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Technology options for feeding 10 billion people

Synthesis report

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Technology options for feeding 10 billion people

Synthesis report

Options for sustainable food and agriculture in the EU

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Abstract

How should Europe respond to the increased demands on our food and agriculture systems arising from global population growth, changing diets, and competing demands on agricultural land? This report offers a view on how the EU could play a role in meeting these challenges in the coming decades and sets out some of the options which merit particular attention. It focuses on options for increasing agricultural productivity whilst adapting to the effects of climate change and reducing emissions from agriculture, the means of reversing continued declines in farmland biodiversity, the reduction of food wastage, ways to achieve a more resource-efficient food sector, and the options for using wastes and residues to meet biomaterial and bioenergy needs in a sustainable way. It brings together some of the analysis and results of five commissioned studies in a synthesis, considering the state of play today and some of the key developments on the horizon moving towards 2050. The European Union has strongly developed common environmental and agricultural policies, and a recently reformed Common Agricultural Policy with a greater emphasis on both the environment and innovation, providing Member States with an opportunity to initiate a change in direction. At the same time, there are major challenges to increasing productivity in an appropriate way whilst reducing damage to European agricultural and natural resources and biodiversity. It will be important to produce more with less in Europe and to cut wastage.

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Kretschmer, Bettina; Smith, Claire; Watkins, Emma; Allen, Ben; Buckwell, Allan; Desbarats, Jane and Kieve, Daniel (2013) Technology options for feeding 10 billion people - Recycling agricultural, forestry & food wastes and residues for sustainable bioenergy and biomaterials. Report prepared for STOA, the European Parliament Science and Technology Options Assessment Panel, under contract IP/A/STOA/FWC/2008-096/LOT3/C1/SC6-SC8. Institute for European Environmental Policy.

All reports are available at: http://www.europarl.europa.eu/stoa/cms/studies

CONTENTS

1 INTRODUCTION

1.1 The challenge

How should Europe respond to one of the most crucial challenges that the world will face in the coming decades? As the global population expands towards 10 billion, a total expected to be reached between 2050 and 2100,[1] and with a persistent inability to eradicate hunger, there are increasing questions about how it will be possible to establish a sustainable agricultural and food system. The challenge is all the greater since it is necessary to improve and enrich diets in large parts of the world as well as feed more people. Nor is it a matter simply of increasing food supply and reducing waste. It is also essential to create sustainable farming systems capable of being maintained within increasingly apparent environmental limits. Agriculture is a major source of pollution, loss of biodiversity and deteriorating soil quality in large parts of the world.

Studies examining the future are growing in number and there are contributions from agri-business and NGOs as well as governments and UN agencies. Some of these envisage a series of mainly incremental changes to the present chains of supply and demand. Others are more visionary, exploring options such as significant dietary change in high income countries, widespread technological transformation of agriculture and food, the revival of more traditional farming systems, and the adoption of new patterns of trade, whether in the direction of more regional self-sufficiency or global liberalisation. It is far from clear that business as usual, even with a serious effort to increase agricultural productivity, will be sufficient to meet the multiple and sometimes conflicting objectives ahead of us.

This report offers a view as to how Europe and the EU in particular could play a role in meeting these challenges in the coming decades and sets out some of the options which merit particular attention. Europe has many resources on which to draw, including a productive and stable agriculture and food system, a mixture of high and low intensity farming systems, strong infrastructure and support services in most countries, a good range of research institutions and an overarching set of agricultural and environmental policies which seek to balance production and sustainability. However, there is not an immediate consensus as to where the priorities lie. In the recent debate on the Common Agricultural Policy there were several voices arguing for an immediate increase in European production, seeing it as a contribution to improving global food security. By contrast, others suggested that it was more appropriate to focus on improving the management of Europe's own resources, including soils, water, infrastructure and skills, and to put the focus on sustainability rather than seeking short term increases in output.

Creating a robust agriculture and food system is not a new challenge of course. The need to make agriculture more sustainable has been the focus of attention for at least the last four decades (eg Altieri, 1983; Carson, 1962; IUCN et al, 1980; Jackson, 1980). However, current concerns about food security have reinvigorated this debate and underpin the importance of sustaining the earth's productive capacity in the long term.

Against this background, the STOA Panel of the European Parliament commissioned five studies on relevant aspects of the food and related bioenergy equation, combining a broad look at future production options and the investigation of some more specific issues, such as the means of reversing continued declines in farmland biodiversity, the reduction of food waste, and the options for using wastes and residues to meet biomaterial and bioenergy needs in a sustainable way. This report brings together some of the analysis and results of the five studies in a synthetic form, considering the state of play today and some of the key developments on the horizon moving towards 2050.

[1] The current UN high fertility variant population projection for 2050 is for 10 billion people; the medium fertility variant predicts a population of 9.3 billion in 2050 and 10.1 billion in 2100 (UNDESA, 2011).

The five studies are:

- Underwood, E, Poláková, J, Berman, S, Dooley, E, Frelih-Larsen, A, Kretschmer, B, Maxted, N, McConville, A J, Naumann, S, Sarteel, M, Tostivint, C, Tucker G M, and van der Grijp, N (2013) Technology options for feeding 10 billion people - Interactions between climate change & agriculture and between biodiversity & agriculture. Report prepared for STOA, the European Parliament Science and Technology Options Assessment Panel, under contract IP/A/STOA/FWC/2008-096/LOT3/C1/SC5-SC9. Institute for European Environmental Policy together with BIO Intelligence Service, Ecologic Institute, IVM-VU University.
- Meyer, R, Ratinger, T, and Voss-Fels, K P (2013) Technology options for feeding 10 billion people - Plant breeding and innovative agriculture. Report prepared for STOA, the European Parliament Science and Technology Options Assessment Panel, under contract IP/A/STOA/FWC/2008-096/LOT3/C1/SC1-SC3. Institute for Technology Assessment and System Analysis (ITAS), Karlsruhe Institute of Technology, member of ETAG, the European Technology Assessment Group.
- Langelaan, H C, Pereira da Silva, F, Thoden van Velzen, U, Broeze, J, Matser, A M, Vollebregt, M, and Schroën, K (2013) Technoloy options for feeding 10 billion people - Options for sustainable food processing. Report prepared for STOA, the European Parliament Science and Technology Options Assessment Panel, under contract IC STOA 2013/122. Wageningen UR Food & Biobased Research.
- Priefer, C, Jörissen, J, and Bräutigam, K-R (2013) Technology options for feeding 10 billion people - Options for cutting food waste. Report prepared for STOA, the European Parliament Science and Technology Options Assessment Panel, under contract IP/A/STOA/FWC/2008-096/LOT3/C1/SC2-SC4. Institute for Technology Assessment and System Analysis (ITAS), Karlsruhe Institute of Technology, member of ETAG, the European Technology Assessment Group.
- Kretschmer, B, Smith, C, Watkins, E, Allen, B, Buckwell, A, Desbarats, J, and Kieve, D (2013) Technology options for feeding 10 billion people - Recycling agricultural, forestry & food wastes and residues for sustainable bioenergy and biomaterials. Report prepared for STOA, the European Parliament Science and Technology Options Assessment Panel, under contract IP/A/STOA/FWC/2008-096/LOT3/C1/SC6-SC8. 2013. Institute for European Environmental Policy.

This synthesis does not aim to be comprehensive in any sense. Particular weight has been given to some key production and environmental issues at the request of STOA, although social and economic concerns are addressed to some degree as well. The focus is very much on Europe and on the agriculture and food system, recognising that there is an important global context for all decisions taken in the EU but without trying to examine production and supply issues in other parts of the world. Fisheries, aquaculture and forestry are not explored to any significant degree, as they are outside the scope of the studies. Aspects of livestock farming are covered but a comprehensive analysis of livestock systems including intensive production was outside the scope of these studies.

1.2 Contents of this report

This report presents options for sustainably increasing agricultural productivity whilst supporting key actions to facilitate agriculture-related climate change adaptation and mitigation and biodiversity conservation. These options are based on a review of the implications of the interrelationships between climate change and agriculture, and between agriculture and biodiversity, and take into account the potential for using a range of innovative options to increase agricultural productivity on a sustainable basis. The report also addresses aspects of how to achieve more sustainable consumption with reduced waste and a more resource-efficient food sector, and how to develop higher value uses for agricultural residues and wastes.

Options for action involve the use of a range of policy instruments to promote sustainable production systems, appropriate resource management and protection, focussed research and effective technology transfer to the farm level, dietary changes, reduced food waste, and more resource efficient food chains.

Chapter 2 offers an overview of Europe's place and role in the global food system.

Chapter 3 outlines some of the challenges facing the agriculture and food sectors in the EU in the coming decades.

Chapter 4 introduces production systems and management options for a sustainable European agriculture.

Chapter 5 reviews these production systems and management options for their potential to reduce greenhouse gas emissions from agriculture, to adapt agriculture to climate change, and to increase productivity in a sustainable way.

Chapter 6 reviews the potential of management options to reduce the detrimental impacts of agriculture on biodiversity and other ecosystem services.

Chapter 7 reviews the potential of plant breeding to contribute to increased productivity and sustainability, and the need for better conservation and use of plant genetic diversity.

Chapter 8 reviews the causes and quantities of food losses and food waste associated with the European food sector, and options for reducing food waste and increasing the efficiency and sustainability of the food sector.

Chapter 9 critically examines the potential for crop residues and food waste to be used to create bioenergy and biomaterials.

Chapter 10 summarises and identifies the key options and actions.

2 EUROPE IN A GLOBAL CONTEXT: DRIVERS OF FOOD DEMAND AND SUPPLY

There is consensus that global **demand for agricultural products** will rise significantly by 2050. The Food and Agriculture Organisation of the United Nations (FAO) has estimated in a trend projection that food production will need to rise by approximately 60 per cent over the next 40 years[2] to feed a rising world population with changing dietary trends, including a 40 per cent rise in cereal production for animal feed (Alexandratos & Bruinsma, 2012). However, projections of future food demand are challenging, varied in their assumptions and subject to revision. For example, there are different predictions regarding income growth and dietary changes, feed use efficiency, productivity increases in smallholder agriculture, use of food crops and cropland for bioenergy, as well as other factors (FAO, 2011a; Grethe et al, 2011). Any future action that may be taken to address access to food and the distribution of food, move to healthier more sustainable diets and reduce food waste, will influence how much of an increase in food production is needed (Tomlinson, 2013). The balance between attempts to modify consumption and to increase production will vary by region and by socio-economic context (Garnett and Godfray, 2012). However this balance is struck, increased productivity (as opposed to production) which improves the efficiency of scarce resource use is clearly necessary, not least as it potentially reduces damaging environmental side effects.

At the same time, the extent of **malnutrition and hunger** worldwide is still unacceptably high. It is estimated that up to one billion people are chronically undernourished, and perhaps another billion suffer from the 'hidden hunger' of not having enough vitamins and minerals (FAO et al, 2013; UK Government Office for Science, 2011). Increasing food production in the future is not sufficient to reduce hunger and must be combined with poverty reduction to achieve better access to food. Increasing the amount of food available globally does not reduce hunger if the hungry cannot access food, for example if they are too poor to buy food. Effectively reducing hunger requires, *inter alia:* stable governance, clear property rights, robust and concerted action to increase incomes and economic access to food and key nutrients, empowerment of women, and provision of social safety nets (OECD, 2013). Agricultural development can make an effective contribution if it is designed and incentivised with hunger reduction as a primary goal (UK Government Office for Science, 2011) (see Box 2-1).

Box 2-1 Strategies for addressing hunger

There is currently, at a global aggregate level, enough food for a sufficient diet for everyone (Alexandratos & Bruinsma, 2012). Most hungry people do not have access to sufficient food because they are poor. Increasing global food supplies will not necessarily reduce the number of undernourished people if they do not have enough income to improve the quantity and quality of their diets and to access improved health services. In order for economic growth to enhance the nutrition of the neediest, the poor must participate in the growth process and its benefits; and governments need to use additional public resources for public goods and services to benefit the poor and hungry (FAO et al, 2013).

Agricultural growth can be an effective tool to reduce hunger and malnutrition because most of the extreme poor depend on agriculture and related activities for a significant part of their livelihoods. Investing in smallholder agriculture is proposed as a key action to improve food security (HLPE,

[2] The FAO previously published a widely cited projection that global food production would need to increase by 70 per cent by 2050 (FAO, 2006; FAO, 2009). However, more recent FAO reports substantially revise their analysis. The most recent (Alexandratos and Bruinsma, 2012) revises the projection down to 60 per cent, and adds significantly more uncertainty to that figure than in the previous reports. Several publications point out weaknesses in the FAO projections (Grethe et al, 2011; Tomlinson, 2013).

2013). Agricultural growth involving smallholders, especially women, will be most effective in reducing extreme poverty and hunger when it increases returns to labour and generates employment for the poor. Smallholder farmers face specific constraints including extreme poverty, weak property rights, poor access to markets and financial services, vulnerability to shocks and limited ability to tolerate risk (FAO, 2012a). Public investment in agricultural research and development, education, and rural infrastructure yields much higher returns for both agricultural productivity and poverty reduction than other expenditures such as input subsidies (FAO, 2012a). A better nourished population and increasing agricultural productivity, in turn, are key drivers of sustainable economic growth (Alene and Coulibaly, 2009).

Two of the key drivers of overall demand for food are **population growth** and economic growth. The United Nation's medium projections show global population is likely to grow by 27 per cent by 2030, reaching 9 billion by mid-century and levelling off at around 10 billion towards 2100, with the greatest growth rate in Africa (UNDESA, 2011). All of this population growth is expected to be absorbed by cities. Migration from rural to urban areas (and vice versa) as well as immigration and emigration trends also influence demand for food and other services from land. By contrast, in Europe, population levels are expected to peak by the mid-2030s and then start to decline (FAO, 2006; Rosegrant et al, 2006; UNDESA, 2011). Indeed populations are already declining in about a quarter of EU Member States. The changing age profile of Europe's population and the increase in smaller and single person households influences food demand and use, including food wastage (Food Ethics Council, 2013a).

As societies enjoy higher incomes and become more urban, they tend to consume more processed foods of all types, more livestock products (dairy produce and meat), eggs, fish and vegetable oils, and to be more wasteful with food (eg Kastner et al, 2009). Increased **demand for livestock products** also increases the demand for cereals and proteins for animal feed. Changes in consumption patterns are occurring rapidly in transition economies such as China and Brazil. For example, world meat consumption has increased by six per cent over the past five years as a result of demand from Brazil, China and other emerging countries (whilst average per capita calorie consumption in India and sub-Saharan Africa has increased only slightly).

In Europe, and other relatively affluent regions, health and ethical considerations are becoming more important in shaping dietary choices in segments of the population while at the same time obesity is a growing problem. A reduction in **meat and dairy consumption** in developed countries could reduce significantly the need to expand global agricultural output, as well as improving public health (Tomlinson, 2013). The FAO estimates that currently around a third of the food produced for human nutrition is lost or wasted globally (Gustavsson et al, 2011). If these **losses and wastage** were reduced the necessary increase in agricultural production would be lower, together with the associated harmful environmental impacts (Grethe et al, 2011). Most studies concur, however, that the goal of sustainable food security for all is not possible without action on all of these issues, because the challenges are so great and the risk of failure needs to be spread (FAO et al, 2013; IAASTD, 2009; UK Government Office for Science, 2011).

The global food supply equation has become more complex and subject to greater stress because of an increasing demand for agricultural biomass for **bioenergy and biomaterials**, including food or feed crops. This is driven mainly by policy targets and subsidies which have the goal of reducing reliance on non-renewable resources, especially energy[3]. Currently, around 80 to 85 million tonnes of cereals

[3] The European Union and other European countries, the USA, Canada, Australia, New Zealand, Japan, China, India, Indonesia, South Africa and Thailand have all adopted policy measures and set targets for the development of biofuels (FAO, 2011a)

and about 10 million tonnes of vegetable oils are used for biofuel production worldwide (FAO, 2011a).[4] Predictions of how much food crop production will be used for biofuel or biomaterial production in 2050 are highly uncertain, ranging from an overall decrease to a tenfold increase, particularly in the use of vegetable oils from oil palm and soya. In addition, whilst the use of food and feed crops for biomaterials, principally bioplastics, is currently minimal in global terms, the potential for increases in this industry are significant (see Chapter 9). This uncertainty is a major factor influencing predictions of overall demand from agriculture in 2050 (Alexandratos & Bruinsma, 2012).

The majority of increased global food demand will both originate and be met **outside the EU**, not least in Africa. It is expected that this will be met mainly by increasing productivity on existing agricultural land, but also by bringing some non-agricultural land into production (Alexandratos & Bruinsma, 2012; FAO, 2011a; OECD and FAO, 2012). A global analysis of productivity growth rates concludes that though land and labour productivity continue to increase, the rate of growth in many countries has slowed (Alston et al, 2010).[5] Global yield trends for the major food crops continue to increase, but there is concern that the rate of increase is not great enough to meet projected demand (Ray et al, 2013). Currently, most of the world's undernourished people are living on small farms (FAO et al, 2013). Although opinions about the role of **smallholder farms** in the future of agriculture and hunger reduction are strongly divided, there is a consensus that smallholder agriculture will continue to feed most of the world's poorest for the near future (IAASTD, 2009; Juma et al, 2013; UK Government Office for Science, 2011). Clearly a great deal depends on the level of productivity growth that can be achieved, mostly outside the EU, and whether current productivity can be maintained in the face of climate change and other environmental constraints (eg Fan et al, 2012). This in turn depends heavily on the level and effectiveness of **investment in agricultural research, development and extension,** because there is much evidence that productivity responds, although with long time lags, to such investment (Alene & Coulibaly, 2009; Beintema et al, 2012; IAASTD, 2009) (see Box 2-2).

Box 2-2 The EU's role in investing in agricultural research and development in developing countries

India, China, Brazil, and other relatively large and advanced middle-income countries have significantly increased their public funding of agricultural research and development and have become major food producers. However most of the world's smaller, poorer, and more technologically challenged countries, particularly in sub-Saharan Africa, have faced decreasing investments in agriculture over the last decade (Beintema et al, 2012) - with some notable exceptions such as Nigeria and Ethiopia where capital investment in agriculture is increasing (Caldecott et al, 2013). These countries are often highly vulnerable to severe volatility in development funding, and hence in spending, which impedes the continuity and ultimately the viability of their research programmes. Many of their R&D agencies lack the necessary human, operating, and infrastructural resources to successfully develop, adapt, and disseminate science and technology innovation (FAO, 2012a). The International Assessment of Agricultural Science and Technology for Development called for an increased agricultural research and development focus on drylands, fisheries, mountain and coastal ecosystems, orphan crops, crop-livestock systems, and adaptation to climate change impacts (IAASTD, 2009). It also called for funding to enhance basic sciences, and technological and

[4] The USA is the largest producer and consumer (mainly maize for bioethanol), followed by Brazil (mainly sugarcane for bioethanol), and the EU (mainly oilseed rape for biodiesel)

[5] This overall trend is influenced by the divergent trends in China and Russia, two of the world's largest cereal producers. In China, land and labour productivity has risen at a significantly faster rate than the rest of the world since 1990, whereas in the countries of the former Soviet Union, principally Russia, productivity growth since 1990 has been negative.

institutional changes to address water and land problems.

The EU Member States remain the largest donors of official development assistance worldwide, collectively providing EUR 55.2 billion in 2012[6], though it is not possible to say how much of this went into agricultural research and development. Europe's new overseas aid policy, the Agenda for Change, sets out a more strategic approach to funding, with sustainable agriculture as one of the priority areas, and focuses on the 48 least-developed countries, nearly all of them in sub-Saharan Africa.[7]

Climate change presents a number of challenges for increasing production in the future. Increased frequency of extreme weather events, incidences of pests and diseases as well as climate variability and higher overall temperatures all have the potential to outweigh the positive impacts on some yields of increased CO_2 density and warming. Although predicting the global impacts of climate change on the food system is extremely complex and uncertain, some climate change scenarios to 2050 project reductions of up to 30 per cent in yields of rain fed maize in developed countries, up to 18 per cent in yields of irrigated rice in developing countries, and up to 34 per cent in the yield of irrigated wheat (FAO, 2011a). Increasingly, experts are warning that the target to limit global warming to 2^{o}C above pre-industrial levels will not be met (UNEP, 2013) and some are warning that the world is on track to a 3.5^{o}C rise.[8] At the same time, agriculture and land use change together are major contributors to global greenhouse gas emissions. The deforestation caused by agricultural expansion causes roughly the same greenhouse gas emissions as agriculture itself (FAO, 2011a). Maintaining food security whilst reducing emissions from agriculture and maintaining environmental sustainability presents significant challenges and will require a broad range of measures addressing both agricultural production and demand (Smith et al, 2013) (see Chapter 5 for further discussion).

Agriculture relies on sufficient supplies of plant nutrients, including nitrogen (N), phosphorus (P), potassium (K), and a range of micro-nutrients. The increased use of **crop fertilizers** has contributed a large share of the agricultural production increases of recent decades, although much of the world's agriculture still relies primarily on nitrogen from natural fixation by plants and bacteria, on naturally occurring phosphorus and potassium, and on nutrient recycling in crop residues, livestock urine and manure (FAO, 2011a). Indeed, sub-Saharan African is exporting nutrients to the rest of the world - the nitrogen balance of its agricultural land was calculated at -26 kg ha^{-1} yr^{-1} in 2000 (Goulding et al, 2008; Smaling et al, 2002)[9]. Predictions of future fertilizer consumption vary widely, but it is clear that increases in fertilizer use, combined with better crop growing techniques and nitrogen-fixing plants, will be needed to increase agricultural production in sub-Saharan Africa, and other regions where soil nutrient levels are currently very low (Alexandratos & Bruinsma, 2012; FAO, 2011a; FAO, 2011b). At the same time, the high to sometimes excessive use of fertilizers in some parts of the world is contributing to widespread environmental pollution and economic costs. More broadly, there is also concern that access to a sufficient global supply of crop fertilizers will be increasingly constrained in future (Malingreau et al, 2012) (see Box 2-3).

