider. However, risks of economic responses with unintended consequences may exist – for example a reduction in EU production of ruminant products may cause increased production at sources where active land use change (i.e. deforestation) occurs. **Consumer awareness and food marketing** affect behaviours and choices.

- **Nutrient cycles and agricultural practices:** Actions to enable cycling of nutrients and more sustainable agricultural practices, both in terms of macro level aspects such as land use choices, and organisation level practices such as crop rotations, use of chemicals, irrigation, species or crop choices can reduce impacts such as biodiversity and nutrient loss.

- **Fisheries:** Reduction of catch through maximising use of 'by-catch', stricter limits to fishing efforts and extension of (or development of new) aquaculture systems to reduce demand on wild catch.

In addition, the continuation of optimization of **industrial processes** (technical or managerial), innovation and decarbonisation is important.

Chapter 10: Policy options

The analysis of the **existing EU policy framework** (in Chapter 7) highlighted a number of deficiencies and areas where policy response is needed. It showed that it **lacks a systemic approach to resource efficiency in the food cycle**. The challenge for policy makers is to move from or complement a focus on specific products and processes, with measures that impact on the system as a whole.

Protecting public goods and resources requires an integrated consideration and appraisal of the food cycle, and particular consideration of the role of consumption in contributing to the sustainable development of food and agricultural systems. From environmental and resource use perspective, diet is now generally similar across the Europe. Meat consumption has grown in most EU countries with dramatic changes in countries with a tradition of moderate use of livestock products (especially in the Mediterranean countries) without any significant policy intervention or response.

Overall, current policies mainly relate to farm production, covering different aspects of resource use and other issues such as water, air and soil, plant protection products, animal welfare, farm assurance schemes and agricultural policy. **This chapter presents policy options that can achieve resource efficiencies and reductions across the food cycle.** As the significant proportion of environmental impacts occur across production and processing stages, improvements at the end of life and consumption stages have high potential. Policies targeted at the latter stages of the food cycle, i.e. retail (retail purchasing) and consumption (catering and consumer purchase), may lead to greater benefit to environmental sustainability of the food cycle and are therefore discussed toward the beginning of this chapter, starting from section 10.2.

10.1 Policy tools

Available policy tools include **information tools** such as awareness-raising campaigns and product labelling, **regulatory tools** to ensure provision of infrastructure for nutrient, food waste and packaging collection and recycling, and **economic tools** such as taxes to incentivise particular behaviours. Soft tools or approaches can be used to work directly with key actors and can pave way for change in mainstream policy later (e.g. nudge through encouragement or incentives). **Overall policy coherence** when designing and implementing policy is critical.

Establishment of **voluntary agreements** such as sectoral roadmap to engage the relevant sectors is recommended, to specify the role of each actor and promote collaboration and integration. Engagement of a wide range of organisations, including retailers, food manufacturers, local authorities and community groups is needed as they communicate with consumers through various initiatives (including local public relations, road shows, cookery demonstrations and recipe competitions). Such agreements could for example include a commitment by **retailers** to abandon quantity based marketing strategies, such as buy-one-get-one-free offers on perishable products[264] and to promote low-impact food in general and/or in-season produce. **Food service establishments** also have a role to play in educating consumers on understanding of food and could enlarge their choice on more sustainable menu, as well as offering options to reduce meat and fish consumption. Initiatives around **packaging** can contribute to minimising food waste through the supply chain by adding the new functionality to reclose a pack or portion food easily. **Industry bodies** can develop 'sector guides', giving product level guidance on date marks, storage, usage and freezing guidance (e.g. Dairy UK).[265]

Setting **environmental sustainability criteria** for EU (i.e. "measure to manage") taking into account the global context could help to provide a clearer understanding of food sustainability. As there is difficulty in evaluating benchmarks for production[266], a mandate for harmonised measurement of data and quantification of impacts may be necessary as a first step. Applications to consider include:

- Environmental sustainability standards and certification schemes for supply chains, and through these, implementation of practice-based criteria, ensuring adherence to "best practice", e.g. N balances to be calculated at the farm level, or regulating the type of feed used.

- Setting limits to resource use at specific stages of the life cycle - especially for livestock (where husbandry methods allow decoupling from the resource base).

10.2 Consumption

Shifts in consumer choices, present significant opportunities to improve resource use efficiency in the food cycle and reduce environmental impacts. These changes in consumption also align with public health goals. Existing initiatives have already prioritised areas for intervention[267] and the EU should set out an action plan to address long-term food-related behaviour change. This could go through schools and agreements with the business community. However, it is notable that earlier national initiatives from other countries for a healthy and eco-friendly diet have met opposition from commercial interests.[268]

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[264] Copenhagen Resource Institute et al (2011), Potential policies to promote SCP via the food retail sector in Nordic Countries

[265] Quested, T. E., Parry, A. D., Easteal S. and Swannell R. (2011), op. cit.