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[6] Annual Report 2013 on the European Community's Development and External Assistance Policies and their Implementation in 2012 http://ec.europa.eu/europeaid/multimedia/publications/publications/annual-reports/2013_en.htm

[7] http://ec.europa.eu/europeaid/news/agenda_for_change_en.htm

[8] Statement by International Energy Agency Executive Director on COP 18 http://www.iea.org/newsroomandevents/news/2012/december/name,34193,en.html

[9] Although sub-Saharan Africa imports nutrients in the form of food imports, these go into the cities and are not returned to the agricultural land.

Box 2-3 Are there enough nutrients to feed the world in 2050?

Constraints on the global supply of crop fertilizers are expected to increase, while at the same time the quantities of nutrients being released into the environment from agriculture are causing significant environmental problems in parts of Europe, the US, China and other areas with intensive agriculture (Dise, 2011; Houser and Richardson, 2010; Liu et al, 2013).

- The main limit to **nitrogen** fertilizer is the huge amount of energy, often natural gas, needed to produce it. Energy costs make up half to two thirds of the production cost of nitrogen fertilizers, and making nitrogen fertilizer accounts for almost half of all the energy used in agriculture in the US and Europe.
- **Phosphorus** is a finite, non-substitutable resource. Phosphate rock is supplied by just a few countries outside the EU, making the security of its supply dependent on the geopolitical situation. Whilst supplies are not yet scarce, demand is expected to increase, and high quality reserves that contain only low levels of soil contaminants such as cadmium (which accumulate in agricultural soils and potentially in crops) are more limited. It is expected that removing contaminants will require increasing amounts of energy (Schröder et al, 2010). Phosphate fertiliser is also vulnerable to price shocks.
- **Potassium** reserves are also in the hands of just a few countries. The EU is only partially self-sufficient and it could become a geopolitically strategic resource in future.
- **Micro-nutrients** (such as sulphur, boron, magnesium and iron) are increasingly critical limiting factors for crop production in some regions (Baulcombe et al, 2009)

In conclusion, local constraints to fertiliser supply and use are currently far more important than global supply factors. However, by improving fertiliser use efficiency and the recycling of nutrients, the EU can reduce pollution loads and increase the resilience of agriculture to price shocks, as well as reducing pressures on global supplies to enable other countries to increase use, principally in sub-Saharan Africa. For example, In the EU, a sustainable phosphorus strategy - which is currently lacking - could focus on closing the cycle by preventing losses anywhere in the chain from mining via agriculture to consumption, and by encouraging recycling of human waste (Schröder et al, 2010).

So, **what is the role for the EU in feeding the 10 billion?** The EU is a region of productive but already relatively intensive agriculture with an array of unresolved environmental issues, and with a current large net import requirement (in terms of volume of biomass) in the agriculture and food sector (although in terms of economic value the EU has recently switched to be a net exporter (European Commission DG for Agriculture and Rural Development, 2012)). Given the challenges outlined in this chapter and the conclusions of the studies undertaken for STOA, it appears that the best contribution Europe can make to global food and environmental security is to demonstrate how to build a sustainable agricultural model which maintains and enhances high productivity, which preserves and improves the agriculture production resource base (especially soil fertility), which moves towards more sustainable consumption patterns associated with reduced waste, and which at the same time radically improves the environmental performance of food production. The next chapter introduces the challenges the EU faces in achieving these goals.

3 AGRICULTURE AND FOOD IN THE EU: SOME KEY CONCERNS

This chapter outlines some of the challenges facing the agriculture and food sectors in the EU in the coming decades.

3.1 Agricultural production in the EU

Within the EU, agriculture is the dominant land use, covering 38 per cent of the total territory, and in terms of value, the EU is the world's biggest food importer and exporter (see Box 3-1). Increasing demand, technological developments, significant investment, enhanced skills and sustained policy support have led to significant productivity gains on land over the last six decades, especially in the more fertile regions. However, economic pressures and physical constraints have at the same time led to marginalisation or abandonment of agricultural land in other regions (IEEP & Alterra, 2010). There has been a steady reduction in the overall agricultural area over the last decades, partly due to abandonment of less productive land and conversion to forest, but also due to urbanisation and infrastructure development.

Box 3-1 European agricultural production and trade

Most of the EU's basic food needs (ie **cereals**) are met through domestic production. In 2010, the EU produced around 140 million tonnes of wheat, 58 million tonnes of maize grain, 55 million tonnes of barley, and 8 million tonnes of rye and mixed cereal[10] (Eurostat, 2012a). Around a third of this is used directly for food, and two-thirds for animal feed, with the actual proportion fluctuating according to relative prices and crop quality (except for some single use varieties eg maize for feed). On balance, Europe exports more cereals than it imports (mainly wheat), but the balance of imports and exports fluctuates from year to year.[11] EU cereal imports are mainly maize from Brazil and the Ukraine, used for animal feed[12]. The EU is a net importer of **oilseeds** (seeds[13], oils, and meal or cake), principally from oil palm[14] and soy – in 2010 the EU imported 13.6% of the world trade in oilseeds (excluding processed products). This is used primarily for animal feed but also for margarine and other fats for food manufacture and non-food uses including biofuel (the vegetable oil market is now strongly influenced by biofuel markets). In total, the EU imports around 30 million tonnes of animal feed annually, including over 20 million tonnes of soy principally from Brazil and Argentina, with smaller amounts from the US.[15] The EU is a net importer of around 10% of its fruit and vegetable demand, but a net exporter of high value food and drink products such as wine, spirit drinks, cheese, pork products and olive oil (European Commission DG for Agriculture and Rural Development, 2012).

Wheat is the EU's principal **arable crop**, grown on around 25 million ha in 2010, followed by maize (grain maize, silage maize and sweet corn), and barley (Eurostat, 2012a).[16,17] The next largest crop areas are oats, rye and mixed cereals, and oilseed rape (in northern and western Europe). Smaller

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[10] maslin, referring to mixed wheat and rye

[11] For example, in 2010/11 the EU exported around 32 million tonnes of cereals and maize and imported around 13 million tonnes, whereas in 2007/08, imports and exports were practically equal http://ec.europa.eu/agriculture/cereals/trade/cereals/2010-2011_en.pdf

[12] Smaller amounts of maize are imported from the US, Canada, Argentina, Paraguay and South Africa, and within Europe from Serbia.

[13] Imported soybeans are pressed for oil in the Netherlands and other EU countries.

[14] Mainly from Indonesia and Malaysia, followed by Central America.

[15] http://ec.europa.eu/agriculture/statistics/agricultural/2012/pdf/d04-1-44_en.pdf

[16] France is the leading cereal producer, followed by Germany, Poland and Spain, which together produce over half of the EU's production.

[17] http://ec.europa.eu/agriculture/statistics/agricultural/2011/

crop areas are sunflower (in southern and eastern Europe), potatoes, sugar beet, pulses, and field peas & field beans. More minor crops (only grown in certain areas) include rice, soybeans, cotton, and flax. In comparison, **horticulture** (fresh vegetables, plants and flowers) and fruits, wine and olive oil from **permanent crops** occupy small areas but contribute around half of the EU's overall (output) value of crop production and 26% of agricultural production value (Eurostat, 2012a).

The EU **livestock** sector is the largest in the world, and meat, milk and eggs make up 40% of the EU's agricultural production value[18] (Eurostat, 2012a). Around 30% of the EU's agricultural land is grassland, and another 10% is used to grow forage crops for livestock, including temporary grass and green maize for silage. However, Europe is deficient in animal feed, and a significant share of Europe's agricultural imports is used to feed animals. High input/output dairy systems, in which cows and cattle are housed for up to 8 months a year and fed maize silage or grass silage and other supplementary feed, account for nearly 85% of total EU dairy cow numbers and milk production (Leip et al, 2010). The EU's pigs and poultry also consume a large proportion of imported feed (Hasha, 2002).

The EU's reliance on soya and maize imports for 70% of its animal feed is referred to as the '**protein deficit**'. In 2011, the European Parliament adopted a resolution that puts forward a series of measures to re-evaluate import policies and to boost the EU's production of feed crops which tend not to be profitable for European farmers at present (European Parliament, 2011a). Recommended crops include legumes (field peas, broad and field beans, lupins, lentils, chick peas) and forages (lucerne and clover).

Average per capita food consumption in the EU is expected to remain rather stable (OECD and FAO, 2010). However, the EU has an increasing demand for biomass for energy purposes grown on agricultural land in response to renewable energy policy (see Box 3-2). In 2007, crops that were used for biofuels (principally oilseed rape, wheat and sugar beet) occupied around 3 per cent of EU arable land[19] (Ecofys et al, 2012; Elbersen et al, 2012), and some studies estimate that by 2020, the EU is likely to be using double the area and crop volume for biofuels[20] (Underwood et al, 2013). It is important to note that some of this crop volume is utilised for animal feed arising as a by-product of biofuel processing, so it is not completely replacing food production. The EU's biofuel demand has a much larger environmental footprint outside the EU, and unless measures are taken it may increase in future. There is also a huge potential to use crop feedstocks to make biomaterials; plastic production could technically be mostly substituted by bioplastics, and bio-based polymer production volumes are expected to triple to 2020 (nova-Institut, 2013) (see Chapter 8).

Box 3-2 Policy drivers of the EU's demand for biofuels

Biofuels are liquid fuels (bioethanol and biodiesel) made mainly from the processing of plant material or waste food products, and are primarily used as transport fuels. The EU's demand for biofuel feedstock (including grain and oil-seed crops) is currently largely driven by policy, specifically the targets set by the Renewable Energy Directive (RED) (Hart et al, 2013). The EU RED currently mandates 10 per cent renewable energy in the transport sector by 2020. How this policy and its associated targets will evolve in the future is currently under debate. The Commission proposed to limit the first generation crop-based biofuels to five per cent of transport fuel consumption (which is

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[18] values at producer prices, this means that taxes and subsidies related to production are not considered

[19] 3.2 million ha of arable land were used to grow biofuel feedstock crops in 2010 (Ecofys et al, 2012); total EU arable UAA in 2012 was just over 102 million ha (Eurostat [ef_oluft])

[20] This assumes an unchanged policy framework, and assumes that the main crop feedstocks and the average cropland requirement per unit of biofuels remain the same as currently

approximately the current level of usage). The remaining five per cent was to be met by second generation biofuels, ie using biofuels produced primarily from wastes and agricultural and forest residues rather than agricultural crops. At present, legislation in this realm is under debate and it may not be agreed very quickly in its present form. Biofuel feedstock prices are currently strongly linked to (and influence) food and feed prices, which are themselves affected by rising fossil fuel prices. In the longer term, biofuels produced from non-land based feedstocks (such as agricultural wastes and residues) may lessen the impact of this relationship although not remove it entirely. It is therefore difficult to assess the likely extent of biofuel feedstock production that will occur within the EU in the next decades.

It is likely that in the EU food and biomass demands will continue to be met largely from increasing productivity rather than expanding the agricultural area. There is still considerable potential to improve crop productivity; although the potential here is less than in several other parts of the world (Hart et al, 2013; Verburg et al, 2013). An analysis of a large dataset on agricultural Total Factor Productivity in 11 Western European countries concluded that productivity growth has not slowed, but overall agricultural production is not increasing due to the withdrawal of labour and land from agriculture (Wang et al, 2012). However the authors point to considerable regional and national differences. The story of productivity growth in EU agriculture is complex; total factor productivity shows the ratio of all outputs to all inputs, and great attention has to be paid to correct measures and quality adjustments. Note there is no contradiction between observed declining yield growth (which compares single crop output to a single input, area sown), and continuing total factor productivity growth. Furthermore, agricultural policy in the EU-15 in the 1990s aimed to cool an overheated agriculture by switching the support mechanism away from commodity market support. In Central and Eastern European countries, agricultural output has almost returned to the levels of the 1980s following the substantial production decreases in the economic transformation in the 1990s (Swinnen et al, 2009).

Europe is already a region of relatively intensive production as seen in yields per hectare, fertiliser use and machinery use per hectare. This is a function of the farm structures and the support systems that are in place. Crop yields in the main productive areas of North-west Europe are already high and the environmental impacts of production are considerable, and in some situations unsustainable (EEA, 2012a; Gay et al, 2009; Sutton et al, 2011), but there is potential on most farms to reduce yield gaps (Meyer et al, 2013) (see Box 3-3).

Box 3-3 Potential for reducing crop yield gaps in the EU

The potential for reducing crop yield gaps within the EU varies according to a range of factors, most notably on how near to their optimum production the farms are already. Crop yield potential represents the ideal yield that could be achieved by a particular farming system, climate and crop variety under optimal management of all yield-restricting factors (such as seeding date, plant density, nutrient supply, protection against pest and disease damage and weed competition, and water in rain-fed systems) (Lobell et al, 2009). The crop yield gap refers to the difference between the yield potential and average farmer's yields for a particular crop variety.

The performance of farmers within closely related agricultural conditions often show a remarkable heterogeneity, with yield differences spanning at least a factor of two (Lobell et al, 2009). Similarly, whilst average dairy cow productivity in the most productive EU Member States is 3.5 times that of the least productive, dairy holdings across the EU are characterised by a wide diversity of sizes, breeds, and degrees of mechanisation (Leip et al, 2010). Inefficiencies are related to complex social, economic and political factors and vary widely by region, and require a range of solutions (Neumann et al, 2010). Interpreting the impact of these different factors on agricultural potential is complex and is one of the reasons why there is limited reported analysis of the gaps between potential and actual yields across Europe (Hart et al, 2013).

Agricultural crop yields in Western Europe (for maize, wheat, potato, rapeseed, rye and sunflower) are considered to be near their current climatic potential yield, whereas crops in Eastern Europe (including maize, wheat, barley, rapeseed and sunflower) are considered to be below their yield potential (Licker et al, 2010), with key limiting factors being nutrient and water limitations in some places (Mueller et al, 2012). Other studies find a gradient of potential maize yields from North-East Europe to South-West Europe (Neumann et al, 2010), with significant limitations due to rainfall variability in Southern Europe (Reidsma et al, 2009). Climate change is predicted to have a significant impact on crop yield potentials in Southern Europe, particularly in relation to water availability (see section 3.2 below). Crop yield potentials can be increased through crop breeding, and this is discussed in Chapter 7.

Agricultural productivity and resource efficiency are influenced by investments in the maintenance of existing infrastructure, in new technology, and in its wider use. This in turn depends on investments in agricultural research, development (R&D) and extension in the EU. Some point to the decrease in investment in R&D in EU countries as an influence on agricultural productivity growth (Piesse and Thirtle, 2010; Thirtle et al, 2004). Others point out that the EU has, in the last two decades, developed a more risk-averse approach to new technology in agriculture than other regions – particularly compared to the Americas, China and Australia (eg EASAC, 2013). This often refers to the EU's position on regulating pesticides and to the lack of consensus on the use of genetically modified (GM) crops.[21] Some consider that this situation undermines the competitiveness of EU agriculture and diminishes the role the EU can play to assure increases in food production. This argument is countered by studies that point to the growth in innovative solutions that maintain yields whilst reducing pesticide use[22] (and see Chapter 7 for discussion of role of GM crops).

High-level political choices about the future of agricultural policy and agricultural innovation can have profound effects on the role the EU plays in global agriculture, whilst at the same time public opinion, drawing on a wide range of values and influenced by local and national-level communication and conflict resolution deficits, can have a significant influence on the acceptability of agricultural innovations (eg Evans, 2013; Horlick-Jones et al, 2006; Levidow et al, 2013). Innovation has risen up the political agenda in the EU but the response on the ground remains to be seen (see Box 3-4).

[21] Eg the recent study commissioned by the European Crop Protection Association reports the decline in the rate of development of new pesticides for the EU market, available at http://www.ecpa.eu/files/attachments/R_and_D_study_2013_v1.8_webVersion_Final.pdf

[22] See for example the abstracts of the 2013 Congress on Future IPM in Europe, http://www.pure-ipm.eu/sites/default/files/content/files/FUTUREIPM_BOOK%20OF%20ABSTRACT_PUREcontributions_0.pdf

Box 3-4 Agricultural innovation policy in Europe

The European Union has recently adopted policies designed to promote an increased rate of innovation in agriculture and food systems. The European Innovation Partnership for Agricultural Productivity and Sustainability[23] (EIP) aims to foster a competitive and sustainable agriculture and forestry industry that 'achieves more with less' input and works in harmony with the environment, including agricultural productivity, the bio-based economy, the food supply chain, and food quality, food safety and healthy lifestyles. It is based on the idea that there is a need to build bridges between research and technology and stakeholders, including farmers, businesses, NGOs and advisory services. It therefore requires the formation of 'Operational Groups' in each Member State that use bottom-up approaches to link research and practice, funded through the European Fund for Agricultural Development. Actions under the EIP will rely on funding from Horizon 2020, the new EU Framework Programme for Research and Innovation. This specifies food security, sustainable agriculture, and the bio-economy as one of the key societal challenges on which funding will be focussed. Funding is available for activities from research to market, particularly innovation-related activities such as piloting, demonstration, test-beds, and support for public procurement and market uptake[24].

3.2 Impacts of climate change on EU agriculture

Agriculture in Europe is already being affected by climate change. The recent Intergovernmental Panel on Climate Change Fifth Assessment Report states that "it is *likely* the frequency of heat waves has increased in large parts of Europe" (IPCC, 2013). It also concluded that "The frequency or intensity of heavy precipitation events has *likely* increased in … Europe", and these assessments are made with more confidence than those for most other regions in the world (IPCC, 2013 p4). Moreover, it is likely that under a 3.5° temperature rise scenario, impacts on ecosystems, crop production and other ecosystem services in Europe may be more marked than currently anticipated in the literature (Donatelli et al, 2012; Olesen et al, 2011; Olesen et al, 2012; Semenov and Shewry, 2011).

Changing climate conditions may threaten crop growth and agricultural productivity, water availability, soil functionality, and energy supply as well as increase the risk of floods, fires, pests, and diseases (Easterling et al, 2007). Crop productivity in Europe is already being affected by climate change, experienced through changes in the growing season of crops, the timing of the crop cycle, water availability and irrigation requirements (eg Van Der Velde et al, 2012). There is increasing frequency and unpredictability of extreme weather events, such as floods, heat waves, droughts, hail, and storms (EEA, 2012b). The effects on production will be both positive and negative, with major regional variations. Higher CO_2 concentrations in the atmosphere will increase plant productivity, though any resulting crop yield increases may be offset by extreme climate events (Easterling et al, 2007). Higher temperatures may also expand areas suitable for certain crop production northward in Europe and result in a longer growing season with potential yield benefits. However, these gains in crop productivity may be outweighed by adverse effects from extreme weather events and yield reductions in the southern European regions due to crop growth cycle changes, heat stress and insufficient water availability (EEA, 2010a; EEA, 2012b; Semenov & Shewry, 2011).

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[23] European Commission (2012) Communication from the Commission to the European Parliament and the Council on the European Innovation Partnership 'Agricultural Productivity and Sustainability'. COM(2012) 79 final. Brussels, 29.2.2012

[24] COM(2011) 808 final. 30-11-2011. Horizon 2020 - the Framework Programme for Research and Innovation. Brussels, European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions.

Water scarcity, particularly in the Mediterranean countries, is predicted to increase under climate change, which could negatively affect agricultural production in the EU (EEA, 2012a; EEA, 2012c; Iglesias et al, 2007a). Additionally, water quality may decrease due to diffuse agricultural pollution or leaching of nitrates and phosphates into water bodies from heavy rainfall (Hoffmann et al, 2009). Climate change is also likely to have complex impacts on European soils since changes in both precipitation levels and temperatures can affect the structure of soil and its capacity to leach and exchange nutrients as well as retain organic matter and water (Commission of the European Communities, 2009; Gregory et al, 2009; Olesen et al, 2011). Over the past 40 years, the number of droughts affecting the EU has increased in varying levels of severity, duration, and location, thus exacerbating the continuing water stress experienced by European river basins (Kossida et al, 2012 p18). Groundwater bodies in many EU countries have been identified as having a poor quantitative status. A growing demand for agricultural water use would intensify the competition with industrial and urban drinking water uses for an increasingly scarce resource (EEA, 2012d).

Long-term decreases in **soil organic carbon** (SOC) are predicted for some areas due to increasing soil erosion, faster decomposition rates in warmer conditions, and climate-driven changes in land use and management (EEA, 2012b). While soil organic carbon decreases have occurred in the past and are ongoing from agricultural practices, factors such as erosion and landslides could exacerbate soil organic carbon decrease at a faster rate than agricultural intensification, deforestation or conversion of grassland to arable land, which occur at a slower rate. Soil organic carbon losses impact soil functionality and thus may contribute to lower agricultural productivity in the EU (Ciais et al, 2010; Lal, 2012). Although the functionality of European soils is generally relatively robust in a global comparison, there are already worrying signs of their degradation (see Box 3-5).

Box 3-5 Arable soil degradation in the EU

Food security is dependent on soil functionality (eg soil structure, water retention, biodiversity, food production). Land use and some agricultural management practices have led to increased soil degradation and declining soil functionality in Europe. Degradation, including loss of organic matter content, soil erosion by water and wind, soil compaction, salinization, and acidification, is most pronounced in arable soil (Jones et al, 2012; Louwagie et al, 2009). Climate change may further negatively impact soils through higher temperatures (increasing evapotranspiration rates), erratic rainfall patterns, and increasing occurrences of droughts, which could harm soil water retention mechanisms and contribute to soil degradation through soil erosion and desertification (Jones et al, 2012; Verheijen et al, 2009). The balance between the contributions of anthropogenic and non-anthropogenic factors to soil degradation has to be examined in each particular farming system in order to identify the potential for improved land management. This is critical for improving soil functionality as well as for improving the adaptive capacity of the wider agro-ecosystem (Poláková et al, 2013).

Various agricultural land management practices can negatively impact soil functionality. For example, the tendency to use larger machines in crop production can lead to compaction. Arable soils become compacted by heavy machinery, especially during ploughing and for some crops at harvest. This collapses the subsoil structure and reduces the soil's biological activity, porosity, and permeability (Jones et al, 2012; Louwagie et al, 2009). Soils' water infiltration capacity may therefore decrease, posing a higher risk of soil erosion due to accelerated runoff over the land. Estimates of the area of compacted soil in Europe vary, but up to a third of European soil is considered at risk (Jones et al, 2012).

Soil organic carbon (SOC) is an essential component of soil organic matter, which influences soil functionality. Although European-wide data on soil organic carbon (SOC) is still heterogeneous and incomplete, several studies document the decline in SOC in arable soils (Panagos et al, 2013). As identified in a study testing precipitation, land use, soil type and management effects on Belgian cropland and grassland soils, climate change may impact SOC levels and increase soil degradation through rising temperatures, droughts, and extreme precipitation events (Meersmans et al, 2011). Losses of SOC were identified in a French case study as well, corresponding with higher temperatures and land use changes (Saby et al, 2008). SOC decline is of particular concern in the Mediterranean region, where high temperatures and droughts can accelerate its decomposition (Jones et al, 2012).

3.3 Impacts of EU agriculture on climate change

Greenhouse gas (GHG) emissions from agriculture are accounted for as methane (CH_4) and nitrous oxide (N_2O) under international methodologies of emissions inventories. Nitrous oxide emissions stem primarily from the application of manure and fertiliser on soils, and methane emissions result from livestock digestion and manure management. These agricultural emissions make up around 10 per cent of the EU's total greenhouse gas emissions. [25] The decrease in agricultural emissions over the past two decades resulted from a drop in livestock numbers particularly in the new Member States following the change in the political and economic framework after 1990, improvements in manure management and farm management practices, improved productivity and feed efficiency and implementation of environmental policies. However, increasing production linked to intensification could cause the GHG footprint of the agricultural sector to increase again, unless it is matched by improvements in resource use efficiency.

Agriculture uses fossil fuels directly for several applications including agricultural machinery, transport, heating and drying. These carbon dioxide emissions are accounted for separately under the energy sector and total one per cent of CO_2 emissions of all sectors ((European Commission, 2009a). Taking a wider life cycle perspective, the impacts of the EU food supply chain also include GHG emissions from upstream activities (eg production of fertilisers and pesticides and the production and maintenance of machinery), and these are not accounted for in official statistics of EU GHG emissions from agriculture itself or land use either. They are 'hidden' amongst the emissions in the energy sector, or in the case of imports of upstream materials, they may be accounted for outside the EU (see Box 3-6). In particular, the amount of fossil fuel energy embodied in nitrogen fertilizer, with corresponding effects on climate change, is already high and it is expected to double at global level to meet demand by 2050 (Malingreau et al, 2012)[26]. These estimations, whilst outside current accounting conventions for the agricultural sector, are helpful in illuminating the linkages between the relative greenhouse gas burdens along the food chain and identifying the most sizable opportunities for mitigation.

Box 3-6 GHG emissions unaccounted for in the official agricultural statistics from 1990 to 2007

Total emissions along the food chain. The full footprint of inputs into agricultural products, such as fertiliser and feed, including the footprint of other aspects of the food chain, for example food waste, differs from the official statistics. A recent life cycle analysis of the EU livestock sector (both beef and dairy), taking into account EU exports, imports and waste, demonstrated that overall emissions are much higher than those reported, amounting to between 630 and 863 million tonnes $CO_{2\text{-eq}}$, or 12–17 per cent of total EU-27 GHG emissions in 2007 (Bellarby et al, 2013).

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[25] Includes CH_4 and N_2O emissions from agricultural soils, manure management and enteric fermentation. Over the past twenty years, emissions from soil management decreased by 23.3 per cent, from manure management by 19.9 per cent and from enteric fermentation by 22.0 per cent. Emissions from land use, land use change and forestry are not taken into account in this calculation.

[26] Similarly, the energy for producing phosphate fertilizers is expected to increase as the easily usable high grade reserves are gradually becoming depleted (Schröder et al, 2010)

Meat imports. EU beef imports have grown since 1990. Lower livestock numbers in Europe played a role in reducing GHG emissions but emissions in countries exporting to Europe will have grown.

Feed imports. Annual feed imports by the EU equal roughly 40 million tonnes of dry matter, contributing roughly 2.5 million tonnes of nitrogen into the agricultural system (Westhoek et al, 2013). This additional nitrogen is integrated into the system through livestock consumption and is only accounted for upon release of N_2O from application of manure on soils, which occurs at approximately 0.37 million tonnes N_2O per year (Westhoek et al, 2013). Estimates based on EU-27 feed imports attribute 142 million tonnes of CO_2-eq emissions to land use change for soybean production in exporting countries (Lesschen et al, 2011).

Biomass production for energy. Biomass production in South American or Asian countries for EU use as biofuel, which increased steeply after 2007, competes with other land uses and has other environmental impacts including emissions associated with deforestation or the ploughing of grass. These effects are accounted for in the countries of origin of feedstocks.

Sources: (Bellarby et al, 2013; Diaz-Chavez et al, 2013; European Commission, 2009b)

Broadly speaking, emissions from agriculture are associated with a range of land management activities as well as natural biological processes (in particular livestock digestion and the release of N_2O by N-fixing species). Cropland soils and vegetation act as a net source of GHG emissions (including CO_2, N_2O and CH_4)[27], releasing approximately 70 million tonnes of CO_2-eq emissions annually (European Commission, 2009a). The major share of these emissions stems from conversion (drainage) of organic soils for cultivation of peatlands or land use change, which amounts to 20–40 tonnes of CO_2 emissions per hectare per year (EEA, 2012b; Smith, 2012). In addition, agricultural soils release large amounts of N_2O emissions from fertiliser application.

At the same time, soils and vegetation have the capacity to act as a sink, or remove CO_2 from the atmosphere. Land use, land use change and forestry in the EU is a substantial net carbon sink (European Commission, 2009a).Grasslands and wetlands have significant soil carbon stocks, containing an estimated 75,000 Mt of carbon in the EU-27 (EEA, 2012b). Climate change and current agricultural practices are two key (inter-related) factors potentially affecting organic carbon loss in agricultural soils (EEA, 2012b; Smith, 2012). Appropriate land management options for cropland, grazing land, and the restoration of cultivated organic soils and degraded land have the potential to significantly lower emissions from agricultural land and increase its carbon sequestration potential, offering an estimated technical mitigation potential of 750 Mt CO_2-eq per year (IPCC, 2007). Wetlands on peat or organic soils can be particularly important carbon sinks as long as they remain intact and do not become degraded through drainage or burning for agricultural use. In contrast, drained peat soils can become a continuing source of GHG emissions. Currently they constitute around 88 per cent of total cropland emissions in the EU (European Commission, 2009b; Gobin et al, 2011; Schils et al, 2008).

3.4 Impacts of EU agriculture on biodiversity and ecosystem services

Agriculture is associated with many habitats of high biodiversity value, but agricultural change since the 1950s has caused the loss of many of the semi-natural habitats and elements that were created by extensive agricultural practices, resulting in a predominance of highly modified and simplified agricultural habitats and landscapes over much of the lowlands of the EU (Poláková et al, 2011).

[27] Included under the land use, land use change and forestry (LULUCF) emissions rather than the agricultural emissions category (European Commission, 2009b).

The EU has lost half of its common farmland bird populations[28] and half its grassland butterfly populations (EEA, 2013a), and over three quarters of the semi-natural habitats associated with agriculture have an unfavourable conservation status (EEA, 2010b). These **biodiversity losses** in Europe's agricultural landscapes are attributable to intensification and specialisation in some areas and abandonment of low-intensity biodiversity-rich farming systems, known as High Nature Value farmland, in other areas (see Box 3-7). In parts of Europe where agriculture is already highly intensive, a major driver of biodiversity loss is eutrophication partly caused by ammonia emissions from manure and fertilizers and phosphate leaching from soils (Ceulemans et al, 2013; Dise, 2011; EEA, 2010c). Marine as well as terrestrial habitats can be adversely affected. These biodiversity losses are projected to continue, and are undermining the EU's ability to meet its nature conservation targets (and those of the Convention on Biological Diversity).

Box 3-7 The loss of High Nature Value (NHV) farming and farmland in the EU

The loss and degradation of **semi-natural habitats** dependent on farming is the most serious threat to agricultural biodiversity in most of the EU (Billeter et al, 2008). These farming systems, characterised by semi-natural habitats, mosaic-like farming landscapes, and a high density of farmland features (such as terraces, walls, hedges, ponds or ditches), are often referred to as **High Nature Value** farming (HNV) (Baldock et al, 1993; Baldock, 1999; EEA, 2004; Veen et al, 2009), and they still make up around a third of the EU agricultural area (Paracchini et al, 2008). Many of these semi-natural habitats and their associated species are of European conservation importance and therefore the subject of conservation measures under the EU Habitats and Birds Directives. But despite the protection of 10 per cent of farmed land within the Natura 2000 network, a particularly high proportion of these habitats have an unfavourable conservation status compared to non-agricultural habitats (EEA, 2010b; European Commission, 2009c).

Such impacts are now mostly attributable to partial or complete abandonment of agricultural management as a result of their low economic viability and social and agronomic change (IEEP and Veenecology, 2005; Keenleyside and Tucker, 2010). Extensively managed livestock systems are most at risk, especially in mountainous and remote regions and areas with poor soils and harsh climates (Dover et al, 2011; Laiolo et al, 2004). Determining the area and distribution of abandoned land across the EU is problematic (Keenleyside & Tucker, 2010), but as examples, annual losses of 0.17 per cent of Utilised Agricultural Land (UAA) in France and 0.8 per cent in Spain were recorded from the late 1980s to the end of the 1990s (Pointereau et al, 2008). Overall, the EU has lost 2.4 per cent of semi-natural farmland since 1990, 40 per cent of which has become scrub or forest, and a fifth converted to more intensive farming (EEA, 2010b). Abandonment of semi-natural farmland is likely to continue over the next decades as, despite increasing agricultural demand (European Commission, 2012a), it seems reasonably certain that the profitability of extensive livestock farming will continue to decline (Nowicki et al, 2009; Rienks, 2008). In some circumstances such abandonment may enable habitat restoration with beneficial biodiversity impacts (Navarro and Pereira, 2012). However, given the high biodiversity importance of the semi-natural grasslands that are at most risk, in most situations large-scale abandonment of semi-natural habitats is likely to be significantly detrimental for biodiversity in the longer term (IEEP & Alterra, 2010; Macdonald et al, 2000; Stoate et al, 2009).

[28] A loss of 50% of the populations of 37 common farmland bird species from 1980 to 2010, based on bird monitoring data from 23 EU countries. Source: http://biodiversity-chm.eea.europa.eu/information/indicator/F1090245995

Substantial **external biodiversity impacts** also occur as a result of EU feed and biofuel imports (AEA, 2008; Lugschitz et al, 2011). For example, EU soybean imports over the last two decades have been associated with a net embodied deforestation of over 3 million ha in Brazil and Argentina (Cuypers et al, 2013). Current EU imports of biofuels and bioenergy feedstocks, equivalent to 2.4 million ha of land use outside the EU, are associated with widespread biodiversity impacts (Campbell and Doswald, 2009; Ecofys et al, 2012).

Why do biodiversity losses in agricultural systems matter? Agriculture relies on good soil quality, low pest and disease pressure, pollination, and other ecosystem services provided by nature, and biodiversity loss may threaten the long-term sustainability of farming in some areas as a result of soil degradation, declines in pollinators, increased outbreaks of pests and diseases, and other impacts. For example, a recent expert review indicates that **soil biodiversity**, which is clearly linked to soil functions (de Vries et al, 2013), is potentially under high pressure in nearly a quarter of the EU[29] (Gardi et al, 2013). Much of this is due to the serious decline of soil organic matter on most of Europe's arable land (Jones et al, 2012). The loss of components of biodiversity such as flowering weed populations and livestock genetic diversity can have significant detrimental impacts on many related ecosystem services, including the loss of **pollination** services through the collapse of European honeybee and wild pollinator populations (see Box 3-8), and the loss of adaptation potential through disappearing European **plant and animal genetic resources** for food and agriculture (see Chapter 7). For example, Europe harbours a large part of the world's recorded domestic livestock diversity (Nitsch, 2006), but almost half of European livestock breeds have endangered or critical status or are extinct[30] (DEFRA, 2013; FAO, 2007).

Box 3-8 Pollinators in the EU: honeybee losses and the decline of wild pollinators

Pollinators, including both domestic honeybees and wild bees and other insects, ensure the reproduction and fruit set of many crops and wild plants by transporting pollen from one flower to another (Klein et al, 2007; Potts et al, 2010). In Europe, the fruit and seed production and quality of a third of food production (by weight) is dependent upon, or enhanced by, insect pollination, including most fruit, nut, vegetable and oilseed crops (Blacquière et al, 2012; Klein et al, 2007; Potts et al, 2010). The economic value of food production from animal-pollinated crops in the EU is estimated at €15 billion per year (European Parliament, 2011b), and we rely on these pollinator-dependent crops for most of the vitamins and other nutrients needed for a healthy diet (Eilers et al, 2013).

In recent years, heavy losses of honeybee colonies have been recorded in many EU Member States (AFSSA, 2008; van der Zee et al, 2012). The causes of honeybee colony loss are disputed and vary across regions, but current knowledge suggests the cause of decline is due to **multiple interacting factors** (AFSSA, 2008; Breeze et al, 2012; European Parliament, 2011b; Schweiger et al, 2010; Tylianakis et al, 2008). Factors include: pests and diseases (*Varroa destructor* mites, *Nosema* parasites, bacterial brood diseases), and the lack of appropriate, adapted and accessible treatments for honeybees; pesticides (particularly neonicotinoids); destruction of habitat including loss of semi-natural grasslands; loss of nutrient sources, diversity and quality in the countryside (loss of flowering grasslands, verges and hedges); poor beekeeper practices; and lack of honeybee genetic diversity and disease resistance. Emerging threats include invasive alien pests and pathogens, and the impacts of climate change. At the same time, there is increasing evidence that populations of wild pollinators are declining strongly (Bommarco et al, 2011; Carvell et al, 2006; Goulson et al, 2008; Kosior et al, 2007). It is likely that many of the same factors are also responsible for the decline in wild pollinators, although evidence for this is mostly lacking (Biesmeijer et al, 2006; Goulson et al, 2008; Whitehorn et

[29] In the EU-25 (excluding Sweden and Finland)

[30] EU biodiversity indicator livestock genetic diversity: http://www.eea.europa.eu/data-and-maps/indicators/livestock-genetic-diversity/livestock-genetic-diversity-assessment-published

al, 2012). The evidence for the factors driving bee declines and the actions that can be taken to reduce losses are detailed in Underwood et al (2013).

There is evidence that the **natural biological control** of pests, diseases and weeds across Europe's arable farmland is compromised because of the non-target impacts of insecticide use and the loss of refuge habitat and floral resources to sustain populations (Geiger et al, 2010; Landis et al, 2005; Rusch et al, 2013). A number of pests, diseases and weeds present challenges to agricultural production in Europe and can destroy yields if not controlled; and it is predicted that climate change and climate variability will increase pest and disease losses in agriculture, especially in Southern Europe (EEA, 2012b; Gregory et al, 2009). However, pesticides can have negative impacts on biodiversity and water quality, and can destroy populations of natural enemies (insects and other organisms including predators, parasitoids, and pathogens) which would otherwise act against these pests.

3.5 The impacts of food processing and food wastage in the EU

The European food and drink industry is the EU's largest manufacturing sector, and has a very important role to play in achieving a more sustainable food and agriculture system in the EU (Langelaan et al, 2013; Sonigo et al, 2013) (see Chapter 8 for a discussion). It is of note that the mitigation potential of reducing the footprint of the total EU food supply chain downstream of agriculture (1.5–15.6 Gt CO_2-eq yr) is potentially much greater than that of agricultural production itself (1.5–4.3 Gt CO_2-eq yr) (Bellarby et al, 2013). The food sector is one of the largest user of energy in the economy as a whole, of which most is used in processing and wholesale, followed by food preparation and consumption in households and the catering sector. A smaller proportion of the energy use goes into agricultural production, packaging and transport (Pelletier et al, 2011).

Reducing food wastage presents a major opportunity for resource efficiency and food security in the EU, where an estimated 89 million tonnes of food is wasted each year (Monier et al, 2010) (see Chapter 8 for discussion). This wastage impacts on water resources, biodiversity and climate change. A more responsible and efficient use of food would result in a saving of resources in terms of land, water, energy, equipment and labour, as well as avoiding the negative biodiversity impacts and greenhouse gas emissions associated with agricultural production. For example, a study for the European Commission estimated that food wastage in Europe is responsible for at least 170 million tons of CO_2-eq greenhouse gas emissions, calculated for all stages of food production from cultivation to consumption to final disposal (Monier et al, 2010)[31]. While fruit, vegetables and bakery products are the most commonly wasted food products in Europe, the highest greenhouse gas emissions per kg are generated by meat products, of which beef products are the most important (Fritsche and Eberle, 2007; Göbel, 2012; Lee and Willis, 2013). Furthermore, food waste is associated with methane emissions from landfill disposal. If food waste is brought to waste incineration plants it reduces their efficiency due to its high water content (Priefer et al, 2013).

A study calculated that the food discarded in the catering sector of the EU-15 member States required an area of 1.5 million ha of agricultural land to produce (Engström and Carlsson-Kanyama, 2004). Avoidable food losses in Germany were calculated to be equivalent to 290 m^2 per capita, or about 13 per cent of the German per capita land footprint of food (Noleppa and von Witzke, 2013). If food waste were reduced, this land could be used for other purposes, such as bioenergy production. Other studies use calculations of the average water footprint associated with different foodstuffs to estimate

[31] Jan et al (Jan et al, 2013) estimate the global carbon footprint of food waste at 3.3 Gt CO2-eq; were this quantity a country, it would be the world's third largest emitter, after China and the United States. Food wastage occupies almost 1.4 billion hectares of land worldwide or 28% of the world's agricultural area, with meat and milk responsible for 78% of the total surface though only 11% of the wastage volume.

the substantial quantity of water use embodied in Europe's food waste, in particular food, such as rice, produced from irrigated agriculture (eg Lundqvist et al, 2008).

In recognition of the problem, the European Commission has set the policy target of halving food waste by 2020 in its Roadmap to a Resource Efficient Europe (European Commission, 2011a), and the European Parliament has warned that food waste will increase by 40 per cent by 2020 unless additional preventative actions or measures are taken (European Parliament, 2011c). The expected EU Communication on Sustainable Food will look at ways to tackle resource inefficiencies across the entire value chain, with the objective of helping the food system become more resilient and competitive[32].

3.6 Diets and dietary change in the EU

The average European diet has a large environmental footprint. EU consumption of meat, dairy, eggs and fish is around twice the global average (Westhoek et al, 2011), and foods from intensive livestock production have much larger environmental impacts than plant-based foods, including high greenhouse gas emissions, high water use, and pollution from ammonia emissions and nitrogen leaching (Aiking, 2011; Steinfeld et al, 2006). Furthermore, some ill health effects, such as cardiovascular diseases and diabetes, are likely to be linked to high consumption of saturated animal fats from red meat and dairy products (Aiking, 2011; Westhoek et al, 2011). Considering that current diets in the EU-15 include on average around 40 per cent overconsumption of calories (Schmidhuber and Traill, 2006) and 60 per cent overconsumption of protein (de Boer et al, 2006), there would appear to be ample room for diets with substantially less consumption of animal products. At the same time, it should not be forgotten that at least 3 per cent of the EU population cannot afford high quality and nutritious diets[33]. Food poverty may be more widespread than EU statistics show; in the UK, for example, it is estimated that 10 per cent of households reduced their fruit and vegetable purchases by a fifth and cut down on the energy content of their food over the last five years (Food Ethics Council, 2013b).

A shift to more environmentally sustainable diets would have benefits for public health, and the costs of providing health services, as well as substantially lower environmental impacts, including high resource efficiency (including reduced land, water and fertiliser use) and lower emissions of greenhouse gases and other pollutants (Aiking, 2011; Erb et al, 2009) (see Box 3-10). Various studies have estimated the kinds of possible environmental benefits that could be obtained from dietary changes in the EU. These calculations assume rather unrealistically that all consumers switch to a given diet, and in this sense are illustrative rather than predictive. The studies also assume that shifts in food demand will result in a decrease in production, principally meat and dairy. In the short term, however, it is likely that reduced food demand in the EU would simply lead to greater exports, possibly stimulating demand elsewhere (Grethe et al, 2011).

Box 3-10 Potential environmental benefits of sustainable diets in the EU

Possible reductions in greenhouse gas emissions: A recent study on changes in dietary choices concludes that a completely vegetarian diet in the EU could lead to a maximum reduction in emissions of 266 Mt CO2 eq. per annum, of which 202 Mt $CO_{2\text{-eq}}$ would occur within the EU. A slightly lower reduction would be expected from a shift to a "healthy diet", involving lower calorie intake and more fruit and vegetables than the current diet, ie a reduction of emissions of 200 Mt $CO_{2\text{-eq}}$, of which 160 Mt $CO_{2\text{-eq}}$ in the EU.. A shift to a diet with a day without animal proteins would achieve a reduction of 50 Mt

[32] See http://ec.europa.eu/environment/eussd/food.htm

[33] Around 7% of the EU population were materially deprived in 2010, of which less than half cannot afford a decent meal every other day. Source: EU Social Situation Monitor: material deprivation statistics, http://ec.europa.eu/social/main.jsp?catId=1050&langId=en

$CO_{2\text{-eq}}$, of which 39 Mt $CO_{2\text{-eq}}$ would be in the EU (Faber et al, 2012). Another study concludes that potential reductions in food waste and changes in dietary choice to reduce meat consumption in Europe would reduce the overall GHG impact of the EU livestock sector more profoundly than mitigation efforts at farm level (Bellarby et al, 2013).

Possible reductions in other environmental impacts: A study calculates that a predominantly vegetarian diet based on pulses and oil crops (including dairy products) in the EU would reduce water consumption by 38% (Vanham et al, 2013). A study that used an index of combined environmental impacts calculated that current food consumption is responsible for a quarter of all environmental impacts in the EU; a shift to a Mediterranean-style diet with lower red meat consumption (which is much more realistic than a shift to widespread vegetarianism) would reduce these impacts by 8% (Tukker et al, 2009). Another study calculates that a scenario of faster growth in animal productivity, a 20% substitution of red meat by pig or poultry, a 25% decrease in meat consumption in high-income countries and a somewhat lower food wastage rate would decrease the area of global land use for agriculture by 2030, instead of the FAO's predicted expansion (Wirsenius et al, 2010).