[266] Lack of disaggregated impact data past sector level prevents using "top-down" data to set criteria. From a "bottom-up" perspective, valid results for setting criteria at each food cycle stage are also difficult to obtain; for example, because of feedbacks and non-linearities in the food system, a simple up-scaling of results from LCAs or simple extrapolation ('crop yields plus 10% means land area minus 10%') would not yield valid results.

[267] The UK Sustainable Development Commission for example has prioritised excessive consumption of meat, dairy products and food and drink of low nutritional value, and waste reduction.

[268] Health Council of the Netherlands (2011) Guidelines for a healthy diet: the ecological perspective. The Hague: Health Council of the Netherlands; publication no. 2011/08E.

Possible interventions by government on food choice may include taxes, subsidies, regulation of claims, labels, influence on the availability of foods and awareness raising.[269] A combination of measures should be taken to address the consumption stage with its related issues (knowledge on portion sizes, healthy diet, and/or reduced environmental impact food choices, food waste, mode of purchase, catering menu options) including **changing dietary patterns** and **improving consumer knowledge** through the provision of information on food labels and education (*e.g.* cooking and meal planning). Awareness on food sustainability and the environmental impact of food as well as of existing labelling schemes related to this is surprisingly limited and should be raised.[270] **Changing the food supply** (*e.g.* "choice editing") can also be a route to changing food choices, discussed in section 10.3).

However, it should be noted that shifts in consumption are likely to be slow cultural processes, which require concerted and committed actions over long timescales.[271] Giving clear guidance to consumers on the issue of 'what is a healthy sustainable diet?' is still complicated by the absence of the answer to that question. It is a complex and multifaceted issue and requires a whole system and evidence-based approach to resolve.[272]

The nature and scale of the wider environmental effects of in-season produce may depend on what (if anything) consumers buy instead of foods no longer available. The issue of product substitution needs to be taken into account. Environmental costs and benefits of an increase in seasonal consumption would have to be assessed on a case-by-case basis and take account of other variables.

10.2.1 Awareness-raising and education campaigns

Targeted information campaigns on the lifecycle environmental impacts of different food and drink products should be increased. Although a number of information, education, and training initiatives are already underway at EU, national and local level, to date, their limited effect in terms of influencing long-term consumption patterns among target groups should be strengthened though drawing on several good practice examples. Resources to support such consumer education, like those specifically designed for teachers and students to use in schools, can be taken from a variety of channels, including television programmes, magazine articles and websites (British Nutrition Foundation's website, etc.) at different national levels. In relations to this, many public initiatives on raising awareness (Change4Life, WRAP's Love Food Hate Waste campaign, etc.) are already underway. Education campaigns such as the provision of general information in schools have reasonable cost (between €90,000 and €180,000 based on the

[269] UK Government Office of Science (2010) Foresight Project on Global food and Farming Futures C8: Changing consumption patterns

[270] Sue Davies (2011), Making sustainable choices easier, British Nutrition Foundation Nutrition Bulletin, 36, 454–459; Riley, H. and Buttriss, J. L. (2011), A UK public health perspective: what is a healthy sustainable diet?, British Nutrition Foundation Nutrition Bulletin, 36, 426–431; Audsley, E., et al. (2009) How low can we go? An assessment of greenhouse gas emissions from the UK food system and the scope to reduce them by 2050.

[271] GO-Science (Government Office for Science) (2011) Foresight. The Future of Food and Farming: Challenges and Choices for Global Sustainability. Final Project Report. GO-Science: London; Audsley, E., Brander, M., Chatterton, J., Murphy-Bokern, D., Webster, C., and Williams, A. (2009), op. cit.

[272] Riley, H. and Buttriss, J. L. (2011), op. cit.

website and network costs of the Green Spider Network). With **low awareness on how much food waste is generated in the home**, more information is also needed to *develop consumers' understanding of the generation of food waste in the home* (with its main elements: practices in the kitchen and while shopping; types of food purchased, their packaging and how they are sold) and associated environmental impacts. The subsequent monitoring of progress on reducing household food waste should be put in place.[273]

More specifically on reducing food waste in homes, the policy can focus on educating consumers about proper storage of foods and developing people's food preparation skills from school age with a help of health professionals and teachers (among others)[274].