Barriers to changes in dietary choice include a range of behavioural factors, such as habitual behaviour, lack of consumer knowledge on the impacts of food, and varied cultural traditions and societal values associated with particular foods (especially meat) (Faber et al, 2012). The policy measures to bring about change in food consumption are, however, difficult and often slow acting. 'Soft' policy measures such as awareness raising campaigns (eg mass media campaigns, school-based interventions, food product labelling), information, nutritional labelling, health messaging and advice are all important but have to be pursued over protracted periods to show impacts (Bellarby et al, 2013; Caspari et al, 2009; Faber et al, 2012; Poláková et al, 2013). More direct economic incentives, such as fat or sugar taxes (Mytton and Clarke, 2012), are politically contentious and their design and impacts require close attention given that poorer people generally spend higher proportions of their income on food. However, over time a combination of policy interventions, including such "nudging", can benefit both health and ecology, because healthy and sustainable food go largely hand in hand (Health Council of the Netherlands, 2011). European governments and NGOs are now providing recommendations and advice on sustainable diets (eg Health Council of the Netherlands, 2011; Macdiarmid et al, 2011) and the European Commission will publish a Communication on sustainable food in early 2014[34].

[34] See http://ec.europa.eu/environment/eussd/food.htm

4 SUSTAINABLE AGRICULTURAL SYSTEMS AND MANAGEMENT PRACTICES

This section provides an introduction to options for a more sustainable agriculture in the EU (Meyer et al, 2013). This is a major topic that can be addressed here only in broad terms, noting the variation between what is appropriate in different regions, farms and systems. It is helpful to distinguish between two levels, that of the production system and that of the individual farming practices that can be employed in different systems. Both are important. This chapter reviews a range of production systems which offer alternative approaches to addressing the productivity and associated challenges that lie ahead. The section also sets out a number of more specific management actions that have been identified for their potential for contributing to improving productivity, climate change mitigation, improving the adaptive capacity of farms and delivering benefits for biodiversity (Underwood et al, 2013). This provides the context for the more detailed discussion of specific challenges, trade-offs and synergies in chapters 5 and 6.

4.1 Defining sustainable agriculture

The interrelated challenges of climate change and biodiversity loss underline the importance of ensuring both environmentally and economically sustainable agricultural practices in Europe, including the selection of appropriate production systems. This will include looking beyond the currently dominant systems to a broader range of options across the spectrum of different approaches and technologies. Both productivity and sustainability are even more critical if it is necessary to increase production to contribute more to global food supply over the longer term. Sustainable agriculture is defined in many different ways by a variety of groups, academies and stakeholders with a more direct interest. However it is broadly recognised that sustainability has environmental, economic and social dimensions[35]. Some of the characteristics one would look for in a more sustainable agricultural sector in Europe include:

- Achieving increased efficiency of resource use, including the use of inputs (especially inorganic fertiliser, energy from fossil fuels, and water) whilst maintaining or increasing yields;
- Achieving significant decreases in emissions of greenhouse gases (especially methane and nitrous oxide), increased carbon sequestration, and other climate change objectives, including contributions to renewable energy supply;
- Achieving decreased losses of nutrients to the environment (especially ammonia, nitrate and phosphorus), closing cycles to a greater degree than currently;
- Conserving and increasing agricultural natural capital (especially soil organic matter, supporting, regulating and cultural ecosystem services from farmland and farmland biodiversity);
- Achieving economically viable farming with less reliance on public subsidy;
- Contributing to the maintenance of the social fabric in rural areas, including appropriate levels of employment in the local context.

[35] For example, ethical, social and economic concerns include; animal welfare (eg European Commission, 2007), the nutritional quality of food (eg White and Broadley, 2009), socially, fair and equitable food systems (eg Environmental Audit Committee, 2012), and the autonomy of smallholder farmers and local agri-food markets (eg Horlings and Marsden, 2011). Other social considerations include employment, working conditions, and health impacts. The economic dimension is also critical. In many parts of the developed world (eg the EU and Japan) much farming is sustained by significant transfers through agricultural policy. In some situations farming is associated with extreme poverty.

The term 'sustainable intensification' has been coined to describe this twin challenge of increasing the productivity of agricultural land to produce more food and more environmental services in the face of a changing climate (Baulcombe et al, 2009; UK Government Office for Science, 2011). Agricultural production as a term needs to refer not only to the production of marketed food, biomass, and fibre, but also to the range of other ecosystem services provided by agricultural land, such as carbon storage, which are generally non-marketed (Tscharntke et al, 2012). Sustainable intensification of existing agricultural land in this sense is preferred to bringing significant areas of new land into cultivation (in the EU and many other regions of the world) because it is judged that this will have a more acceptable environmental impact, particularly on climate and biodiversity. Although it is generally agreed that increasing the production of food and biomass on existing farmland is an important goal for European agriculture over time, key questions arise as to how this is achieved in practice in the varied conditions found in Europe.

Sustainable intensification refers to the increase in desired outputs with the same or fewer inputs, but with significantly reduced or eliminated environmental degradation. Intensification should refer to the development of agricultural production systems which are knowledge, technology, natural capital and land intensive, but decreasing in their intensity of use of non-renewable inputs and consequential environmental damage (Baulcombe et al, 2009). Sustainable intensification in this sense seeks to encapsulate new approaches which are clearly different from the intensification pathways of the past which were based mainly on increasing use of external inputs.

Consensus on what sustainable intensification means, and crucially, how to measure it, is still evolving. Some of the current debates in this area are due to the relative weightings given to the "sustainability" and the "intensification" components of the concept, and the misunderstanding of the intensification component as referring only to food production rather than all of the desired outputs of agriculture[36]. Sustainable intensification represents an aspiration of how food production should change, and is not a description of a particular agricultural type or system (Garnett & Godfray, 2012). It is plain that sustainable intensification will lead to quite different development paths for the varying production systems found in the EU. For example, in Northwest Europe there is a particular challenge of achieving productivity gains while at the same time reducing environmental pressures. Furthermore it is necessary to consider the sustainable intensification of EU agriculture in its global context because the EU is such a significant player in world markets.

4.2 Production systems for sustainable agriculture

The response to the sustainability challenge for European agriculture should involve farmers adopting a more systems-oriented approach to their management. This means looking at their whole business and its interaction with soil, water, the atmosphere, biodiversity and landscape above and beyond traditional agronomic and economic concerns. It is helpful to distinguish between the development of different farming systems on the spectrum of intensity, scale and location. The mainstream R&D effort often focusses to an excessive degree on the most productive and profitable systems. These represent the largest share of economic output in Europe, but represent only a minority of European farmers and are only one component of the interlocking systems that together maintain European landscapes and are appropriate for making efficient use of the resources available. Europe's diversity of farming systems and environmental and climatic conditions present a range of opportunities for more sustainable farm production.

In taking forward a stronger focus on the farming systems level in Europe, the priorities include (Meyer et al, 2013):

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[36] Eg Tudge (2011) What does sustainability mean? And what on earth is sustainable intensification? The Campaign for Real Farming, http://www.campaignforrealfarming.org/2011/07/what-does-sustainability-mean-and-what-on-earth-is-sustainable-intensification/, accessed 10 May 2012

- a clear sense of the value of different systems according to local conditions in Europe;
- giving greater emphasis to increasing the efficiency of input use on all farms but particularly on more intensive systems both to improve their environmental performance and either to maintain or improve yields; soil related factors are particularly significant considerations for intensive arable systems;
- increasing the productivity and social and economic viability of more extensive systems that are adapted to environmental and agronomic constraints in an appropriate way;
- paying more attention to the role of farms outside the main commercial sector to encourage appropriate practices and a larger contribution to local food supplies.

Five production systems that are particularly relevant in this context are highlighted below, focusing primarily on arable farming in the EU (but see Box 4-2 for a global view) (FAO, 2011b; IAASTD, 2009; STOA, 2009). These systems are characterised by particular aims and principles and each encompasses a range of management actions and approaches to soil and water management, the use of nutrients and the management and control of diseases, pests, and weeds. They cover different approaches, both more conventional and more agro-ecological in their orientation. All are the focus of active innovation research in Europe[37]. These five production systems are as follows (Meyer et al, 2013):

- Precision agriculture;
- Conservation agriculture;
- Organic farming;
- Agroforestry; and
- Mixed crop-livestock production / integrated farming.

These production systems are not mutually exclusive, and they can be implemented in a number of combinations. The key objectives of each system and the relevant techniques are summarised briefly below.

Precision agriculture

Precision agriculture in a broad sense is the information-based management of agriculture. Precision agriculture in a more narrow sense is the spatially variable management of crop production in order to optimise the application of inputs (fertilisers, lime, seeds and pesticides) to the right places at the right times (Meyer et al, 2013). Its key objectives are to apply crop management measures more accurately both spatially and quantitatively according to crop needs and local conditions, thereby using resources more efficiently, increasing yields, and reducing the environmental impacts of excessive input use. The approach emerged from the increasing availability and applicability of information technologies such as sensor technologies, remote sensing, satellite-supported positioning systems, and geo-information systems, combined with farm equipment that allows variable rate application. Precision crop management may use data collected by sensors in the field and adjust application rates directly, or information from surveys and field maps to pre-adjust application rates, or a *combination* of both approaches. Precision livestock farming uses electronic tagging and software to make efficient decisions about feeding, reproduction, slaughtering etc.

There is a lack of up-to-date information on the adoption of precision agriculture in the EU. It is of most relevance to larger-scale farms with a high level of machinery use and significant input rates, and has therefore been adopted mainly in the high productivity farming areas of Denmark, France, Germany, and the UK, followed by the Czech Republic, France and the Netherlands (Pölling et al,

[37] See for example: http://www.ecpa2013.udl.cat/; (Basch et al, 2012; Mäder and Berner, 2012); the TP Organics Platform http://www.tporganics.eu/; EURAF proposals for agroforestry innovation http://www.agroforestry.eu/; the FP7 Cantogether project on integrated farming systems http://www.fp7cantogether.eu/objectives

2010; Reichardt and Jürgens, 2009). Many farmers are still unaware of precision agriculture techniques (Reichardt et al, 2009) although it is now spreading more widely.

Conservation agriculture

Conservation agriculture is a production system based on the three principles of minimal or no mechanical soil disturbance through zero or reduced tillage, permanent organic-matter soil cover, and diversified crop rotations (Meyer et al, 2013). Conservation agriculture refers to a range of soil management techniques, including non-tillage, zone, strip or row tillage, non-inversion tillage, surface incorporation of crop residues, cover crops, green manures, mulching of crop residues, direct seeding, and changed weed management with the use of contact herbicides (such as glyphosate) instead of residual herbicides and/or soil cover management. It aims to prevent soil degradation and preserve and enhance soil fertility by strengthening natural biological processes above and below ground, and it can significantly reduce GHG emissions because of reduced energy use and reduced oxidation of soil carbon (FAO, 2011b; Louwagie et al, 2009). Soil conservation techniques such as cover crops and green manures are now widely used in European crop production[38].

The Farm Structure Survey records only 3.4 per cent of EU-27 arable land under zero tillage (Eurostat, 2011), but reduced tillage uptake on arable land is much higher, particularly in Finland, the UK, France, Germany and Portugal (Louwagie et al, 2009), and conservation tillage techniques are recorded on over 30 per cent of arable land in Bulgaria, Czech Republic, Germany and Cyprus (Eurostat, 2011).

Organic farming

Organic farming systems are identified by a shared set of objectives and principles, as defined by the International Federation of Organic Agriculture Movements (IFOAM), and a range of national or private schemes[39]. Organic farming can be described as a production system that sustains the health of soils, ecosystems and people, by relying on ecological processes, biodiversity and nutrient cycles adapted to local conditions, rather than the use of external inputs (Meyer et al, 2013). It aims to combine tradition, innovation and science[40]. Organic farms are part of a controlled certification system that aims to guarantee the standards for consumers who pay a premium for the labelled produce. Key organic farming techniques include a reliance on organic fertilisers (manure and compost) and nutrient cycling through the use of diversified crop rotations, predominantly biological pest control methods, and no use of synthetic pesticides[41], fertilisers or GMOs. The implementing rules are fairly complex and allow for certain flexibility, for example for transitional situations. Within the EU organic agriculture is legally defined by Regulation 834/2007[42]. This framework stipulates standardised requirements on production, control system and imports; however, there is variation between Member States in eligibility conditions, requirements, and payment rates (Sanders et al, 2011).

According to EU farm statistics, organic farming currently covers 5.4 per cent of agricultural land and continues to expand, albeit in highly varying rates across the EU (Eurostat, 2011). Organic farmers receive financial support under rural development programmes in most parts of the EU.

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[38] In some Member States they are obligatory through CAP cross-compliance rules

[39] Such as Demeter, Soil Association, KRAV, Nature & Progres

[40] http://www.ifoam.org/en/organic-landmarks/principles-organic-agriculture

[41] Detailed specifications vary, but generally allow the use of minerals and other 'natural / simple' chemicals such as sulphur, copper, soap, some pyrethroids, and paraffin oil, as well as certain micro-organisms including viral or bacterial products such as Bt, as insecticides or fungicides

[42] Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91. http://ec.europa.eu/agriculture/organic/eu-policy/legislation_en and associated implementing rules

Agroforestry

Agroforestry is an integrated land use system that combines cultivation of trees and shrubs with annual crops and/or livestock on the same land, with the aim of benefiting from the complementarities (Meyer et al, 2013). Agroforestry systems include: *silvoarable systems* with annual crops and shrubs/trees, including modern systems of alley cropping; *silvopastoral systems* with trees and pasture or meadow, with use of cut fodder from trees; and combinations of both systems (STOA, 2009).

Traditional agroforestry systems such as wooded pasture, dehesa and montado, orchards and olive or nut groves have formed key elements of Europe's agricultural landscapes for centuries (Bergmeier et al, 2012; Burgess, 2011; Eichhorn et al, 2006). However, these have declined over the last decades and a number have already become extinct or exist only in a threatened state, while silvoarable agroforestry remains of importance in many regions of Southern Europe. More contemporary variants are much less widespread than the traditional forms (Palma et al, 2007). Official data on agroforestry in the EU are not available.

Integrated crop-livestock production

Integrated crop-livestock production[43], as promoted for example by the FAO, describes farming in which livestock and crops are produced within a co-ordinated framework, according to the principles that farm operations should be linked to create closed loops, including the internal use of crop products for feed, management of farm waste for fertilisation, and the diversification of farm production (Meyer et al, 2013). Approaches may include the integration of forage crops into crop rotations, and integrated nutrient management combining livestock manure, compost, green manures and mineral fertilisers (Roy et al, 2006).

Once widespread, mixed farming has declined in the EU over the last decades, due to the trend of farm specialisation across the EU (Cooper et al, 2009; Poláková et al, 2011), and mixed crop-livestock farms now account for only around 12 per cent of EU agricultural land and 13 per cent of farms (Eurostat, 2012a). However farming and networks supporting integrated farming are growing[44], and such systems may become more attractive as fertiliser prices increase (Goulding et al, 2008).

Box 4-2 Innovative production systems for global agriculture

There are many innovative production systems that are having a significant impact outside the EU, besides the five described in this chapter. One example is the **system of rice intensification** for paddy rice production, a set of innovative practices that improve the survival of transplanted seedlings, enhance soil fertility, and achieve higher yields due to better plant growth, without the need for greater inputs (STOA, 2009). It is not discussed further in this report since rice systems in the EU are limited to a few key producing regions in the Mediterranean and Romania (COGEA, 2009). Another example is the 'push-pull' system of integrated pest and fertility management through the use of an intercrop that repels pests and a border 'trap' crop that attracts pests but does not allow their multiplication. The system has the added benefits that the cover crop fixes nitrogen and protects the soil, and the border 'trap' crop can be used for forage. It is being pioneered successfully in East Africa (Cook et al, 2007; Hassanali et al, 2008).

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[43] This is a farming system concept promoted by the FAO amongst others, eg see http://www.fao.org/agriculture/crops/core-themes/theme/spi/scpi-home/managing-ecosystems/integrated-crop-livestock-systems/en/

[44] Eg EISA (European Initiative for Sustainable Development in Agriculture (http://sustainable-agriculture.org/integrated-farming/) and LEAF (Linking Environment and Farming) in the UK (http://www.leafuk.org/leaf/)

It is important to note that these production approaches are not equally suitable for all farming systems and local conditions (Meyer et al, 2013). For example, advanced precision agriculture fits best with intensive larger-scale crop and livestock farming, and less so with other systems. Conservation agriculture has a high relevance for larger-scale farming as well as extensive farming in less favoured areas. Agroforestry is suitable for extensive farming in less favoured areas as well as semi-subsistence farming, and not for large-scale crop and corporate farming (Rigueiro-Rodríguez et al, 2009). Organic farming is more easily reconciled with extensive farming in less-favoured areas or medium intensive mixed farming systems. Integrated crop-livestock systems are most suited to medium intensive mixed-farming systems. In each case, the principles of these production systems have to be adapted to local environmental and economic conditions.

4.3 Management options for sustainable agriculture

These five production systems each combine a range of specific farm management actions. Some of the farm management practices of particular relevance to sustainable intensification are innovative, whilst others are already relatively well known and established. Together, they have the potential to contribute to production, agronomic and environmental objectives in different ways according to the context. Policies to encourage their development will play a key role in national and EU strategies to support sustainable agriculture. An illustrative selection of such management actions is set out in Table 4-1. The actions are grouped according to their use for:

- Grassland management;
- Cropland management;
- Land use change;
- Non-land based livestock management;
- Energy use efficiency and sustainable use;
- Water use efficiency and sustainable use;
- Risk management.

The table is not exhaustive but provides an overview of some of the leading actions discussed in the literature. More detailed descriptions are found in one of the reports summarised here (Underwood et al, 2013). The table suggests an indicative qualitative scoring for each action according to its potential impacts on the issues of prime concern to this study, viz: agricultural productivity, climate change mitigation, adaptation, and biodiversity conservation[45]. The scoring indicates the predominant potential effect of the action if it is designed and implemented to deliver the specific benefit shown in the table. It is of note that the actual effect in practice will depend on the particular environmental, climatic and agronomic conditions.

The following chapters of this report provide a perspective on these benefits, trade-offs and synergies at farm level. The successful application of these practical farm management options also requires cross-cutting supporting actions, including training, research and information services for farmers. In some cases they will be attractive to farmers in their own right, in others incentives will be required to accelerate the rate of take up.

[45] It should be noted that the scoring indicates the predominant effect of the action if it is carried out according these goals. The actual effect always depends on particular situations. It is therefore possible that in some cases the action might have unintended negative effects, for example changes in grazing rates that are inappropriate for the grassland habitat and climate could increase soil erosion and biodiversity loss instead of reversing these trends.

Table 4-1: Management options for European agriculture that provide co-benefits for climate change mitigation and adaptation, biodiversity conservation, and productivity

Management option (see next page for footnotes to the table)	**Potential benefits for:**			
	Climate Change Mitigation	**Climate Change Adaptation**	**Biodiversity**	**Productivity**
GRASSLAND AND LIVESTOCK MANAGEMENT				
Optimising manure application on grassland	**		*	+
Reducing and optimising use of fertiliser on grassland	**	*	*	0/-
Maintaining (protecting and restoring) natural and semi-natural grassland	**	*	**	+/-
Extensive pasture management (decreased grazing density, avoiding overgrazing, mixed stocking, mosaic / rotational grazing)[a]	**	*	**	+/-
Extensive meadow management (late cutting, restricted or no fertilisation)		*	**	0/-
Use a wider range of livestock breeds including traditional varieties[b]			**	-
CROPLAND MANAGEMENT				
More catch crops / green manure	**	**		+
More winter cover crops /bird food crops/overwinter stubbles	*	*	**	+/-
Crop residue management[c]	**	*		+
Diversifying crop rotations[d]	*	**	*	+/-
Under-sowing spring cereals[e]	**			+/-
Greater intercropping	*	**		+/-
Alley cropping (mixed arable and tree crops)	*	*	*	+/-
Zero or reduced tillage	**	*	*	+
Restricting agricultural activities on slopes/contour farming[f]	*	**		+/-
Reducing / optimising use of fertiliser[g]	**	*		+
Introducing vegetated field margins/strips[h]	*	*	**	-
Introducing arable in-field bare patches (eg bird patches)			**	-
Maintaining and enhancing crop genetic diversity; cropping with seed mixtures		*	**	+/-
Using better adapted crop varieties and improving plant breeding		*		+
Introducing improved pest strategies & reduced pesticide use[i]	*		**	+

Integrated Pest Management (IPM)/ Integrated Weed Management (IWM)	*		**	+
Modifying sowing dates		*		+/-
Introducing and maintaining permanent ground cover under permanent crops	*	**	*	+/-
Establishing more firebreaks		*		+
LAND USE CHANGE				
Introducing set-aside, rotational fallow	*	*	**	-
Conversion of arable land to grassland [j]	**	*	*	-
Afforestation of cropland/ woodland creation	**	*	*	-
Establishing and restoring farmland features (hedges, trees, woodland patches, ponds, terraces, walls etc)	*	*	**	0/-
Restoring peatland and wetland (including rewetting of organic soils)	**	*	**	-
Restoring river and riparian wetland in agricultural areas		*	**	0/-
Shifting crop and grazing areas to changed climate zones		*		-
LIVESTOCK MANAGEMENT (non-land based)				
Improving manure processing (including introduction of anaerobic digestion for methane recovery)	**	*		0
Optimising manure storage	*			0
Breeding for climate adaptation and using adapted livestock varieties[k]	*	*		+
Feeding techniques to improve digestive nutrient capture, changing livestock diets	*			+
ENERGY EFFICIENCY AND RENEWABLE ENERGY USE				
More energy efficient equipment and reducing machinery fuel use	**	*		0
Greater efficiency of farm buildings/greenhouse buildings	**	*		0-
Installing small-scale renewable energy (solar, wind, geothermal)	**	*		0
WATER EFFICIENCY AND SUSTAINABLE USE				
Introducing precision irrigation		**		+
Improving irrigation equipment; water metering		**		+
Re-using greywater and rainwater harvesting on farms		**		+
Improving irrigation scheduling		**		0
RISK MANAGEMENT				
Introducing defences against floods and extreme events (hails etc)		**		+
Establishing disaster information systems and monitoring		**		+
Establishing crop insurance schemes[l]		*		0/-

Source: own compilation based on Underwood et al (2013). The scoring was carried out based on a review of 95 studies (re climate change) and 135 studies (re biodiversity) spanning the period 2000 to 2013.

Notes to Table 4.1:

a) **Extensive pasture management** (decreased grazing density, avoiding overgrazing, mixed stocking, mosaic / rotational grazing): In situations where this management option is planned for carbon sequestration and adaptation benefits, it should focus on adjusting grazing rates and introducing rotating grazing to avoid soil erosion and optimise vegetation growth; Where it is planned for biodiversity benefits, it may require greater decreases in grazing rates and conversion to mixed livestock grazing (eg sheep and horses), or more intensive grazing rates for certain types of grasslands.

b) **Use a wider range of livestock breeds including traditional varieties**: This option conserves livestock genetic diversity but also brings benefits for grassland management through the use of breeds that are adapted to grazing on rough forage in all seasons, including grazing in particularly wet or dry conditions.

c) **Crop residue management:** In-field practices such as incorporation of straw in soil.

d) **Diversifying crop rotations**: Includes crop rotations with or without legumes. Note that the use of rotations with legumes brings particular benefits for sequestering carbon, and legume crops often host more diverse and beneficial invertebrate populations, such as pollinators.

e) **Under-sowing spring cereals**: May include the introduction of grass-clover leys in cereal rotations.

f) **Restricting agricultural activities on slopes/contour farming**: May include a ban on the growing of row crops, such as maize, potatoes, sugar beet, and sunflowers on slopes above a specific gradient. Contour farming is the alignment of soil activities (ploughing, furrowing, planting) with contours in order to slow soil erosion and increase water infiltration.

g) **Reducing / optimising use of fertiliser**: An important component of precision agriculture. It includes optimising the rate, placement and timing of fertiliser. Reducing the amounts of mineral fertilisers below the economic optimum may be suitable in some areas and produce greater benefits for climate change mitigation, although not as a general principle, due to potentially displaced food production.

h) **Introducing vegetated field margins/strips**: May include grass and shrub buffer strips, flower rich field margins, 'beetle bank' strips, bird food strips.

i) **Introducing improved pest strategies & reduced pesticide use**: An important component of precision agriculture. It may have benefits for mitigation where wasteful pesticide use is addressed. Otherwise the benefits for climate change priorities are unclear.

j) **Conversion of arable land to grassland**: In situations where this management action is planned for mitigation and adaptation benefits, it must target specific soils in high risk zones. Where it is planned for biodiversity benefits, the conversion should introduce species-rich permanent grassland.

k) **Breeding for climate adaptation and using adapted livestock varieties**: Includes breeding and using cattle varieties that are heat resistant or breeding cattle for high productivity with a potential effect on methane production.

l) **Establishing crop insurance schemes**: Note the element of moral hazard associated with this action: support for risk management might discourage farmers and foresters from strengthening their adaptive capacity by offering them support regardless of the actions taken.

5 OPTIONS FOR AGRICULTURE TO ADAPT TO AND MITIGATE CLIMATE CHANGE

5.1 Overview of available management options

The list of technically available actions for addressing climate change mitigation and adaptation within the agricultural sector is long and expanding (Bellarby et al, 2013; Frelih-Larsen et al, 2008; Hjerp et al, 2012; Smith and Olesen, 2010; UNFCCC, 2008). Many of these actions can be carried out at farm level, but some require collective approaches involving, for example, associations or a mix of stakeholders. Chapter 4 introduced some of the management actions that have the potential to contribute to sustainable agricultural production while also mitigating the anthropogenic GHG emissions from agriculture and agricultural land use and adapting to climate change.

Mitigation-related actions have been identified on the basis of their technical mitigation potential documented in the publications of the International Panel on Climate Change (IPCC) and the modelled estimates of their economic potential. The economic potential is typically lower and generally derived from models based on Marginal Abatement Cost Curves[46] where these appear most pertinent. The actions address both direct and indirect emissions arising from agriculture. These include: nitrous oxide emissions from soils and drainage, methane and nitrous oxide emissions from the storage, processing and application of manure, enteric methane emissions from livestock management, carbon dioxide emissions from land use change and soils, carbon dioxide emissions from machinery use and energy use on farms, and indirect carbon dioxide emissions from the production of fertilisers.

In addition, a range of adaptation actions are available to farmers to deal with the threats and opportunities arising from climate change. Adaptive actions at farm level can decrease the vulnerability of affected agro-ecosystems and agricultural soils, reduce exposure of a farming system to the effects of climate change such as droughts or heavy rainfalls, and strengthen the resilience of farms and agro-ecosystems (Bindi and Olesen, 2011; EEA, 2012b; Hjerp et al, 2012; Iglesias et al, 2007b; OECD, 2010; Smith & Olesen, 2010). A large proportion of actions aiming at adaptation of farms can also deliver adaptation benefits for wider ecosystems and biodiversity, as well as increasing resilience to flooding.

Mitigation and adaptation actions can be classified in the following categories:

- **Land-based management**, including grassland and cropland management and management action involving land use change; and
- **Other management actions** at farm level, including actions to improve livestock management (non-land based), energy efficiency and renewable energy use, water efficiency and sustainable water use, and risk management.

An underlying meta-review of 95 studies concluded that a large number of management actions can bring co-benefits for both climate change mitigation and adaptation, and may deliver other environmental co-benefits, although these would not occur across all types of farming and climatic situations (Underwood et al, 2013). The particular ways in which farmers develop their production systems and incorporate climate related actions into their production approaches in their local circumstances will affect the resulting GHG profile of the particular farm, as well as the benefits that these actions bring for farm adaptation and potentially for other environmental objectives.

[46] Marginal Abatement Cost Curves are an informative way of assembling data on methods of mitigating GHG emissions by modelling the potential quantities of GHG avoided and the extra costs of doing so

Table 4-1 provides an overview of options that were identified in the underlying analysis (Underwood et al, 2013). 44 options are likely to have high benefits either for mitigation or for adaptation, or potential synergistic effects for both.

The priority options for mitigation include:

- Grassland management: optimising manure application on grassland, reducing and optimising use of fertiliser on grassland, maintaining (protecting and restoring) natural and semi-natural grassland, extensive pasture management (decreased grazing density, avoiding overgrazing, mixed stocking, mosaic/rotational grazing);
- Cropland management: more catch crops/green manure, crop residue management, under-sowing spring cereals, zero or reduced tillage, reducing/optimising use of fertiliser;
- Land use change: conversion of arable land to grassland, afforestation of cropland/woodland creation, restoring peatlands and wetlands (including rewetting of organic soils);
- Livestock management: improving manure processing (including introduction of anaerobic digestion for methane recovery); and
- Energy efficiency and renewable energy use: more energy efficient equipment and reducing machinery fuel use, greater efficiency of farm buildings/greenhouse buildings, installing small-scale renewable energy (solar, wind, geothermal).

The priority options for adaptation include:

- Cropland management: more catch crops/green manure, diversifying crop rotations, greater intercropping, restricting agricultural activities on slopes/contour farming, introducing and maintaining permanent ground cover under permanent crops;
- Land use change: conversion of arable land to grassland, afforestation of cropland/woodland creation, restoring peatlands and wetlands (including rewetting of organic soils);
- Water efficiency and sustainable use: introducing precision irrigation, improving irrigation equipment (water metering), re-using greywater and rainwater harvesting on farms, improving irrigation scheduling ; and
- Risk management: introducing defences against floods and extreme events (hails etc), establishing disaster information systems and monitoring.

5.2 Productivity issues

Adapting agriculture to cope with climate change challenges so that it can produce more food whilst also helping to mitigate climate change will be a complex task.

Approximately a third of the 44 potential priority actions are likely to increase productivity, whereas nearly half of the actions are likely to have a variable, uncertain or neutral impact. Less than a quarter of the practices are likely to have a negative impact according to the literature reviewed (Underwood et al, 2013), although it is worth noting the rather general nature of this analysis.

At a more detailed level, the analysis suggested that actions expected to have an uncertain or variable effect on productivity are spread across all the categories of land-based management actions, but are primarily concentrated in the grassland and cropland management categories. Cropland management actions which target soil nutrient enhancement through catch crops, crop residue management, and optimal fertiliser application and better adapted crop varieties were the primary actions showing positive effects on productivity. Land use change actions dominate in terms of potentially posing negative impacts on production, attributed to the fact that the possible actions take some land out of agricultural production in order to facilitate either mitigation or adaptation.

Other management actions at farm level could potentially contribute to mitigation and adaptation but may have varying effects on productivity. Under livestock management actions, manure management would not affect productivity, but breeding for climate adaptation and changing livestock feeding techniques could increase productivity. The energy efficiency and renewable energy use options were all considered to have a neutral effect on productivity, but both the water efficiency and sustainable use and the risk management categories contained actions predominantly likely to have a positive impact on productivity.

It remains unclear how far it is possible to adapt EU agriculture to climate change, reduce its contribution to GHG emissions, and limit its other adverse environmental impacts without adopting actions that cause reductions in productivity. Creative and innovative ways will need to be found to limit these reductions. Less widespread management approaches such as paludiculture[47] and agroforestry may have a role to play in this.

If a net reduction in EU production did occur, then – unless matched by reductions in EU consumption – increasing imports would be likely, with consequences for emissions and biodiversity in the exporting countries.

5.3 Costs

Overall, cost estimates were identified for the range of management actions at farm level contributing to climate change mitigation, adaptation and biodiversity conservation. Around half of the land-based actions analysed (Underwood et al, 2013) were estimated to be low or low-moderate cost and some would actually increase farm incomes. The land use change category contains a number of actions which were estimated to be high cost, but in practice this is likely to vary, based on each farm's context. For example, restoration of peatlands and wetlands was estimated to be low to high cost depending on the costs of rewetting the organic soil and the opportunity costs of not producing crops or livestock on that farmland. Low cost may occur if the land use change only involves reducing drainage on peatlands where agricultural activity (such as grazing) is both uneconomic and poses a threat to valuable habitats (Poláková et al, 2011). High costs may be associated with rewetting actions where opportunities for production are significant. Given the negative effect these actions are thought to have on production at a local scale, relatively few of them seem likely to be widely taken up without policy support.

At the other extreme, almost all the management actions in the livestock management, energy efficiency and renewable energy use, water efficiency and sustainable use, and risk management categories were estimated to involve moderate to high costs. Despite offering potentially high levels of mitigation or adaptation and either positive or neutral impacts on productivity, actions such as introducing flood defences or crop insurance schemes against climate change-related disasters and new technologies for managing manure (eg anaerobic digesters) and renewable energy (eg solar, wind, geothermal) were estimated to be high cost. This suggests that some types and sizes of farm enterprises may find it easier to respond to climate change than others; therefore, targeting policy support toward specific measures and types of farm may be appropriate.

Overall, it appears that some of the actions identified represent basic farm management or land management that could be achieved with little or no additional cost to the farmer and may even involve financial benefits. Some actions would involve moderate costs for farmers in the short term but would 'pay off' in the future, while other actions might be very helpful in terms of mitigation or adaptation but require significant upfront investment, some of which farmers are unlikely to make on their own.

[47] Paludiculture is sustainable agricultural production on peatland that has undergone rewetting, such as reed or alder plantations (eg Förster and Schäfer, 2010)

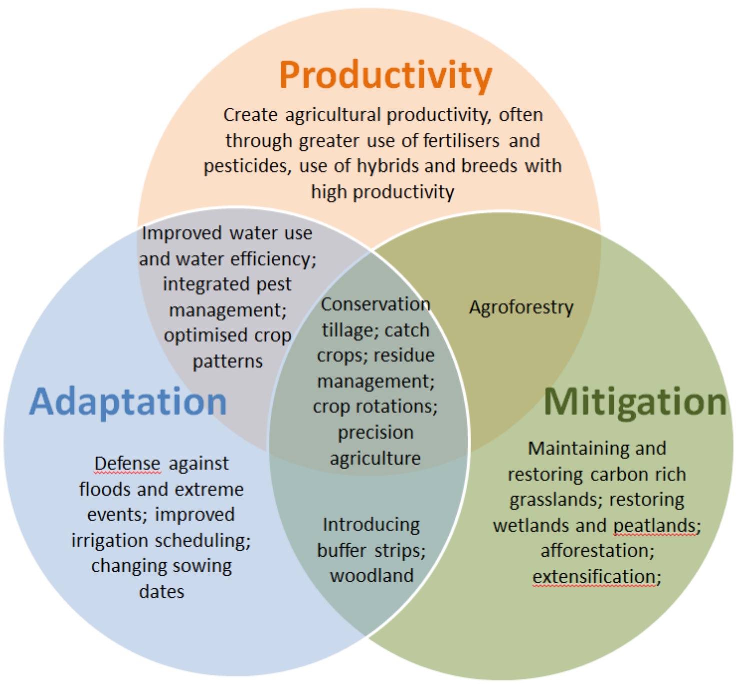
These rather qualitative assessments demand more detailed empirical analysis, and the more widespread and systematic construction of marginal abatement cost curves across the EU would be helpful.

5.4 Synergies, co-benefits and trade-offs

This chapter identifies 44 actions that could help European agriculture in meeting the challenge of adapting to climate change, whilst simultaneously reducing its GHG emissions and other environmental impacts and increasing its productivity (2013). These actions, however, can have varying implications for other goals in agriculture and rural areas. Some actions are essential for climate change mitigation but will reduce productivity; some may be extremely beneficial for adaptation but may increase GHG emissions or have other adverse environmental consequences. An important consideration is also the time scale of the effects. Some actions may reduce the absolute yields in the short term, yet be very important for maintaining productivity over the long term by maintaining soil health and soil productivity (for example, diversified crop rotations which replace monoculture).

Figure 5-1 provides a visualisation of some key examples of management actions in terms of potential synergies that they have for the mitigation, adaptation, and food production goals.

Figure 5-1 Potential synergies and trade-offs between climate change adaptation, mitigation and food production goals



Source: own analysis using a graphic adapted from (Campbell et al, 2011)

An obvious strategy for meeting the central challenge of sustainable agriculture is to focus first on those actions that lie within the intersection of all three circles in this diagram. These are likely to be beneficial wherever they are deployed and, where they have income benefits, farmers may undertake them for purely economic reasons. Conservation tillage, residue management, catch crops, diversified crop rotations and precision agriculture are relevant for all three objectives. It is important to note that these actions may nonetheless entail certain trade-offs which, however, can be managed. Conservation tillage (reduced tillage), for example, improves soil carbon storage and soil organic matter in arable soils, increases water holding capacity and reduces soil compaction/erosion thus strengthening resilience against weather extremes, as well as benefitting water quality by reducing nutrient concentrations in surface run-off and improving soil quality (Louwagie et al, 2009; Poláková et al, 2013). It can, however, increase fungal problems which reduce yield or increase denitrification as soil is less aerated. These problems can be minimised so that the multiple benefits prevail.

There are also options which might have a highly relevant role in meeting only one or two objectives of productivity, mitigation or adaptation, and which may require policy support in order to achieve these objectives. Introducing flood defence and other types of defence against extreme events (for example, firebreaks), improving irrigation scheduling and improving animal rearing conditions have the most relevance for supporting farm level adaptation as they increase the resilience against changing climatic conditions and ensure that productivity levels can be maintained. These do not have any significant trade-offs.

Some actions might be of high priority for achieving only one of the goals and have important trade-offs for the other goals. Land use change actions, for example, such as maintaining and restoring carbon rich grasslands, restoring wetlands and peatlands, or afforestation have significant potential for mitigating climate change as well as supporting biodiversity. As already noted, they may be highly important to carry out to in certain situations to achieve these benefits, even though they can also have implications for agricultural yields as they reduce the available agricultural area. These are important policy decisions that should result from conscious prioritisation and should be co-ordinated by agricultural and environmental authorities.

This underscores the need for careful management supported by improving farmers' skills, building up and transferring research applicable to farm-level management decisions, and increasing advisory support. This is a pre-condition for farmers to be able to identify the right management options and target them appropriately to the particular types of soils and climate in order to optimise synergies and minimise trade-offs.

The management actions identified in this study can support all five production systems in European agriculture outlined in Chapter 4 (precision agriculture; conservative agriculture; organic farming; agroforestry; and integrated crop-livestock production / integrated farming), albeit to a varying extent. Meyer et al (2013) concluded that all these systems tend to have high relevance for improved crop production. All of them can contribute to improved farm input efficiency, as well as to improved site specific yield potential. There is some variation, however, in terms of their implications for higher yields. Conservation agriculture has high relevance for higher yields. Agroforestry, precision agriculture and integrated crop-livestock systems, on the other hand, have restricted benefits for higher yields. The implications of organic farming for higher yields often depend upon the system of comparison with conventional farm yields and the local context (Meyer et al, 2013).

Beyond the 44 management actions identified by Underwood et al (2013), various technologies can be applied to ensure stable food supply. Critical are those enabling reductions in crop losses and food waste, including technologies related to harvesting, drying, storage, or transportation, due to their potential to contribute to increase food security. These options are further discussed in Chapter 8.

5.5 Barriers to uptake

The analyses of priority actions for adaptation and mitigation identified farmers as key actors to implement the actions. For most of the farmers, cost and localised negative impacts on productivity are two obvious barriers to uptake. Nevertheless, there are also actions available which could potentially have positive impacts on productivity. Experience to date suggests, however, that even for these actions, widespread uptake may require additional incentives. Farmers may not be willing to try new techniques. Risks and transaction costs may be higher, or perceived to be higher, than stated in the literature. Further factors preventing optimal decisions by farmers may include risk and uncertainty, poor access to technology, and the limited availability and cost of credit. In other situations farmers may not be able to implement the actions on their own and need advice, training, or the co-operation of others, for example, in sharing costs (Ingram et al, 2012).

In addition to farmers, other important actors are involved in research and development (supporting agricultural supply industries and food processors). Engagement of national and sub-national governments is particularly needed for measures concerned with land use change as well as water management and other measures. This may reflect the fact that these categories more often require regulation, financial incentives, action at a larger scale, and infrastructural change. More generally, governments have an important initial role in raising the awareness of all parties involved in the food chain to be more aware of the threats and opportunities brought by climate change.

The most important barriers[48] for the introduction of **sustainable soil management**, whether it supports conservation agriculture or other production systems, include (Meyer et al, 2013):

- *Mind-set*: a paradigm shift from the way agriculture is practiced conventionally demands a change of mind-set.
- *Awareness of soil degradation problems*: Farmers need to recognise the necessity to reduce soil degradation problems and potential actions to address this issue.
- *Adaptive research and demonstration efforts*: Principles of sustainable soil management need to be adapted to specific farming situations. Therefore, adaptive research and exchange of experiences between farmers are important.
- *Competing uses of biomass*: Reduced availability of biomass for soil management (for example, crop residue management or soil cover) because of other uses such as biofuels can be a problem, especially on already depleted soils and soils in arid and semi-arid regions.
- *Availability of machinery*: Specialised direct seeding and/or planting equipment is more easily obtained by large-scale farmers. Smallholders need different machinery appropriate for a smaller scale or a specific system of custom hire services.
- *Profitable alternative crops for diversified crop rotations*: Higher profitability of a restricted number of crops and economic gains from specialisation can be obstacles for the diversification of rotations.
- *Availability of incentive programmes*: The full benefits take time to materialise as soil physical and biological health takes time to develop. Support for the transition period helps to spread the benefits of appropriate soil management techniques.

Major barriers to the implementation of **precision agriculture** methods comprise (FAO, 2011b; Meyer et al, 2013; Reichardt & Jürgens, 2009):

- *Awareness and knowledge*: Information about technological possibilities and profitable applications is not always sufficiently available at farm level.
- *Farm structure*: Advanced precision agriculture techniques demand a minimum application area to be economically feasible, whereas smaller-scale farming may require simple approaches.
- *Capability and training*: Advanced precision agriculture approaches are integrative and interdisciplinary. The different interactions of growth factors in yield development become even more important in agronomic understanding with precision agriculture. Technical schools are lagging behind in addressing precision agriculture issues.

[48] Information on constraints for agroforestry and mixed farming systems can be found at Meyer et al (Meyer et al, 2013), Sections 4.1.5 and 4.1.6.

- *Gaps in technically mature products*: Some precision agriculture approaches still require research and development (eg hyper-spectral sensor applications for assessing pre-harvest quality or micro-nutrient deficits).
- *Proper decision-support systems*: Data and knowledge about the spatial distribution of site characteristics (such as soil characteristics, slope, microclimate, crop canopy) is insufficient without agronomic understanding of how to interpret these data and how to convert such information into cultivation measures. The development of decision-support systems is lagging behind.
- *Demand for management time and data management skills*: Handling of diverse data and information and their conversion into management decisions may be time-consuming and not straightforward. Precision agriculture technology can only reach the majority of farmers if it becomes easier to use and less time-consuming.

Constraints for the continuation of **organic farming** growth are mainly the certification costs, challenges in managing changes from conventional production systems and linked investments, certain issues in nutrient supply, weed and pest management, lack of adequate advisory services able to address conversion problems, a potentially limited market for organic food, unavailability of group certification for smallholders, and limited availability of specific funding under the framework of agro-environmental programmes (Sanders et al, 2011).

5.6 Enabling mechanisms and policy incentives

Any individual action alone will be insufficient to meet the full scale of the challenge regarding adaptation, mitigation, and food production needs. Using mixes of actions will bring with it the imperative to manage the complex trade-offs that result as well as to change farming practices from the status quo. The evidence gathered for this report suggests that this will require: a systems approach pursuing and weighing different objectives and trade-offs; focussed advice and support to farmers; coordinated and targeted action at a landscape scale; cooperation and collaboration in order to facilitate coordinated action at a landscape scale; additional research and development, for example, regarding actions with the greatest potential for co-benefits, such as agroforestry; as well as active involvement of government at all levels.