Increasing environmental awareness on potential households improvements such as home deliveries of groceries and household meal planning can also contribute to the avoidance of waste as these require a more structured shopping behaviour, as in Internet-shopping, and facilitate the correspondence between planned meals and items purchased, and should be supported by appropriate tools and regulations.[275]

Good practice example: the Love Food Hate Waste campaign in the UK[276] aims to stimulate behaviours that are conscious of the environmental impacts and the annual cost to households of food waste, while providing practical advice on shopping and meal planning, food storage, portion sizing and recipes for making the most out of leftovers. Nationally, since the Love Food Hate Waste campaign launched, 2 million homes have changed their food consumption habits, saving £400 million, and WRAP estimates that 137,000 tonnes of food waste have been prevented. Similar initiatives exist in France[277], Ireland[278] and Denmark.[279] Based on the WRAP Love Food Hate Waste campaign, the cost is estimated at €0.04 per inhabitant and total cost for an EU27 campaign (at local, national and EU levels) approximately € 20 million.[274]

Sustainable food and health agendas also need to be developed in parallel and integrated. Many Member States provide national dietary advice, these could be revised to provide coherent guidance across the EU, highlighting the potential of a healthy diet to reduce environmental impacts. This would avoid conflicting messages and encouraging more sustainable choices.

There is a potential 'win-win' opportunity for the environment (reducing the GHG emissions associated with food and agriculture through a reduction in livestock production) and for public health (improvements in cardiovascular health) by reducing intake of meat and dairy products. The simple message that 'sustainable' diets, in general, are healthier may serve as convincing point for consumers to shift to the food with reduced environmental impact.[280] This guidance

[273] Quested, T. E., Parry, A. D., Easteal S. and Swannell R. (2011), op. cit.

[274] BIO Intelligence Service, Umweltbundesamt, AEA, (2010), Preparatory study on food waste across EU-27, Contract No: 07.0307/2009/540024/SER/G4, Final Report, October 2010

[275] Weidema, B. P., Wesnæs, M., Hermansen, J., Kristensen, T., Halber, N., (August 2008), op. cit.

[276] www.wasteawarelovefood.org.uk/

[277] Réduisons Nos Déchets: French national campaign for waste prevention uses communication channels such as online and radio to disseminate tips for waste reduction, notably food waste reduction, and provides estimates of possible waste avoided by each action. For example, by buying food by the slice or in bulk, each person can reduce their waste by 2 kg per year. The campaign's goal is to reduce waste produced per person annually by 390kg.

[278] www.stopfoodwaste.ie

[279] www.stopspildafmad.dk

[280] Westhoek, H. et al. (2011), The Protein Puzzle. The consumption and production of meat, dairy and fish in the EU, The Hague: PBL Netherlands Environmental Assessment Agency

would also tie into food labelling and there is potential to substantially clarify the assortment of food product information currently in use.

Good practice example: the Food 4U video competition funded by the Italian Ministry for Agriculture, Food and Forestry Policies, with the objective of raising awareness among European adolescents about the importance of healthy and balanced food choices and lifestyle. The competition is targeted at adolescents between the ages of 14 and 19, which is a strategic age range, as young people are increasingly buying their own food, but have an influence on their families' food choices. The 2011 edition is open to students and teachers of secondary schools in all 27 Member States of the EU.

10.2.2 Product labelling

For sustainable food choices, more information on how to deal with different trade-offs (e.g. buying local vs. supporting Fairtrade) may be necessary.[281] The option of the extension of the EU Ecolabel to food, feed and drink products has been explored; issues include the expected consumer confusion of an EU Ecolabel with organic labels and that the costs of application may be particularly burdensome for SMEs (given that the process of multi-criteria assessment and verification is likely to be resource intensive).[282]

A clear definition of "produced in season" is needed to communicate simple message to consumers on the benefits of foods produced in season. For example: "*Outdoor crops grown or produced during the natural growing/production period for the country or region where it is produced*" or "*Crop protection methods that do not use heat generated from fossil fuel; that minimise transport and do not use air freight; and that minimise chilled or frozen storage*".[283] Development of such a definition might be best established through a voluntary initiative between producers and retailers.

For date labelling, *improving consumer understanding and use of 'use by' and 'best before' date marks* can be strengthened by *removing 'display until' dates* (leading to perfectly good food being thrown away).[284] Harmonisation of date labels with the Food Information Regulation can help to improve clarification and understanding and encourage consumers to use their own judgement (visual, olfactory and taste) to reduce the amount of food waste generated.[285]

Packaging should inform the consumer on its recyclability at the end of the product's life to promote and engage behavioural change.