The Common Agricultural Policy (CAP) can play a prominent role in two ways. The first is by developing the instruments of the CAP, across both pillars, to facilitate and encourage the adoption of beneficial system approaches with the practices and actions which have been identified above. The second is by requiring that Member States recognise and act on the need to integrate climate adaptation and mitigation priorities into their decisions about how to implement these CAP instruments. One area where the CAP is likely to have an important role is in facilitating the actions that are necessary to reduce GHG emissions or to help the agriculture sector adapt to climate change but which may have negative effects on productivity or which impose other costs on farmers. This may require a combination of a stronger regulatory regime, perhaps making better use of cross-compliance and greening as instruments of the CAP, as well as financial incentives.

In addition to the key possibilities under Pillar 1 (cross-compliance, green payments, and farm advisory systems) which can reach broad segments of agricultural producers, Pillar 2 offers a number of possibilities to fund targeted action. The key RDP measures supporting capital investments in infrastructure include support for investments in physical assets (Article 18), basic services and village renewal in rural areas (Article 21), and restoring agricultural production potential in areas damaged by natural disasters (Article 19). To ensure environmental additionality, investments should only be granted where sound evidence is provided taking into account multiple environmental objectives. Care should also be taken to avoid funding investments that are stipulated as requirements in national and/or EU legislation. Where new infrastructures are constructed, attention should be paid to ensure that it does not increase greenhouse gas emissions or decrease water availability.

Key RDP measures for soil and land management actions include the agri-environment-climate measure (Article 29), support for afforestation and creation of woodland (Article 23), and support to establish agroforestry systems (Article 24). It is important to ensure that the support provided under these measures is used to deliver public goods and results in environmental additionality, particularly where there is a risk of negative environmental outcomes. For example, in order to mitigate climate change, there is a risk that semi-natural grasslands might be used to cultivate energy crops or short rotation coppice, resulting in the loss of a carbon sink and important biodiversity habitats. Where the afforestation and agroforestry measures are being used to deliver mitigation, care should be taken to ensure that the use of these measures is coherent with other environmental objectives, especially biodiversity.

6 AGRICULTURE THAT SUPPORTS BIODIVERSITY AND ECOSYSTEM SERVICES

There has been considerable progress in the last two decades in recognising that agricultural production and environmental land management must go hand in hand in Europe. This progress is indicated, for example, by the explicit incorporation into the Common Agricultural policy of cross compliance conditions for the receipt of farm payments, agri-environment schemes and the need for special attention to be given to marginal farming areas which are often associated with important semi-natural habitats. Despite these efforts the scale of the actions to protect biodiversity and the ecosystem services it supports is still inadequate. This chapter summarises further needed actions and options. First it considers actions to protect biodiversity-rich farming, the high nature value farming systems. Second it reviews a number of possible actions to enable general farming practices to increase farm biodiversity and ecosystem services. Third it focuses on the actions still required to reduce environmental damage. Fourth it discusses the supports required for bees and other pollinators. The chapter concludes by considering the external environmental impacts of EU food imports.

6.1 Protecting and supporting biodiversity-rich agricultural systems

Active interventions to support and protect semi-natural farmland and the farming systems that maintain it are needed. Part of the response should be focussed on arresting the continued decline of the High Nature Value (HNV) farming systems still characteristic of considerable areas of Europe, particularly extensive livestock grazing. These play an important role in maintaining semi-natural habitats, many of which require protection and management under the Habitats Directive. The challenge is to maintain these systems through a combination of support for the public goods they produce, alongside the development of new approaches and adaptation to changing socio-economic conditions. Farmers who deliver the essential management of biodiverse habitats and species of conservation value on farmland often farm under difficult circumstances using labour-intensive systems on marginal land. This requires an integrated package of support measures that ensures the **long-term viability of High Nature Value farming systems** and their value for biodiversity, including combined support from both pillars of the CAP[49], as well as better management within the Natura 2000 network.[50]

Member States can use the new Common Agricultural Policy framework to develop a High Nature Value policy package that 1) ensures that farming of semi-natural habitats continues; 2) supports the long-term viability of the farming systems that protect and maintain biodiversity; 3) builds farm capacity and add value to farm produce to improve economic and social sustainability; and 4) supports specific conservation actions for habitats and species on farmland (Oppermann et al, 2012). Specific support and advice should be targeted at farming systems that maintain and restore Natura 2000 habitats and species, both within Natura 2000 sites and outside, especially where they buffer or connect Natura 2000 sites (Olmeda et al, 2013).

It is important to recognise the substantial ecosystem services supplied by semi-natural farmland and farming systems by more explicitly linking public support to their continuation (including carbon

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[49] It is estimated that maintaining HNV farming practices over 80 million ha of EU-27 farmland would need €16 to €23 billion per year (including the farmland within Natura 2000) (Beaufoy and Marsden, 2010; Hart et al, 2011), compared to current annual spending on CAP Pillar 2 environmental measures (axis 2) of €41.2 million (including Member State co-financing.

[50] It is estimated that currently only a fifth or less of the funding that would be necessary to maintain and restore the Natura 2000 network to favourable conservation status, including the 22.2 million ha of farmland, is actually being made available (European Commission, 2011b; Gantioler et al, 2010; Kettunen et al, 2011).

storage, water flow regulation and purification, cultural and recreational value), through better monitoring, assessment and recognition of multifunctional land management and outcomes (Cooper et al, 2009). Many of these are 'public goods' and may require landscape-scale approaches that combine the individual contributions of many farms that are economically insignificant at the farm level (Benton, 2012).

6.2 Agricultural practices that increase biodiversity and ecosystem services

A range of farming practices and actions were reviewed in Underwood et al (2013) for their benefits to biodiversity and ecosystem services, as shown in Table 4-1 in Chapter 4. These actions have been shown to increase biodiversity at the farm scale and field scale in Europe (Cooper et al, 2009; Dicks et al, 2012; Poláková et al, 2011; Wilson et al, 2009) and their biodiversity benefits are described in more detail in Underwood et al (2013). The actions primarily aim to maintain and provide suitable habitats for breeding and feeding, ensure abundant food resources for animals, and limit mortality factors (such as from machinery, pesticides and livestock trampling).

Most of the beneficial practices listed in Table 4-1 are supported under agri-environment schemes in Member States' Rural Development Programmes, though the range and scope of actions varies greatly amongst programmes (Keenleyside et al, 2012). A meta-analysis of published research shows clear evidence that agri-environment schemes benefit species richness and abundance on both arable and grassland across Europe (Batáry et al, 2010), but reviews also show that current agri-environment schemes are not sufficient to reverse the declines in Europe's farmland biodiversity (Berendse et al, 2004; Kleijn et al, 2006; Kleijn et al, 2011). Many agri-environment schemes are insufficiently targeted at biodiversity conservation or do not cover enough area (Concepción et al, 2012; Le Roux et al, 2009; Merckx et al, 2009). A number of reviews conclude that agri-environment programmes need to be better targeted to the nature of the landscapes of the regions where they are implemented and the type of species groups that should be benefiting (Batáry et al, 2010; European Court of Auditors, 2011; Whittingham et al, 2007).

The spatial scale over which agricultural biodiversity is delivered needs to be increased significantly and the efficiency and effectiveness of measures improved to ensure that biodiversity thrives in the wider countryside as well as in protected areas (Poláková et al, 2011). For example, a study estimated that Germany would need active management actions over at least 15 per cent of its agricultural area (UAA) in order to reverse the declines of farmland species and secure habitats, including restoring and maintaining semi-natural landscapes, extensifying 10 per cent of intensive grassland, and allocating 7 per cent of arable and grassland to farmland features (Hampicke, 2010). A Netherlands study estimated that a country-wide approach to conservation of farmland biodiversity would require active biodiversity management practices on at least 20 per cent of its agricultural area (UAA) (Overmars and Zeijts, 2010).

Farmers are generally more likely to take up changed field margin management practices rather than in-field practices such as bird patches or fallow fields, over-wintered stubbles, crop diversification, or integrated pest or weed management (Poláková et al, 2011; Vickery et al, 2008). However, modelling based on bird conservation requirements shows that the main priority for most of the declining bird species on farmland are practices that provide in-field resources and breeding habitat, although some species also benefit from field edge management practices (Butler et al, 2007a; Butler et al, 2007b; Butler et al, 2009; Butler et al, 2010).

Conflicts between increasing scale, specialisation and input use on arable land and in horticulture on the one hand, and the revival of biodiversity on the other, can only be addressed by action at different levels. This includes stronger education and advice for farmers, measures to maximise the biodiversity benefits of ecological focus areas being introduced into the CAP, more focussed and effective agri-environment schemes and further deployment of good practises. Most of the actions listed in Table 4-1 bring biodiversity benefits and co-benefits for climate change adaptation and/or mitigation, and should be implemented as widely as possible.

6.3 Avoiding and reducing the detrimental impacts of agricultural practices

Ambitious actions are needed to constrain and reduce the negative impacts of intensive agricultural production on biodiversity to below threshold levels in order to meet the goal of sustainable agriculture. There are opportunities to manage the pressures arising on biodiversity in the more specialised, high yielding and intensively managed parts of European agriculture. Firstly this involves the effective implementation of existing EU legislation, such as the Nitrates Directive and legislation on pesticides. In addition, greater priority for the development and application of integrated pest management (IPM) could bring substantial biodiversity, climate and agronomic benefits (Popp et al, 2013). CAP cross-compliance regulations have established a baseline of minimum environmental standards for farmland management across the EU (Poláková et al, 2011). In the new CAP regulations Member States have been given greater flexibility to set GAEC[51] requirements. It is therefore important that Member States ensure high and properly enforced national standards that include the protection and management of permanent grassland, riparian buffer strips, and farmland features.

EU policy targets to reduce nitrogen (N) emissions and leaching[52] all demand substantial action from the agricultural sector. Nitrogen Use Efficiency could be increased by 25 per cent, while ammonia emissions would decrease by 31 per cent and N leaching by 41 per cent, through the strict and uniform implementation all over the EU of: balanced fertilisation (fertiliser use that does not lower crop yields[53] but that decreases N leaching losses to less than 50 mg NO_3^- l^{-1} [54]), combined with improved crop and manure management; low-protein animal feeding, combined with improved herd management; and ammonia emissions abatement measures, including improved manure application and storage (Oenema et al, 2009). This would bring substantial benefits for biodiversity both on farmland and in freshwater and marine habitats in Europe.

Farmers are continually adapting and changing the pesticides they use, but new regulations are currently driving a faster rate of change by regulating the use of more persistent and toxic pesticides. Pesticide use increased up to 2002 then declined in 2003 (the most recent EU-wide data), but there are contrasting trends in the consumption of pesticides and their use across Member States, and it is difficult to determine the full extent of pesticide impacts due to the lack of consistent EU-level data and long-term studies (see Box 6-1). The EU can push for ambitious pesticide reduction targets and full implementation of integrated pest management under the Sustainable Use of Pesticides Directive.

[51] Rules for Good Agricultural and Environmental Condition, including establishment of buffer strips, protection of groundwater and soil organic matter, minimum soil cover and management to limit erosion, and retention of landscape features

[52] The Nitrates Directive, the Thematic Strategy on Air Pollution, and the National Emission Ceiling Directive

[53] although there may be an increased risk of reduced yields under favourable growing conditions when N demand of crops are relatively high (Oenema et al, 2009)

[54] The Nitrates Directive specifies that nitrate concentrations entering groundwater and surface waters must be reduced to less than 50 mg NO_3^- l^{-1} in all designated nitrate vulnerable zones (NVZ). Overall, 46% of the EU is NVZ; some Member States, such as Denmark and Germany, have designated their whole land area as NVZ; others such as Poland have designated only 10% or less.

Most Member States have produced pesticide plans[55], indicating that training and awareness is improving; however, currently only two set quantitative pesticide reduction targets.[56]

Some fear that the pace of pesticide withdrawal from the market will leave farmers with too few practically and economically viable alternatives due to the lack of feasible Integrated Pest Management techniques (eg Hillocks and Cooper, 2012). However, the new EU pesticide regulation gives a specific status to non-chemical and natural alternatives to conventional chemical pesticides and requires them to be given priority wherever possible. The risk assessment requirements for low-risk substances have been reduced, so approval can be given more quickly (Chandler et al, 2011). Moreover, the requirement for Integrated Pest Management is stimulating increasing research and innovation (Labussière et al, 2010)[57]. This is supported by the new Common Agricultural Policy framework, under which Farm Advisory Services are now obliged to provide farmers with IPM advice.

Box 6-1 Changing pesticide use in Europe – assessing impacts

Overall pesticide use in Europe steadily increased by weight up to 2002, and then decreased in 2003 (the most recent data available for the EU-25), with decreases in fungicide use countered by increases in herbicide use (Eurostat, 2007). By weight, over half of pesticide use was on fruit and vegetables, particularly fungicide use in vineyards (in 2003 25% of the total volume of pesticides was inorganic sulphur, which is used in vineyards). Most of the rest was on arable crops, mainly herbicides on cereals. However, weight is not a good measure of the environmental impact of pesticide use. Some pesticides are bulky but environmentally relatively benign, such as sulphur, whilst others are used in low doses but have significant environmental impacts.

Pesticide active ingredients are therefore classified according to their environmental impact, combining data on eco-toxicity, persistence and environmental characteristics (Eurostat, 2012b). In addition, pesticide impacts are strongly affected by the method of use; ie applied volume, application method and timing, and interaction with crop variety and soil type. The real risk of pesticide use is therefore calculated by multiplying the environmental impact rating of the active ingredient with data on the use (ie dose per ha, type of crop, time and method of application) taking into account influencing environmental factors (eg the Environmental Yardstick for Pesticides in the Netherlands[58]). There is currently no agreed EU-wide indicator for the environmental impact of pesticides and a lack of harmonised data on pesticide use (Calliera et al, 2013), though the EU research projects HAIR[59] and FOOTPRINT[60] have developed proposals and tools for aggregated pesticide risk indicators. The widely used Environmental Index Quotient (EIQ), developed by Cornell University, has established EIQ values for pesticide active ingredients incorporating data regarding mode of action, plant surface residue half-life, soil residue half-life, toxicity to indicator organisms (including bees, birds, fish, and beneficial organisms), and ground-water/run-off potential. EIQs range from over 80 for the insecticide disulfoton (a systemic seed and soil treatment used on potatoes,

[55] http://ec.europa.eu/food/plant/pesticides/sustainable_use_pesticides/national_action_plans_en.htm

[56] The Danish plan aims to reduce pesticide use by 40%; the French Ecophyto plan aims to reduce pesticide sales in France by 50% by 2018 (http://agriculture.gouv.fr/Ecophyto-in-English-1571). Source: http://www.pan-europe.info/News/PR/130620_letter_Borg.pdf

[57] See for example the activities of the European Centre for IPM at http://www.eucipm.org/projects.htm and PURE FP7 project at http://www.pure-ipm.eu/. The European Innovation Partnership on Agricultural Productivity and Sustainability has assembled an expert focus group on IPM in Brassicas, see http://ec.europa.eu/agriculture/eip/focus-groups/index_en.htm.

[58] http://www.milieumeetlat.nl/en/home.html

[59] HAIR: http://www.hair.pesticidemodels.eu/home.shtml

[60] FOOTPRINT: http://www.eu-footprint.org/ppdb.html

fruit trees, beets, hops and other crops in the EU) to only 8.67 for flonicamid, a relatively new insecticide now widely used to control aphid on potatoes, wheat and fruit trees.[61] This means disulfoton is assigned over 10 times greater impacts on birds and beneficial insects per unit of pesticide than flonicamid. However, there is a risk that new pesticides are considered to be more benign partly because of lack of evidence of effects. There are still many knowledge gaps about the environmental impacts of pesticides as they degrade in the environment, and it has sometimes taken decades for the toxicity of pesticide degradation products to be clarified (Fenner et al, 2013).

EU pesticide regulations are currently driving a faster rate of change. In 2009, a new EU pesticide regulation defined a positive list of approved 'active substances' (chemical ingredients of pesticides) at EU level, leaving Member States to license pesticide formulations on the basis of this list.[62] Around 75 per cent of the more than 1000 active substances that were available for use in at least one Member State in 1993 have already been withdrawn from the European market.[63] Around 31 are being reviewed in the next years.[64] In addition, the Sustainable Use of Pesticides Directive[65] requires Member States to implement plans setting targets to reduce pesticide use and promote Integrated Pest Management, to train and inspect pesticide users, to monitor pesticide use, and to implement measures to protect water courses from pesticide pollution.

6.4 Research, monitoring and innovation to maximise biodiversity benefits

Some of the beneficial practices on intensive arable and grassland may reduce overall output or constrain productivity increases per unit area over the short term, principally fallowing and grazing extensification; however this does not take account of their contribution to the long term sustainability of farming practices, for example through co-benefits for soil organic matter and climate change adaptation.

This has led to a debate on the degree to which actions that focus on enhancing biodiversity within existing farmland ("land sharing") drive agricultural expansion and thus the loss of non-farmed or extensively farmed habitats elsewhere, and whether it would be better for overall biodiversity if yields are maximised on existing farmland despite the biodiversity loss, in order to retain and recreate biodiversity-rich habitats outside agriculture ("land sparing") (Balmford et al, 2005; Green et al, 2005; Phalan et al, 2011). Current evidence suggests that in mega-biodiverse countries with large areas of natural habitat, land sparing would be a more effective conservation strategy than land-sharing. However, the situation in Europe may be very different, due to the high biodiversity importance of semi-natural habitats that depend on the continuation of low-intensity farming practices.

More research is therefore needed to establish the applicability of the land sparing concept in the EU, the influence of scale on the issues, and policy options that support land-sparing if needed (Ewers et al, 2009; Oeckinger and Smith, 2007; Phalan et al, 2011; Tscharntke et al, 2012). Further research can

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[61] http://ec.europa.eu/food/plant/protection/evaluation/newactive/technical_review_flonicamid.pdf

[62] Regulation (EC) No 1107/2009 of the European Parliament and of the Council of 21 October 2009 concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414/EEC

[63] DG SANCO (2009) EU action on pesticides "our food has become greener". http://ec.europa.eu/dgs/health_consumer/information_sources/docs/plant/factsheet_pesticides_en.pdf

[64] The requirements of the Water Framework Directive may also trigger restrictions if some pesticides cannot be kept out of water courses (particularly the herbicides propyzamide, carbetamide, and chlorotoluron, and the molluscicide metaldehyde)

[65] Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for Community action to achieve the sustainable use of pesticides

clarify the benefits of sustainable intensification approaches that increase productivity whilst also benefiting biodiversity. Our understanding of the dynamics between farming and biodiversity and the application of best practices will rely in improved in-field monitoring and assessment of the impacts of changing farming practise on the species and habitats dependent on agricultural ecosystems, and that underpin agro-ecological functions.

6.5 Supporting beekeeping and wild pollinators

Public funding is urgently required to address the multiple factors causing European honeybee losses, and the loss of wild pollinator populations. Because the interactive effects can cause greater impacts than each factor in isolation, an integrated response with concerted actions by public authorities, beekeepers, farmers, the pharmaceutical industry, and researchers is needed. The fact that no one factor seems to be the cause of bee decline should not be used as a reason for inaction.

Specific actions, detailed in Underwood et al (2013), include: increasing knowledge of the risks posed by neonicotinoids and other systemic pesticides; measures to increase breeding for *Varroa* mite resistance and improve availability of better treatment methods; and actions that increase flower resources for pollinators in agricultural landscapes.

6.6 Reducing the impacts of Europe's food, feed and biofuel feedstock imports

Whether EU food production increases, and contributes to feeding the world, depends on global price trends, trade policies, biofuel policies, and consumer preferences for domestic versus imported food products (Hart et al, 2013). There is a fear that a substantial scaling up of biodiversity-friendly farming practices in the EU could reduce agricultural production and increase demand for agricultural imports, increasing the EU's impacts on global biodiversity loss. However, as described above, some of the biodiversity actions will also increase agricultural sustainability, or, if well designed and implemented, have little productivity impact.

Furthermore, the EU can make a more substantial contribution to reducing global biodiversity loss through actions to improve the environmental footprint of the EU's food, feed and biofuel feedstock imports, and to encourage consumer demand for environmentally sustainable food, including:

- active EU engagement in international initiatives to develop global environmental principles for food, fibre and energy production, and clarification of assessment standards in the forthcoming policy paper on sustainable food[66];
- encouragement and support for voluntary and private certification schemes and products, such as the Roundtable on Sustainable Soy, Roundtable on Sustainable Palm Oil, organic, fair trade, GlobalGAP;[67]
- education and awareness campaigns to reduce unhealthy meat consumption levels, whilst promoting the livestock products from European High Nature Value farms;
- and actions to increase domestic production of animal feed that also brings benefits for biodiversity and adaptation to climate change, such as legume crop systems that do not require high levels of pesticide use.

[66] See http://ec.europa.eu/environment/eussd/food.htm

[67] http://www.globalgap.org/uk_en/for-producers/

7 PLANT BREEDING AND USE OF PLANT GENETIC RESOURCES

This chapter provides an overview of the potential of plant genetic resources and crop breeding to increase the productivity and environmental sustainability of agriculture in Europe. Agricultural genetic diversity is discussed in the context of its value for plant breeding, but it is important to note that it is far more than just a source of material for breeders: it is an important component of Europe's agricultural diversity and is a valued part of our cultural heritage. This chapter is based on the more detailed analysis in Underwood et al (2013) and Meyer et al (2013), and does not address food safety issues.

7.1 Challenges for plant breeding and plant genetic resources in the EU

Plant breeding in Europe has throughout history produced new crop varieties designed to deliver high and stable yields under changing environmental conditions and crop management methods, to meet different demands for taste, to feed animals, and/or with structural properties that are suitable for food processing. It also plays a vital role in maintaining and increasing the resistance of crops to pests and diseases. Plant breeding therefore aims both to increase the yield potential of a crop and to provide a stable yield with a high product quality for a range of desired uses.