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[281] Riley, H. and Buttriss, J. L. (2011), op. cit.
[282] Sengstschmid, H., Sprong, N., Schmid O., Stockebrand N., Stolz, H., Spiller A. (October 2011), EU Ecolabel for food and feed products – feasibility study, Oakdene Hollins
[283] Brooks, M., Foster, C., Holmes M. and Wiltshire J. (2011), Does consuming seasonal foods benefit the environment? Insights from recent research, University of Plymouth, SERIO, Plymouth, UK; British Nutrition Foundation Nutrition Bulletin, 36, 449–453
[284] Quested, T. E., Parry, A. D., Easteal S. and Swannell R. (2011), op. cit.
[285] Bio Intelligence Service, Umweltbundesamt, AEA, (2010), Preparatory study on food waste across EU-27, Contract No: 07.0307/2009/540024/SER/G4, Final Report, October 2010: ec.europa.eu/environment/eussd/pdf/bio_foodwaste_report.pdf

For nutritional labelling, *wide-spread use of the schemes including traffic lights*, which explain how the levels in a food relate to guideline daily amounts is proposed.[286]

The multiplicity of labelling schemes has led to issues relating to incoherence, reliability, and information overload. To help consumers to make easier choices that are healthy and sustainable (or low impact), labelling schemes should be: *streamlined* (one universal symbol); *user-friendly* (standard thing on every package); *obvious* (more distinct on where they appear); *independent* (independently awarded logo, not by supermarkets); *having broad coverage* (one label to all the factories); *promoted/advertised* (linked to broader government messages).

Given the relatively low level of consumer understanding on environmental effects, consumers are unlikely to be able to make complex assessments through a product ecolabel or other point of sale material unless a clear and simple presentation method has been developed. Supermarkets along with other major food procurers may be better placed to apply environmental sustainability assessment as 'standard practice'[287], and develop presentational options that their customers will comprehend.

10.2.3 Pricing

Pricing can reinforce (or undermine) healthy or sustainable food purchase. This could be addressed through a system of *differentiated consumption taxes based on the environmental performance of products,* e.g. reduced VAT rates for eco-labelled food products. Under VAT Directive 2006/112/EC a specific list of goods and services for which Member States may apply a reduced rate of VAT is set out and the EU could for example consider *reducing or removing VAT for sustainable food products.*[288]

Taxing ("fat tax") unhealthy products may contribute to changing consumption patterns by the dual advantage of potential reduced purchases of products high in saturated fats and generated income from tax for funding public awareness-raising campaigns. However, a tax on fat *per se* may jeopardise the consumption of nutrients essential for health (vitamins, calcium, magnesium, potassium and phosphorus). It may also generate higher welfare costs among low-income households than among richer households. The determination of the fat tax linked to measurement of social cost and tax implementation are difficult. It is almost impossible to determine precisely the marginal social cost of a negative externality and convert that amount into a monetary value presented in the tax set. Political factors can complicate the implementation of fat tax.[289] Compliance costs would be particularly large for the food sector due to its multitude of products. Further, there is also the risk of the rebound effect in that the market share of reduced VAT products will increase, increasing overall consumption and possible environmental impacts[290].

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[286] Sue Davies (2011), op. cit.
[287] Brooks, M., Foster, C., Holmes M. and Wiltshire J. (2011), op. cit.
[288] EC (2007), Study on reduced VAT applied to goods and services in the Member States of the EU; EC (2008), Reduced VAT for Environmentally-friendly products
[289] Allais O., Bertail P., V. Nichèle (2010), The Effects of a Fat Tax on French Households' Purchases: A Nutritional Approach, American Journal of Agricultural Economics, 92:228-245
[290] EC (2007), op. cit.; EC (2008), op. cit.

Financial incentives such as bonuses or grants can also be used to encourage purchase of new and energy-efficient refrigerators and freezers, energy-efficient ovens and microwaves and water-efficient dishwashers.

10.2.4 Green Public Procurement

Green Public Procurement (GPP) can stimulate demand for more sustainable food . Although GPP is a voluntary instrument, it has a key role in stimulating a demand of EU's public authorities for more sustainable goods. Harmonisation of national GPP criteria across Member States to facilitate provision for GPP and set clear and verifiable environmental criteria for products would help. This could involve introduction of a benchmarking system, an incentive scheme to reward effective GPP, making the GPP criteria for Food and Catering services mandatory, or setting an EU wide target.[291]

10.3 Retail

As discussed in section 10.2.2, removal of the "display until" date (printed on the product alongside the best before date), has the potential to reduce waste after the point of purchase. This could be achieved through either voluntary or regulatory approaches.

Voluntary: Retailers can be incentivised to redesign packaging (example: Courtauld Commitment (UK)) or use 'choice editing', meaning that, for example, endangered fish species are not available for purchase in their stores[292], or could collaborate on a voluntary approach to environmental sustainability labelling, to help guide consumer choice.

Regulatory: Reassess inclusion of fruits and vegetables (26 types) in the EU specific marketing standards (according to their size and shape). Consider relaxing the standards for other fruit and vegetables where appropriate.

[291] EC (2012) Policies to encourage sustainable consumption
[292] Riley, H. and Buttriss, J. L. (2011), op. cit.