Europe has well developed public plant breeding institutions and programmes and an important private plant breeding sector (Mwila, 2013; Visser and Borring, 2011). The EU seed and reproductive material market is worth around €6.3 billion per year, and the EU is also the world's largest seed exporter (European Commission, 2013). It is estimated that crop breeding has contributed around 25 to 50 per cent of the yield increases in EU agriculture since the 1940s (with differences between crops) (Meyer et al, 2013). The other component of yield increases has come from changes in management practices, including developments in fertiliser use, machinery, irrigation and drainage (Sinclair and Rufty, 2012). There are concerns, however, that the rate of increase in yield potentials from new crop varieties is no longer sufficient to meet the demands of increased food production, and that yields need to increase at a much faster rate (FAO, 2011a; Ray et al, 2013). Equally, it may be that European agriculture is failing to use varieties adapted to the pressures of climate change (Brisson et al, 2010).

A range of new and versatile plant breeding techniques have been developed over the last decade which have the potential to produce new crop varieties that meet the current and future challenges. Some of these techniques generate new crop genetic variation through mutation, but many rely on access to sources of plant genetic diversity. Agriculture therefore relies on a reliable supply of crop varieties from a diverse and productive plant breeding sector and the effective conservation and use of plant genetic diversity. The genetic diversity of agricultural crops is a crucial factor in agriculture's ability to adapt to a changing climate, to maintain and increase the resistance of crops to pests and diseases, and to meet changing consumer preferences.

The FAO has warned that the continuing erosion or extinction of plant genetic diversity is threatening the world's ability to adapt to climate change and to ensure food security, as well as curtailing the options of future generations (FAO, 2010). Plant genetic resources for food and agriculture (PGRFA) include the modern crop cultivars used by most farmers, breeding lines and genetic stocks maintained by plant breeders, obsolete cultivars, ecotypes, landraces and crop wild relatives (CWR), as well as weedy races and primitive forms of crops (Maxted et al, 2008; Maxted et al, 2011). Whilst the adoption of high-yielding modern crop cultivars in Europe has significantly increased crop production, much of the resource of locally adapted genetic variation in landraces has been lost.

Landraces[68] are generally highly genetically diverse and adapted to low-input farming. They are an important source of breeding material for high yield stability under stress and pest and disease pressure (Feuillet et al, 2008). A few farmers in Europe still cultivate them, for example in Hungary and Italy (eg Piergiovanni and Lioi, 2010), but it is difficult to assess the threats facing European landrace diversity partly because of the lack of information (Negri et al, 2009; Veteläinen et al, 2009). At least 11.5 per cent of the high priority European crop wild relative species are near extinction due to unsustainable farming practices, urbanisation, and other infrastructure developments, and many are affected by gene flow and hybridization with crops (Bilz et al, 2011; Kell et al, 2012; Underwood et al, 2013).

7.2 Ensuring the conservation and use of plant genetic resources in Europe

It is vital that EU and Member State level policies recognise the current threats facing European plant genetic resources, and ensure that policies are in place to support their enhanced conservation and use. A number of initiatives are being undertaken in Europe both to reduce the threats to plant genetic resources and to conserve crop genetic diversity and crop wild relatives (Damania, 2008; Hajjar and Hodgkin, 2007; Johnson, 2008; Maxted and Kell, 2009; Treuren et al, 2012). See Underwood et al (2013) for details.

Europe has a relatively well developed capacity for *ex situ* conservation in gene banks and botanical gardens, with approximately 500 gene banks maintaining 2 million *ex situ* accessions, and research programmes are contributing to the development of conservation methods, knowledge and access to information. However they do not effectively conserve the range of diversity necessary for conservation and required by contemporary plant breeders, and there is a need for better EU-wide coordination and collaboration (EASAC, 2011; Underwood et al, 2013). Only 6 per cent of European crop wild relatives have any material conserved *ex situ* (Maxted et al, 2012), and there is no estimate of what percentage of traditional farmer-bred crop landraces are conserved (Veteläinen et al, 2009). An increasing range of *in situ* or on-farm genetic resources conservation projects in Europe are stimulating the use of landraces, rare breeds, and neglected crops (Underwood et al, 2013). However, this does not constitute a systematic conservation framework. For crop wild relative diversity the main focus of *in situ* conservation should be the implementation of genetic reserves, but there are no European genetic reserves that meet the minimum quality standards (Iriondo et al, 2012), and the Natura 2000 network does not recognise the conservation of crop wild relative diversity as a goal.

A systematic European network of *in situ* genetic reserves for crop wild relatives and on-farm conservation sites for landraces is particularly needed, together with support measures for farmers to use and conserve genetic diversity on-farm (Kell et al, 2011; Kell et al, 2012; Veteläinen et al, 2006). The European Commission is currently evaluating the Community funding for genetic resources in agriculture (2006-2011) with a view to launching a new funding programme that is better integrated with farmers and other end-users[69]. This could build on the European Cooperative Programme on Plant Genetic Resources (ECPGR) networks for *in situ* and farm conservation, and for plant genetic resources research[70].

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[68] Landraces are unique varieties of crops that have adapted to local conditions through a process of farmer selection, and are usually characterised by a high capacity to tolerate biotic and abiotic stress, resulting in a high yield stability and an intermediate yield level under low input agricultural systems (Krik et al, 2010)

[69] See http://ec.europa.eu/agriculture/genetic-resources/ and http://www.ideassonline.org/public/pdf/EU-RisorseGeneticheENG.pdf

[70] See http://www.ecpgr.cgiar.org/

A more coordinated European Genebank Integrated System would provide crop breeders with improved access to conserved resources and help enhance use[71]; as would greater actual or predictive characterisation and evaluation of conserved plant genetic resources, and more available online information linked with better mutual cooperation between gene banks.

The opening of marketing opportunities for local, traditional and diverse breeds and crops should contribute to creating a sustainable and economically viable use of agricultural genetic resources. This could also provide health benefits through diversifying European diets to include a more diverse range of fruits, vegetables and other foods (Fanzo et al, 2013).

Greater prominence could be given in the Horizon 2020 programme to research on the use of genetic resources, responding for example to the need to establish a more biodiverse crop base better adapted to climate change. The expert focus group being set up under the European Innovation Partnership for Agricultural Productivity and Sustainability to identify bottlenecks to cooperative use of genetic resources in Europe can be expected to make concrete recommendations.[72]

7.3 Innovation in plant breeding techniques

Plant breeding involves three essential steps: the identification or creation of new plant genetic variation with desired trait(s); the selection and propagation of suitable parent material for creating new varieties; and the testing and registration, maintenance and reproduction of a variety (via seeds, propagules or tubers). Plant breeding techniques aim to: broaden the range of genetic variation screened to identify new traits; increase the novelty of genetic variation in order to produce new traits; and increase the efficiency, speed and accuracy of the plant breeding process.

There is concern that current crop breeding does not utilise sufficient genetic diversity. For example, a genomic analysis of maize breeding in the US found that breeding has primarily involved the selection and recombination of relatively common alleles from a limited set of ancestral lines, and has had limited impact on the overall level of genetic diversity (van Heerwaarden et al, 2013). The "classical" process could only cross-breed varieties and species that are naturally compatible. Modern plant breeding has opened up the possibility of combining distantly related or even completely unrelated species in plant breeding by overcoming natural crossing barriers, including greater use of crop wild relatives and landraces, and this is increasingly being used by plant breeders (Able et al, 2007; Feuillet et al, 2008; Hajjar & Hodgkin, 2007; van de Wouw et al, 2010). This does not address the other factors behind the low genetic diversity in some modern crop varieties, such as the influence of intellectual property rights restrictions and corporate market dominance, but does enable plant breeders to develop more diverse products.

Traditional and new plant breeding techniques that are available for each step of the plant breeding process (Meyer et al, 2013) include:

- Marker-assisted selection and genomic sequencing;
- Phenotyping platforms;
- Hybrid breeding;
- Participatory breeding;
- Tissue culture techniques including: embryo rescue method, protoplast fusion, micropropagation, and the double haploid method used for hybrid breeding, marker-assisted selection, etc;
- Mutation breeding;
- Breeding with genetic modification (GM) based on transgenesis;

[71] This is based on a 2009 proposal by ECPGR for a European Genebank Integrated System (AEGIS), see http://aegis.cgiar.org/about_aegis.html

[72] See http://ec.europa.eu/agriculture/eip/focus-groups/index_en.htm

- New plant breeding technologies that use aspects of the GM breeding process, including: intragenesis and cisgenesis; grafting on GM rootstocks; zinc-finger nuclease technology; oligonucleotide directed mutagenesis, agro-infiltration; floral dips; RNA-dependent DNA methylation; reverse breeding; and synthetic genomics.

These techniques are used in various combinations in the plant breeding process. It is important to note that the classical breeding process also still plays an important role in most plant breeding. For example, a new cross between durum pasta wheat and the wheat ancestor wild goat-grass used traditional crossing combined with modern tissue culture techniques to create wheat that may have the potential to increase UK yields by 30 per cent in future[73].

The "classical" plant breeding process generally involves the crossing of an existing elite variety with another variety with desirable traits, followed by a number of generations of breeding and back-crossing to eliminate undesirable traits and ensure that the desired trait or traits are stable. Historically, plant breeding could only use phenotypically detectable, easily measurable traits such as plant growth form, yield, or measurable resistance to pests or pathogens. Modern techniques now provide a range of possibilities to create new genetic variation, identify and track individuals with desirable traits and combine them in one line or variety (Meyer et al, 2013). The modern breakthrough in plant breeding has been driven by the ability to use genetic information from marker-assisted selection combined with advanced phenotypic characterisation techniques to identify and track desired multi-gene (quantitative) traits through the breeding process. Marker-assisted selection describes the selection of favourable genotypes based on genetic data. It is now possible to quickly identify genetic markers[74] that are associated with the genes (ie quantitative trait loci) that express the trait of interest, and use the markers to track the genes through the whole plant breeding process, increasing its efficiency and accuracy (Collard and Mackill, 2007).

In Europe the lack of consensus on genetically modified (GM) crops means that only two GM crops are currently authorised for cultivation – insect-resistant Bt maize (MON810) and BASF's starch-modified Amflora potato. Only MON810 maize is grown on a commercial scale, principally in Spain. Globally, around 130 different GM transformations or 'events' are used in commercial GM crop varieties[75], and these have been bred and combined (stacked) into a wide range of different crop varieties or cultivars[76]. However these all express only four different transgenic trait types in four main crops, dominated by herbicide-tolerance, followed by insect-resistance using Bt proteins, with a minor use of virus-resistance and starch-modification (James, 2012). This situation contrasts sharply with the far broader range of GM traits, genes and crops that have been developed in small-scale tests, but that have not been cleared for commercial use. Even so, these crops and traits have resulted in rapid adoption rates, significantly changing soybean, maize, and cotton production in North and South America, China, India and Australia (James, 2012).

It is argued that the EU is losing out on innovation by the lack of regulatory approval for GM crop varieties (EASAC, 2013). There are however also concerns about the impacts of GM crops on the environment and on biodiversity (see Underwood et al (2013) for discussion). Current GM herbicide-tolerant (HT) and insect-resistant (Bt) GM crops have brought net economic benefits to farmers through reduced pesticide costs or more flexible and less labour-intensive weed management, and by

[73] 13/05/2013 NIAB NEWS: Break though in wheat breeding science offers greater yields http://www.niab.com/news_and_events/article/282

[74] These are known as molecular markers, including "random amplified polymorphic DNA" (RAPD), "amplified fragment length polymorphism" (AFLP), "short simple repeats" (SSR) also called microsatellites; and "single nucleotide polymorphism" (SNP) markers

[75] including more than 90 GM varieties approved in the US, around 30 in Brazil.

[76] Crop cultivars and varieties are genetically different strains of the crop that can all contain the GM gene, so that for example in China the Bt insect-resistance transgene can be found in over 500 different varieties.

the facilitation of zero-tillage cropping systems (Brookes and Barfoot, 2012; Kaphengst et al, 2010; Qaim, 2009). GM HT cropping systems and GM Bt corn rootworm resistant maize have also facilitated the trend to greater use of continual cropping and minimised crop rotations in the US (Devos et al, 2013; Mortensen et al, 2012). A survey that compared Spanish adopters and non-adopters of GM Bt maize found Bt maize, like other pest-control technologies, produced variable impacts on maize yields in different provinces, ranging from neutral to a 11.8 per cent yield increase (Gómez-Barbero et al, 2008)[77]; more recent data based on plant breeding industry trials show a 10 per cent yield increase potential (Brookes, 2008).[78] In the US, GM Bt and HT maize has in some places resulted in yield increases where pest pressure is high and the pest/weed control methods prior to adoption had a relatively low efficiency (National Research Council, 2010). However, another analysis shows that the average yield increase of GM maize in the US Midwest since the 1960s has been lower than non-GM maize in Western Europe (Heinemann et al, 2013). In most cases, GM herbicide-tolerant crops have little direct impact on yield other than where they enable the control of particularly persistent weed problems (Qaim, 2009). Average yield gains are highest in developing countries where pest and weed control inefficiencies are highest (Hall et al, 2013; Kathage and Qaim, 2012). Future GM crops may have a far greater variety of traits and therefore also a wider range of impacts on cropping systems.

7.4 Plant breeding for increased productivity and sustainability

Is plant breeding producing the kinds of varieties farmers will need in order to farm more sustainably in Europe? Plant breeding is increasingly able to offer farmers new and diverse traits that were previously considered impossible. However, most current plant breeding selects and produces crop varieties primarily for increased yield under optimal growing conditions, whereas sustainable intensification demands an accelerated production of crop varieties that maintain increased and stable yields with lower levels of inputs such as fertilizer and in more stressful environments (Tester and Langridge, 2010). Indeed, some varieties bred for higher yield, such as cereals containing semi-dwarf genes against lodging under high-input conditions, have been found to have poorer nutrient-use efficiency under low-input agronomic conditions (Lammerts van Bueren et al, 2011). New crop varieties have not always maintained nutritional quality; for example the soft white wheats used for pastry flour have a low mineral content compared to historical varieties and to modern bread flour varieties (Murphy et al, 2008).

Breeding goals may increasingly focus on pest and disease resistance, drought and salinity tolerance, and nitrogen use efficiency, as well as traits to meet differentiated market demands such as industrial uses or nutritional qualities (Baulcombe et al, 2009) (see Box 7-1). One key focus for sustainable agriculture is to improve the productivity and yield stability of legume crops for animal protein feed and forage, such as field beans and peas. These are currently economically disadvantageous for farmers because of their low economic value and vulnerability to damage from pests, diseases, stalk lodging etc (Bues et al, 2013). The crops have been neglected by breeders because of the lack of commercial value and are therefore a candidate for public investment (DAFA, 2012; Moran et al, 2007). The use of molecular markers and other genomic techniques are enabling more effective selection of quantitative traits and root traits (Beaver and Osorno, 2009).

[77] The survey was carried out among 402 commercial maize farms, including both adopters and non adopters of Bt maize (event 176), during three growing seasons (2002-2004) in the three Spanish provinces in which Bt maize adoption levels are highest.

[78] Unpublished industry-led commercial-scale field trials of MON 810 Bt maize

Box 7-1 Key traits for plant breeding for sustainable agriculture

Pest and disease resistance will become increasingly important as international trade continues to bring new pests and diseases into Europe and climate change increasingly facilitates their movement and survival in different regions and cropping systems. It is also increasingly important for more sustainable agricultural production systems. For example, conservation tillage requires crops that germinate healthily in colder soil and that maintain yields under elevated levels of soil disease (Cook, 2006). A key factor in pest and disease resistance is the evolutionary capacity of crops to develop induced resistance in response to pest and disease pressures, as well as adapting to unpredictable environmental conditions. This depends on sufficient genetic diversity both within crop varieties and in crop mixtures (Hajjar et al, 2008; Ratnadass et al, 2012), which in turn relies on evolutionary breeding methods using composite crosses and modern landraces to obtain genetically diverse crops (Finckh, 2008).

Drought and salinity tolerance are key to maintaining cereal yields both under irrigation and under climate change (Cominelli et al, 2012). Plants are often subjected to multiple stresses, and it is important to ensure that stress tolerance traits are evaluated under realistic field conditions (Cominelli et al, 2012). Stress tolerance is generally more stable using polygenic or multiple gene adaptations rather than relying on single gene traits (Bhatnagar-Mathur et al, 2007).

Nitrogen use efficiency (NUE) has not been targeted by plant breeders in the past because the processes and the genetics involved are extremely complicated (Masclaux-Daubresse et al, 2010). One of the challenges is that it is necessary to select for NUE whilst maintaining the level of adaptation in other traits such as drought tolerance, requiring comprehensive genotypic and phenotypic screening of the whole-plant response (Hirel et al, 2007). However, breeding is now opening up a range of possibilities (Masclaux-Daubresse et al, 2010).

Enhanced nutritional qualities such as increased levels of vitamins and minerals or lower levels of saturated fats can contribute to more healthy diets (White & Broadley, 2009) - for example the Sun Black tomato with high levels of cancer protecting flavonoids.

Modern plant breeding techniques can be useful for breeding for stress-related traits, such as root systems with more efficient nutrient use and disease tolerance, but to be successful they need close collaboration between breeders and scientists conducting basic research, and confirmation of phenotypes in field tests as a 'reality check' (Wissuwa et al, 2009). Yield stability with stress tolerance is harder to select for than increased yield, because it requires selection in many different seasons and environments. Furthermore, crop varieties must simultaneously meet increasingly differentiated food standards. For example, there is an increasing demand for crop varieties bred specifically for organic farming conditions and with the qualities suitable for organic food. Organic crop varieties need to provide stable yields under different environmental conditions than conventional crops, as well as produce that can be made into high quality foods using artisan production methods.

A technique that may become increasingly useful in Europe is participatory plant breeding, which is already a key component of breeding for organic farming in Europe (Bocci and Chable, 2009; Dawson et al, 2011; Lammerts van Bueren et al, 2011). This is breeding that takes place primarily in farmers' fields, with the close collaboration of farmers and researchers through the whole breeding process. The process is effective because it uses farmers' experiences and agronomic knowledge, it selects varieties adapted to local conditions and farmers preferences, and breeding time is reduced by the use of many parallel trials and farmers' selection labour (Ceccarelli and Grando, 2007). The varieties tend to have a high acceptance and adoption rate within the target farmer group[79].

[79] See for example the European Consortium for Organic Plant Breeding (ECO-PB) http://www.eco-pb.org/

7.5 Regulation and risk assessment of agricultural innovation and crop varieties

Ensuring that seed legislation achieves both standardised high quality seed markets and maintaining and enhancing crop genetic diversity and seed saving options is still a challenge in the EU (see Box 7-2). The EU could stimulate the use of plant genetic resources and the marketing of a greater variety of crops by enacting legislation that systematically fosters diversity in each link of the plant breeding cycle and food production chain, and that reduces the administrative burden on plant breeders and farmers using minor crops and varieties. The priority in legislation should be to create an environment that fosters a constant flow of plant genetic resources into utilisation programmes. Europe still has some informal networks for seed exchange between farmers and gardeners[80], maintaining the use of genetically diverse seed material such as landraces, but the official plant variety registration system, as well as aspects of intellectual property rights protection, works against the use of such seeds.

Box 7-2 The regulation and testing of new plant varieties in the EU

Certification and testing of seeds and other reproductive material is currently organised differently across the EU, and regulated by some 90 different pieces of EU legislation. GM varieties are regulated separately under dedicated GM legislation, according to the EU definition of GMOs. Each Member State is required to maintain a national catalogue or list of officially recognised varieties which may be freely marketed in its territory. The European Commission then registers each variety in the EU Common Catalogue. Most varieties registered for sale on a national catalogue are also protected by Plant Breeders Rights. Varieties which are not listed in a national or the Common Catalogue are, technically speaking, not allowed to be marketed in the EU.

All varieties submitted to be registered need to be tested for DUS (distinctiveness, uniformity and stability) and, for some crops, VCU (value for cultivation and use) over a minimum two-year period. Distinctiveness means that the variety is distinguishable by one or more characteristics from all other registered varieties. Uniformity means that all plants from the same batch of seed are the same. Stability means that the plant is the same after successive generations. VCU means that compared to other registered varieties, the variety being registered offers a qualitative or technological advance (either when grown or processed).

In response to the demand for a more standardised EU-wide approval system, and in order to streamline and simplify the existing regulations, the European Commission has approved a draft plant reproductive material law. The draft regulation has been advertised as offering a liberalised and flexible system with no obligatory variety registration and opportunities for Member States to provide alternative certification for niche varieties. It is however criticised by seed saving groups and organic farming groups as actually stating the opposite in the draft regulation, and prohibitively raising the costs and requirements of seed registration so as to exclude all local genetically diverse seeds.

The proposal attempts to promote the suitability of new crop varieties for a more sustainable agriculture. The draft regulation contains a provision (Article 59) for the Commission to adopt delegated acts that set out rules for plant variety testing to determine the sustainable value for cultivation and/or use. Listed priorities include: resistance to pests; reduced need for input of specific resources; decreased content of undesirable substances; or increased adaptation to divergent agro-climatic environments.

[80] See for example the Eastern European Seed Network (EESNET) and the NETSEED project http://archive.ceu.hu/node/25566, listed in the Seed Quest Directory http://www.seedquest.com/directories.php

Sources: European Commission (2013) Impact assessment accompanying the document Proposal for a Regulation of the European Parliament and the Council on the production and making available on the market of plant reproductive material (plant reproductive material law). SWD(2013) 163 final. ARCHE NOAH und GLOBAL 2000 coalition 'Eine derart restriktive Saatgutverordnung kann nicht im öffentlichen Interesse sein' at http://open-seeds.org/wp-content/uploads/2013/05/130507_press-release-1.pdf; Tonio Borg DG SANCO European Commission Letter to Arche Noah 03.05.2013 at http://ec.europa.eu/dgs/health_consumer/docs/letter_cab_prm_en.pdf

Greater commercial use of the new breeding technologies will require either a clear separation from GM legislation or a regulatory approach to biological novelty that resolves the GM regulatory stalemate. The GM breeding process and other new breeding technologies enable the introduction of a much wider range of novel traits than conventional breeding. This may deviate in many ways - genetically, biochemically, physiologically, ethically and in regulatory terms, and in public perception - from what classical, selection-based breeding has achieved. In turn this may pose a new scale of potential risk, justifying a more intensive risk assessment process for GM crops (Nielsen, 2003). Other new plant breeding technologies also enable the introduction of novel traits (Lusser et al, 2011), and can therefore present many of the same types of possible risks to biodiversity as GM crops (eg Busconi et al, 2012; Krato and Petersen, 2012; Perez-Jones et al, 2010; Peterson and Shama, 2005). They pose a legislative challenge in Europe because their status as GM or non-GM is currently not legally defined.