10.4 Processing and manufacture

Voluntary agreements:

Regarding *waste*, producer responsibility in the food industry could include obligations to report and achieve prescribed levels of waste minimisation, recovery and recycling. For example, increasing use of beverage by-products for anaerobic digestion and other alternatives (e.g. butanol biofuel production or treatment of wastewater high in metal ions[293]).

To improve *water efficiency* in the food and drink sector can be developed (example: Federation House Commitment on reducing water use). Alternatively, a *stewardship approach* may be more suitable, as suggested by the Food Ethics Council.

Regulatory:

For *wastewater management*, the EU framework for the use of bio-solids in forestry or for land restoration can be developed to drive the use of relevant technologies: for example, on-site separation of effluent can also be implemented (e.g. membrane bioreactors can allow extraction of water for reuse); and the use of anaerobic digestion with Combined Heat and Power to produce biofertiliser and biogas, and use of biosolids (treated sludge) as fertiliser and soil conditioner. Eliminate the need for treatment through enhanced processing and reuse of resources at the source of wastewater.

The *Ecodesign Directive* (*2009/125/EC)* sets efficiency classes for many energy related products, which can be displayed through the *EU energy label*, an information tool. For *energy use*, reviewing whether other equipment associated with the food cycle can be brought within scope of the Ecodesign Directive, whether existing measures can be further enhanced and encouraging use of the *EU Energy Label* to allow selection of equipment based on its efficiency, can help to reduce energy consumption.

10.5 Production

10.5.1 Farming

For **farming systems**, it is important to move to a holistic view of all aspects of resource production, use, soil protection, countryside stewardship, water protection, air protection and crop and livestock production.

Develop the regulatory approach: Continued 'greening' and coupling cross-compliance measures to environmental performance provide the most robust means of improving resource efficiency and wider environmental performance of farming and agricultural systems. These

[293] The hydroxyl, carboxyl and amine groups present in spent grains have a high affinity for metal ions and can be used in treatment of wastewater high in these pollutants, such as textile and dye industries.

could be reinforced using measures targeted specifically at resource use, for example nutrient balancing.

Funding research: Support to research to assess potential resource efficiencies: e.g. feed strategies, nutrient and water recycling, and other sustainable management methods.

Dissemination/awareness-raising, voluntary agreements and subsidies: To incentivise best practice and technologies in farming (example: Milk Roadmap for Environmental Improvements (UK)).

Demand-side measures: Develop a "high environmental quality" food label (or certification at farm level) to inform consumers.

10.5.2 Land use change

For addressing land use change, integrated policies that optimize production and consumption are required. Leakage is a problem for Europe: increased demand can be covered by external supply (imports), externalizing environmental costs. In overall terms, policies that aim at increasing land use efficiency should be based on assessments of the interrelationship between resource gains and associated negative effects on the biosphere, e.g. on ecosystem functioning. Here, the spatial scale effects are particularly important: For example, ongoing trends such as globalization can result in a more efficient global allocation of agricultural production; however, at the same time globalization might allow for dislocating negative land use effects away from domestic drivers or ecosystems and thus withdraw it from (nationally or supra-nationally organized) environmental legislation.[294,295]

From a policy perspective it is **important to consider what land uses (and agricultural techniques) we can consider acceptable**. If the imports (such as soy and palm oil) cause large dependencies of land elsewhere, and possibly related socioeconomic or environmental problems in other countries, it cannot be considered a sustainable choice. **Trade policies generally do not consider the impacts of global land use due to imported agricultural goods**.

It is **necessary to develop a method for assessing or indicating global land use** to obtain a true picture of the environmental sustainability of imports and exports. Several approaches could be used for this purpose, including indicators such as ecological footprint, life cycle assessment (within which indirect land use change must be included), or material flow analysis. The will of local governments and authorities may also be crucial in managing and measuring the impacts of global land use; indications of effective government policy exist in Brazil.[296]

[294] Kastner, T., Erb, K.-H., Nonhebel, S., 2011. International wood trade and forest change: A global analysis. Global Environmental Change In Press, Corrected Proof.
[295] Lambin, E.F., Meyfroidt, P., 2011. Global land use change, economic globalization, and the looming land scarcity. Proceedings of the National Academy of Sciences 108, 3465 -3472.
[296] Partlow, J. 2008. Brazils decision on deforestation draws praise. Washington post, 6 December. Available at: www.washingtonpost.com/wp-dyn/content/article/2008/12/05/AR2008/120503325.html

10.5.3 Fisheries

About 80% of global commercial fish populations are fully exploited or overexploited, leading to large impacts on marine biodiversity. 40% of global fish production comes from aquaculture, compared to 20% in the EU.[297] There is a need to maintain marine biodiversity.

At systems level there is a need to move consumption away from the 5 'big' fish species (to reduce pressure on their stocks) and toward a wider range of species. There is also a need to evaluate gains and impacts of a shift in production of fish from wild fish catches to fish farming and assess the potential herbivorous aquaculture. Incentivising and supporting development of technology that helps to reduce by-catch and enable energy efficiency (e.g. fishing gear, trawling methods, etc.) is also recommended.

Develop the regulatory approach: Continuation of the development and enforcement of the CFP, with focus on sustainable resource management (biodiversity, stock management, fuel efficiency, etc.), with increased producer responsibility of the fishing industry. The marine spatial planning approach may provide further opportunities for improving resource efficiency. Removing the ban on marine fuel taxation (*Energy Tax Directive 2003/96/EC*) could encourage development of more fuel efficient technologies and methods.

Funding research: Support to pilot projects to test equipment. Improved gear technology could be embedded in management systems where the benefit is proven through evaluation.[298] Support to research in aquaculture to asses efficiency (of aquaculture products compared to other protein sources), on feed strategies and other sustainable management methods.

Dissemination/awareness-raising, voluntary agreements and subsidies: To incentivise best practice and technologies within the industry, and support resource efficient aquaculture and sustainable fishing techniques. Encourage industry scheme to increase variety of species fished (linking it to the demand-side measure to increase profit to be gained from other fish species).

Demand-side measures: Giving value to fish species outside the 'big' 5 and to by-catch (through awareness-raising), mandatory labelling, or pricing policies. Environmental sustainability certification and labelling of certain fish farming methods.

10.6 Pre-production

Pricing: Water for agriculture is widely under-priced and even free or illegally abstracted in many situations. Lack of water pricing has significant effects, other than potentially exacerbating local scarcity. For example, deficit irrigation can reduce water use to 60% of that required for maximum yield without reducing profit, but capital costs meant that the overall economic benefits of deficit irrigation is inextricable linked to water pricing policy.

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[297] Westhoek, H. et al. (2011), The Protein Puzzle. The consumption and production of meat, dairy and fish in the EU, The Hague: PBL Netherlands Environmental Assessment Agency

[298] Jennings, S., and Revill, A. S. (2007). The role of gear technologists in supporting an ecosystem approach to fisheries. – ICES Journal of Marine Science, 64: 1525–1534.

Regulatory:

With the exception of some Scandinavian countries, the focus of **wastewater treatment** is to reduce the nutrient related hazard of discharged water and sludge rather than to recover nutrient to conserve resources. There is a case for a systematic examination of Europe's wastewater treatment infrastructure and municipal waste treatment (e.g. incineration) in relation to the goal of using waste streams for phosphorus and nitrogen recovery. Use of sustainable drainage systems should be encouraged. Catchment/basin sewage management to meet Water Framework Directive (WFD) criteria should be enhanced. Whole river basin management approach - as outlined in the WFD, could place stricter controls on wastewater produced by industry and agriculture.

For manufacture and marketing of **plant production products (PPPs)**, the question remains as to why a regulatory system is concerned with efficacy of PPPs. This requirement has consequences for the approval of biological pesticides, for example semiochemicals which are natural chemicals that modify the behaviour of insects, but non-lethal and therefore may not pass conventional efficacy tests. Testing accounted for up to 50% of registration costs (compared with 10% for agrochemicals) and the low market value of biological control agents (compared with conventional pesticides) are hindering the development of biological control. A scheme to reduce regulatory and financial hurdles can be initiated (example: UK).

Funding research: The use **plant breeding** for resource efficiency is a neglected area. The privatisation of public breeding programmes in the 1990s in particular put plant breeding outside the public sphere. There is a case for revitalising public-good plant breeding in Europe, perhaps through the research programme (example: research-based development (UK)).

10.7 Summary of policy options to address recommended actions

Table 13 summarises the policy options and links these to the improvement actions that they would address.

Table 13: Improvement actions addressed by policy options

Policy option	Relevant improvement actions stimulated
Mandates for measurement methodologies and setting of environmental sustainability criteria	**Research and innovation:** - Cross-sectoral initiatives to develop criteria to distinguish between sustainable and less sustainable food and drink products - Greater cooperation between policymakers and the statistical offices or research institutes responsible for producing resource efficiency indicators - Communication of clear messages on sustainable food and monitoring of the progress - Indicators for global land use **Consumption:** - Examination of the trade-offs and synergies with other social and environmental goals, notably in dietary guidelines, and biodiversity - Improved uptake and use of Green Public Procurement criteria, and the development of more product groups - Environmental sustainability standards and certification schemes **Development of criteria to support:** - Nutrient balances to be calculated at the farm level or the regulation of the type of feed used - Limits to inputs at specific stages of the life cycle, e.g. for livestock (where husbandry methods are less impacted by local conditions) and manufacturing stages
Consumption	
Awareness-raising and education campaigns (and harmonisation of nutrition and sustainable diets guidance)	**Food waste:** - Education on use of leftovers, date labelling, and when food is not long fit for consumption. - Home delivery of groceries and household meal planning. **Food choices and diet:** - Sustainable food and health agendas developed in parallel: 'win-win' opportunity for environment and public health improvements through reducing intakes of meat and dairy products. - Adjustment of intake recommendations to target health effects unique to some fish and promotion of fish from sustainable stocks - Discouragement of the consumption from out-of-season production
Product labelling for	**Food choices and diet:**

Policy option	Relevant improvement actions stimulated
environmental sustainability guidance/certification	- Encouragement of the purchase from in-season production and farming methods that promote high environmental quality - Promotion of fish from sustainable stocks **Research and innovation for sustainable food:** - Communication of clear messages on sustainable food and monitoring of progress **Retail:** - Increase awareness of consumers of the consequences of their expectations and emphasise in-season produce, changing offer to match seasonal availability
Pricing (taxes for consumption of specific food groups)	**Food choices and diet:** - For example, increasing VAT rates for meat or dairy products, or reducing VAT for sustainable fish
Green Public Procurement for catering in public institutions	**Food choices and diet:** - Making the GPP criteria for food and catering services mandatory, or setting an EU-wide target - Re-design of menus - Provision of more food products that serve as alternatives to meat and fish - Reduce need to provide late diners with a full range of menu options. Reduce over-supply at buffets, etc.
Retail	
Voluntary agreements (packaging and products offered)	- Use 'choice editing', e.g. removing endangered fish species from shops - Lightweight packaging, using retail transit packaging, or shelf-ready packaging **Food waste:** - Date labelling better designed to discourage waste - Increase the use of home deliveries **Food choices and diet:** - Reduced consumption of fragile and out-of-season produced produce; change offer to match seasonal availability
Reassess/relax marketing standards for fruit and vegetables (according to their size and shape)	- Relax standards and/or offer optically lower grade produce **Food waste:** - Reduce/eliminate standards that are not related to food safety
Processing and manufacture	
Voluntary agreements to reduce waste and improve water efficiency	- Process optimisation, plant /machinery efficiency increase - Metering of water use (benchmarking) and setting targets for water reduction (or the introduction of key performance indicators) - On-site processing wastewater management and rainwater harvesting, with return via the soil to the aquifer (irrigation and ponds etc.)

Policy option	Relevant improvement actions stimulated
	- Reduced consumption of certain products – esp. from the cool chain will impact the food chain equipment and the cool chain - Producer responsibility for waste - impose obligations to report on waste and achieve prescribed levels of waste minimisation, recovery and recycling - By-products recovery to reduce waste (AD and other alternatives)
Production	
Develop labels for high environmental quality farmed foods and sustainable fish (promoting diversity of consumption)	- Farming systems are often categorised in labelling schemes in relation to 'branded' approaches to farming – organic, etc. What matters is not the brand, but the practices and resource flows that the farm uses. Farm system improvements can be achieved through the use of key inputs and practices, and integrating resource flows between crop and animal production has the greatest potential. Depending on the situation, this requires change at all scales – for example, from methods used by farmers 'on-field' to European-level policy and infrastructure. - Reduce consumption of marine fish and farmed fish that are fed on feed produced from other marine species **Food choices and diet:** - Encouraging purchase of less out-of-season production - Promoting of fish from sustainable stocks **Research and innovation for sustainable food:** - Increasing demand for farming methods that promote high environmental quality - Communicate clear messages on sustainable food and monitor the progress **Retail:** - Increase awareness of consumers of the consequences of their expectations and emphasise in-season produce, changing offer to match seasonal availability
Voluntary agreements in farming and fisheries industry	- Incentivise best practice and technologies: improvement possible throughout the cycle - Phosphorus and nitrogen: better use of manures through better distribution of the manure resource in relation to crop production, and the systematic recovery of nutrients post consumption (i.e. from sewage, AD digestate from of waste) - Soil: improvement requires a broad range of measures, including halting the loss of soil. Reducing cultivation intensity to leave crop residue on the surface can protect soils from erosion but claimed benefits for soil organic matter are disputed. Leaving crop stubble and residue over-winter has the same effect and improves biodiversity. - Water use: drip irrigation technologies can provide 'more crop per drop' - Energy use: further optimisation measures to reduce tillage intensity, increase CHP, and reduced greenhouse cropping - Choice of crop and cropping sequence: More diverse crop cover improves farm biodiversity, reduces pesticide and fertiliser use. Nutrient enrichment (e.g. legumes). Crop by-products can be better used for animal feed or soil improvement. Erosion protection-endangerment (soil degradation prevention). Water availability improvements (vegetation cover conserves soil moisture). Varieties with better pest resistance may reduce inputs (pesticides). Crop rotations systems can also be optimised for carbon mitigation (reduced emissions from soil).

Policy option	Relevant improvement actions stimulated
	- Land use change: in Europe (grassland to arable) a major source of C emissions and cause of biodiversity loss. Globally, LUC (mainly deforestation) causes more GHG emissions than agricultural production and is the most important driver for terrestrial habitat loss and thus pressures on biodiversity. - Farmland biodiversity loss: less intensive farming practices, habitat conservation/restoration, organic farming (pesticide-free) - Feed: Reduced livestock production, more efficient feeding, more precise nutrition, greater use of co-products - Manure: Reduced local/regional concentration of livestock production and/or advanced manure processing - Animal welfare: impact on resource use and emissions is overall relatively small, but specific measures can be positive or negative - By-catch and wasteful discarding: reducing with improved technology and management, e.g. better fishing gear, different trawling methods, selective gear, area closures, discard bans and data enhancement. Better monitoring, reporting and standards could be a means to reduce by catch of seabirds in fisheries. Encouraging larger variety of species fished (linked to demand-side measure to increase profit to be gained from other fish species) - Control fishing intensity to allow stock recovery (virtuous circle leading to more efficient fishing) **Food waste:** - Reduce/eliminate standards that are not related to food safety
Funding for agricultural and, fisheries research and development	- Support to research to assess potential resource efficiencies: feed strategies, benefit of aquaculture products compared to other animal protein sources, nutrient and water recycling, and other sustainable management methods - Support to pilot projects: technologies to reduce by-catch and enable energy efficiencies (e.g. fishing gear, trawling methods, etc.)
Develop the regulatory approach for farming (continuation of the Common Agricultural Policy "greening" and cross-compliance) and fisheries (sustainable resource management in the Common Fisheries Policy (CFP)	**Agriculture:** - Continued 'greening' and cross-compliance measures coupled to environmental performance provide the most robust means of improving resource efficiency and environmental performance of agricultural systems, practices such as farm-gate nutrient balancing could be incorporated - Requirements could also be made for the environmental impacts of inorganic fertilisers (e.g. max GWP per kg) **Fisheries:** - Continued development and enforcement of the CFP, with focus on ecosystem approaches, sustainable resource management (biodiversity, stock management) and producer responsibility - Reduce fishing capacity and effort, remove tax exemption on marine fuel - The marine spatial planning approach may provide further opportunities for improving resource efficiency - Stock recovery allows more efficient fishing creating a virtuous circle – provided fishing intensity is controlled
Pre-production	
Introduce pricing for water	- Pricing to reduce water consumption and promote water efficiency technologies: water recycling and use of waste water from processing for aquifer recharge (feasibility depends on the discharged waste water and willingness of the processing sector to invest in water

Policy option	Relevant improvement actions stimulated
	treatment), more precise irrigation and reduced consumption of water-demanding crops
Revise WFD and nitrates directive to actively achieve nutrient cycling and reduce discharges (enforce stricter standards on wastewater and enhance sewage management)	- Increased efficiency of use of phosphorus from animal manures, especially in areas with high animal populations **Production:** - Improved recycling of phosphorus and nitrogen - better use of manures through better distribution of the manure resource in relation to crop production - The systematic recovery of nutrients post consumption (i.e. from sewage) - Manure: Reduced local/regional concentration of livestock production and/or advanced manure processing
Reduce regulatory and financial hurdles for biological plant production products and new varieties	While PPP manufacture has been the cause of major incidents in the past (e.g. Bhopal, Seveso), recent legislation has reduced risks. **Production:** - Choice of crop and cropping sequence: more diverse crop cover improves farm biodiversity, reduces pesticide and fertiliser use. - Varieties with better pest resistance may reduce inputs (pesticides). - Land use change: in Europe (grassland to arable) is a major source of C emissions and a major cause of biodiversity loss. Globally, LUC (mainly deforestation) causes more GHG emissions than agricultural production and is the most important driver for terrestrial habitat loss and thus pressures on biodiversity. - Farmland biodiversity loss: less intensive farming practices, habitat conservation/restoration, organic farming (pesticide-free)
Research funding for plant breeding	- The GMO (herbicide tolerant crops) regulation policy that has considered system impacts one of the few examples of regulation drawing on system-level considerations - The regulation of new crop cultivars has implications for the use of crop genetic improvement to reduce impacts - GMOs have in the medium term the potential to reduce resource use and impacts - Investment in plant breeding can provide traits that reduce resource use and impacts **Production:** - Choice of crop and cropping sequence: varieties with better pest resistance may reduce inputs (pesticides). - Support to research assessing potential resource efficiencies: e.g. crop cascade utilisation potentials

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