An expert group convened by the European Commission has evaluated whether eight new techniques[81], including cisgenesis and intragenesis, constitute genetic modification within the scope of EU GMO legislation[82] (see Box 7-3 and Underwood et al (2013) for discussion). Because the EU risk assessment and approval process for GM crops for cultivation in the EU has more or less reached a regulatory deadlock, plant breeders fear that if the techniques are defined as falling under the EU definition of GMOs, further development will be stifled (EASAC, 2013). There is an argument that policy should regulate the novel trait(s) and the product of the breeding process rather than being defined by the technology itself (ADAS, 2013; EASAC, 2013; UK ACRE, 2007).

Box 7-3 Status of cisgenic and intragenic crops

It is not clear whether crops produced through **cisgenesis** or intragenesis – gene movement using recombinant nucleic acid transformation between organisms in the same species or species complex[83] – are defined as GM crops or not. Because cisgenesis introduces genes that have been present in the species gene pool for centuries, using promoters and other genetic sequences from the same species, some argue that these crops should not be subject to such strict requirements because their risks can be regarded as comparable to conventionally bred crops (as long as the possibility of unintended genetic effects is considered) (Schouten et al, 2006). Others argue that cisgenic GM crops may still have novel traits in novel settings (Russell and Sparrow, 2008) and that the regulation is therefore warranted. Also, it is argued that public perception could backlash if cisgenic GMOs were

[81] These are: zinc finger nuclease (ZFN) technology (ZFN-1, ZFN-2 and ZFN-3), oligonucleotide directed mutagenesis (ODM), cisgenesis and intragenesis using recombinant nucleic acid transformation; RNA-dependent DNA methylation (RdDM); grafting of non-GM components onto GM rootstock; reverse breeding; agro-infiltration (agro-infiltration "*sensu stricto*", agro-inoculation, floral dip); and synthetic genomics.

[82] New Techniques Working Group (2012) Final Report, European Commission http://ec.europa.eu/food/plant/gmo/new_breeding_techniques/index_en.htm

[83] The two techniques differ in their mechanism of genetic modification; see definitions in the glossary

deregulated, which could be more costly in the long run (Russell & Sparrow, 2008). EFSA has published a scientific opinion on the risks of cisgenesis and intragenesis, concluding that cisgenetic crops present similar hazards to conventionally bred plants whilst novel hazards can be associated with intragenic and transgenic plants, but that all these breeding methods can produce variable frequencies and severities of unintended effects which need to be assessed case by case (EFSA, 2012).

Innovations are not inherently more sustainable or biodiversity-friendly than current practice and their potential impacts need careful research and evaluation, with environmental safeguards associated with any incentives for use. Achieving a socially acceptable balance between ensuring environmental safeguards and furthering innovation requires a participatory and broad risk assessment and risk-benefit analysis process. GM crops can be beneficial or detrimental to biodiversity depending on their traits and management (see Underwood et al (2013) for a discussion of the impacts of GM crops on biodiversity). A relatively narrow stock of GM crops and traits is currently used globally, whilst a wide range of new generation traits and crops for potential future use is being developed. It is too early to conclude whether these new crops would have beneficial or detrimental biodiversity impacts in Europe if they were to be authorised for deliberate release. It is also important to bear in mind that plant breeding now has the potential to produce biologically novel crops and cropping systems without the use of transgenesis; consequently their potential environmental impacts should also be carefully assessed[84].

[84] For example, the herbicide-tolerant CLEARFIELD maize, canola, rice, sunflower, wheat and lentil crops were produced using induced mutagenesis, see http://pnwsteep.wsu.edu/directseed/conf2k3/dsc3ball3.htm

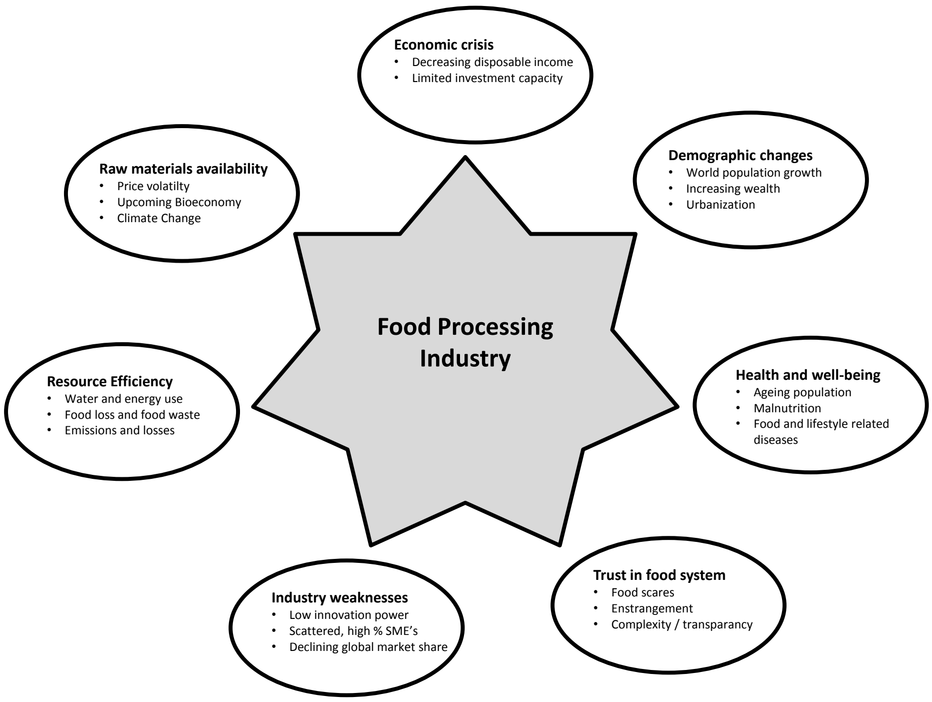
8 CUTTING FOOD LOSSES AND INCREASING FOOD CHAIN EFFICIENCY

This chapter reviews the causes of food wastage in the EU, and reviews options for reducing wastage at each stage in the food production chain, based on the reviews by Priefer et al (2013) and Meyer et al (2013) as well as Scialabba et al (2013). The chapter also reviews the potential for innovation to increase the sustainability of food processing, based on Langelaan et al (2013).

8.1 Challenges for the European food and drink industry

The European food and drink industry is the EU's largest manufacturing sector, and has a very important role to play in achieving more sustainable food and agriculture in the EU (Langelaan et al, 2013). The industry is facing a number of interdependent challenges (see Figure 8-1). Price competition and increasingly volatile raw material prices put pressure on small businesses (ETP Food for Life, 2013). The industry is also under pressure from food contamination scandals and outbreaks of food borne illnesses. Food safety standards and food chain transparency and traceability of raw materials and ingredients are becoming more and more important. At the same time, the food and drink sector is being asked to take action to promote more healthy diets (such as by reducing saturated fat, salt and sugar in products) and to reduce food waste.

Figure 8-1 Major challenges facing the European food processing industry



In the short-term, sustainability gains and cost reductions can be achieved through increased resource use efficiency, but in the medium to long-term, the challenge is to harness innovation for the achievement of more ambitious goals (Langelaan et al, 2013). These include: 1) new and more sustainable food products that feed more with less, help to prevent life-style related diseases, and meet consumer demands; 2) resource-efficient manufacturing processes that minimise dependency on high-value crops, water and energy; prevent losses and waste; produce high quality products with high and stable nutritional content; and allow for diversification to meet particular consumer requirements; 3) integrated and transparent food supply chains that provide food security in developing and developed countries; connect local food production and globalised and complex supply chains; produce safe food and increase consumer trust in the food system; and reduce losses and waste. This is supported by a European Parliament study which concludes that shifts in dietary patterns, waste prevention, and closing resource loops provide the greatest opportunities for improved resource efficiency in the EU (Sonigo et al, 2013).

A number of technology options and their objectives for more sustainable food processing are discussed in this chapter. It should be realised that for many companies these challenges are not within the focus of day-to-day business, and thus will not automatically lead to the start of innovation projects (see Box 8-1). It is therefore essential to link these challenges to the appropriate business drivers for each type of business.

Box 8-1 Innovation potential in the EU food and drink industry

The EU food and drink industry is the EU's largest manufacturing sector in terms of both economic turnover and employment[85]. Over 280,000 small and medium-sized enterprises (SMEs) generate about half of this turnover and account for the majority of the employment (FoodDrinkEurope, 2012). However, the big companies (including some multinationals such as Nestle and Kraft) are responsible for the major part of R&D spending in the sector, whilst the innovative power of the SMEs is considered to be very limited (Langelaan et al, 2013). The European Technology Platform "Food for Life"[86] recognises that the food and drink industry must increase the pace of innovation in order to meet the challenges of the next decades (ETP Food for Life, 2013). In particular, the European food industry is weak in R&D investment and innovation in products and processes, especially for biotechnology which is an important tool to develop more sustainable food products. The food sector needs to continue to invest in new technologies to improve agricultural systems and to widen the scope of R&D investment to improve resource use and security, notably in terms of waste avoidance. In the beverage sector, increasing pressure for sustainability performance will stimulate demand for resilient supply chain logistical models and increasingly efficient water management (de Boer and Van Bergen, 2012). This will require a substantial increase in the capacity of SMEs to manage innovation and commercialisation of R&D outputs, as well as the dissemination and use of existing knowledge from R&D. Much is expected from funding under the Horizon 2020 programme.

8.2 Quantification and characterisation of food wastage in the EU

There is a need for an agreed and binding definition of the term 'food waste' in the EU. The definition of food wastage is currently being considered at international level, and 'food loss' and 'food waste' are often distinguished in relation to different stages of the supply chain. 'Food loss' is commonly used by agronomists in relation to agricultural and post-harvest processes, where food intended for human consumption leaves the supply chain due to environmental and technical limitations, such as poor weather conditions, pest or disease damage, poor storage technologies, infrastructure and packaging, as well as insufficient knowledge and skills. Unconsumed food suitable for human consumption, leaving the supply chain downstream (in retail, food service and households), is governed by waste legislation and is thus more commonly referred to as 'waste'. 'Food wastage' is commonly used to refer to both food losses and waste, encompassing "any food lost by deterioration

[85] In 2011 the sector had an economic turnover of EUR 1.017 billion and employed 4.25 million people. The employment in the entire food chain is about five times higher.

[86] The European Technology Platform Food for Life is a public/private partnership encouraged by the European Commission and led by FoodDrinkEurope to drive innovation and unite stakeholder communities in reaching strategic research objectives. It brings together the main European stakeholders of the food sector; consumers and society, food and related industries, and the academia and research community.

or discard" (Scialabba and et al, 2013)[87]. This definition is being retained by the EU FUSIONS Food Waste Dialogue, a European FP7 project, to be published at the end of 2013.[88]

Two main data estimates on food waste in Europe are currently available, but the estimates are not comparable (see Box 8-2). Standardisation of the methods used by Member States for the collection of data on food waste would enable the tracking of progress towards food waste reduction targets (Priefer et al, 2013). Food waste data for 2012 is already being collected by 17 volunteer Member States via Eurostat, but neither the definition nor a standardised quantification methodology has been agreed at this time. The FUSIONS project will publish guidelines for harmonised data collection across the Member States by 2016[89].

Box 8-2 Quantification of food waste in the EU

The European Commission estimated annual food waste in the EU-27 at 89 million tonnes, excluding agriculture and post-harvest losses, or around 180 kg per person in 2010 (Monier et al, 2010). The FAO estimated food waste, agricultural and post-harvest losses in the Europe region, including non-EU-27 countries and Russia, at 245 million tonnes per year or 336 kg per capita in 2007 (Jan et al, 2013). These studies are not comparable in scope (including sector boundaries and commodity groups covered), definitions or methodologies. In 2010, ten Member States had national food waste data available for one or more stages of the supply chain. The UK produces the most robust, comprehensive and regularly-published data.

The methodology used by Monier et al (2010) for the European Commission used specific national food waste data when available, EUROSTAT data in the animal and vegetal waste stream by sector where national data was lacking, and made extrapolations based on the closest possible neighbouring data where both sources were lacking. The FAO methodology used by Gustavsson et al (2011) and Jan et al (2013) is based on FAO food balance sheets, broken down by world region, commodity group and supply chain stage, to which waste percentage estimates, differentiated by world region, are applied.

Priefer et al (2013) subjected the Monier et al estimates to a reliability check, by applying the Gustavsson et al methodology of food balance sheets and waste percentages to the EU-27 scope. Its findings point to flaws in both methodologies. The minimum scenario used by Monier et al for Member States lacking food waste data in the household sector is likely to be too low. On the other hand, where detailed national food waste data was collected by Monier et al, the data suggests that for many of the EU-15, the waste percentage for the Europe region used in the Gustavsson methodology may be too high.

Since the publication of the European Commission study in 2010 and the rising profile of food waste on the policy agenda, many additional Member States have undertaken food waste quantification work. The FUSIONS Food Waste Dialogue, a European FP7 project, is collating all new data and will update the EU baseline in 2015-16, while also developing guidelines on definitions and measurement harmonisation.

One trend that emerges from the available data is that the household sector generates overwhelmingly the largest proportion of food waste in the EU (see Table 8-1). Given that the EU is

[87] Please note that the application of concepts of 'negligence' and 'intention' to distinguish food 'loss' and 'waste' is not considered to be relevant, as negligence and intentional discard can occur at any stage, and the attribution of blame can be counter-productive in addressing the problem. Thus food wastage refers to any edible food intended for human consumption that fails to be consumed, encompassing both loss and waste if the distinction is needed by the user.

[88] EC FP7 Project to reduce food waste: http://www.eu-fusions.org/

[89] EU FUSIONS project and Food Waste Dialogue funded by the European Commission Framework Programme 7, see http://www.eu-fusions.org/what-is-fusions

expected to have a relatively efficient supply chain, it could be expected that the greatest fraction of wastage arises at the point of consumption. Trends can also be identified in terms of product groups. Fruit and vegetables, followed by bakery goods, are discarded at a far higher rate than animal-derived products, although the latter have significantly higher environmental impacts because they are associated with much higher greenhouse gas emissions, water use, and nitrogen and phosphorus emissions.

Table 8-1 Percentage of total food waste originating in each stage of the food chain in different European countries and the EU-27 (updated based on Priefer et al 2013)

Country	Germany	Switzerland	UK	Sweden	EU-27
Source	(Hafner et al, 2012)	(WWF, 2012)	(WRAP 2013[90])	(Jensen et al, 2011)	(Monier et al, 2010)
Processing/ manufacturing	17%	30%	28%	17%	39%
Retail and distribution	5%	7%	3%	4%	4%
Food services	17%	5%	6%	13%	14%
Households	61%	45%	62%	67%	43%

8.3 Causes of food wastage in the EU

A wide range of actors are involved in the generation and prevention of food wastage, including the food processing sector but also food producers, retailers and consumers. Both food losses and waste can arise at the farm level; at the various stages of food storage, transport, processing, packaging and distribution; in the retail sector; and at consumption level in the household and the hospitality sector (restaurants, cafes, bars, hotels, hospitals, schools, prisons etc). There are many causes for food losses and wastage at each stage of the supply chain. Göbel et al (2012) distinguish seven cross-cutting causes: process- and market-based standards and quality requirements; the legal framework for ensuring food safety; common market practices; human errors; technical faults; logistic errors; and cultural influences. Sector-specific causes are considered below, based on the analysis in Priefer et al (2013), Meyer et al (2013), Langelaan et al (2013), Monier et al (2012) and Jan et al (2013).

Agricultural production losses and post-harvest losses

Poor weather conditions, pests and diseases, poor storage technologies, infrastructure and packaging can contribute to 'food losses' at farm-level (Meyer et al, 2013). In addition, commodity price fluctuations (where low market prices do not justify the expenses of harvesting or storage), and planned overproduction (to manage production risks and meet unpredictable client demands), contribute to wastage (Milepost, 2013). Contractual conditions where orders can be changed or cancelled freely present another risk (Jan et al, 2013). Rigorous aesthetic quality standards lead to wastage where non-uniform produce is deemed unsalable, though some of these standards have now been cancelled. Lastly, the cost of storing produce effectively before food banks are able to collect it usually makes disposal a more economical solution. Post-harvest losses are a particularly serious issue in developing countries, as reviewed in Meyer et al (2013). Furthermore, food losses and wastage from wild fisheries at sea can be significant, with the discard of by-catch in Europe currently estimated at 20 to 50 per cent (Tsagarakis et al, 2013; Uhlmann et al, 2013).[91]

[90] http://www.wrap.org.uk/sites/files/wrap/RSC20Facts%20%20Figures%2C%207%20October%202013.pdf

[91] NB this may change in response to altered by-catch policies and limits

Wastage in the food chain – transport, processing, packaging and distribution

During the preparation of food products errors can occur during washing, peeling, slicing and boiling, food safety risks, packaging, through process interruptions or when products are rejected as unsatisfactory, leading to wastage (Monier et al, 2010; Priefer et al, 2013). In distribution (wholesale and retail), discards may be triggered by transportation and storage problems linked to the cold chain, by identified packaging and labelling errors, breakages or damage, inadequate stock management, proximity to expiry dates, marketing strategies, logistical constraints or product rejection due to quality standards. Rejected foods can sometimes not be donated due to the donor's VAT or food hygiene liability.

Food waste at consumption level

In the food service sector, portion sizing is a major issue (Monier et al, 2010). While there is more flexibility in a cafeteria setting, full service restaurants are more challenging, as they offer a very limited range of different serving sizes. "Doggy bags" have different levels of acceptance across the EU, still being frowned upon in France for example. Donating left over food to food banks is logistically more challenging (though by no means impossible), due to high perishability and rigorous hot/cold chain requirements. In schools, the amount of time spent at the table can have an impact on waste,[92] as well as the time of lunch, where children eating after break times waste less than those eating before breaks (Priefer et al, 2013). In hospitals, a lack of autonomy in expressing meal preferences, portion sizes or meal times compounds food wastage, and low food quality in both schools and hospitals can also be a contributing factor (Monier et al, 2010).

At the stage of final consumption, wastage arises due to consumer behaviour, poor purchase planning, confusion about date labels, suboptimal storage and packaging, poor portion sizing, preferences (dislike of bread crusts or apple skins for example) and lack of knowledge of how to use leftovers, especially in households. A lack of value for food or perception that it is cheap may be an underlying problem. Socio-economic factors such as household size, age and income can also influence wastage habits (BCFN, 2012; Gustavsson et al, 2011; Møller et al, 2012; Monier et al, 2010; Parfitt et al, 2010).

8.4 Cross cutting options for policymakers to reduce food waste in the EU

The following options are aimed at EU institutions and Member State legislatures, presenting key opportunities for policymakers to provide a framework for food chain efficiency that is measurable, sends unambiguous market signals, provides coherent consumer information, stimulates awareness, and supports research on innovations with potential for the greatest impact. They summarise the options presented in Priefer et al (2013), Meyer et al (2013), and Langelaan et al (2013).

Setting binding targets to reduce food waste and establishing standardised monitoring systems

Measurement and target setting are critical first steps in addressing food wastage across the EU (Priefer et al, 2013). While some Member States have already made progress on target-setting, improvements in food waste measurement that would enable the tracking of progress towards targets has been slow to catch up. At EU level, the European Parliament called for a 50 per cent reduction target for 2025[93] and the European Commission has declared a 50 per cent reduction target for 2020

[92] O'Connor et al (2012) Cahiers de préconisations pour la réduction du gaspillage alimentaire en restauration collective (Conseil Général de la Gironde), available at: http://www.gironde.fr/upload/docs/application/save/2012-06/cahier_restauration_collective_1806122_95p.pdf

[93] European Parliament resolution of 19 January 2012 on how to avoid food wastage: strategies for a more efficient food chain in the EU (2011/2175(INI)). Text A7-0430/2011. Adopted Thursday, 19 January 2012 – Strasbourg

(European Commission, 2011a), though the scope of the latter should be expanded beyond its current focus on the retail, food service and household sectors, in order for coordinated action across the chain, reducing the risk of food wastage shifting between sectors. France has set a national target to reduce food waste by 50 per cent by 2025[94], and the Netherlands has a national target to reduce food waste by 20 per cent by 2015[95]. Targets are being considered in Sweden and Austria, providing early examples to other Member States. The Waste Framework Directive requires Member States to produce mandatory national waste prevention programmes by the end of 2013, and these could include mandatory food waste reduction targets[96]. Local authorities can break down the national targets to their area of influence. Individual sectors like manufacturing, retail and hospitality could develop voluntary commitments on food waste reduction following, for example, the effective Courtauld Commitment in the UK[97]. The introduction of separate collection of food waste at all stages of the food supply chain, whether voluntarily or mandatory, would be beneficial (Monier et al, 2010).

Reviewing EU regulations and standards in order to reduce incentives for waste and increase food chain efficiency

The identification of any inappropriate barriers presented by EU regulations and standards is imperative in enabling optimal food chain efficiency in the EU. A review of food safety regulations such that margins of error are not excessive and that opportunities for efficiency gains are not missed would be helpful. One example might be current EU legislation preventing the use of catering waste as feed for pigs and chickens. A legal framework ensuring safe processing of catering waste would assure food safety and make an important efficiency gain with this currently underexploited resource. Further research may be required to decide where current limits across relevant legislation may be revised without running a risk for food safety (Priefer et al, 2013). Perceptions of food safety regulations need to be considered, and clarification provided to different sectors via guidelines, as fear of breaking safety regulations may often have more impact than the regulations themselves.

European marketing standards that have no impact on safety have already been rolled back but remain binding for ten principal fruits and vegetables[98]. The necessity of these standards could be reviewed, as they trigger significant wastage at farm level, nature not producing tomatoes or peppers of homogenous shape and colour (Priefer et al, 2013). Standards linked to taste, nutritional value or growing conditions could be considered instead, along with logistical considerations in packing and transporting produce of heterogeneous size.

It is also advisable to review renewable energy legislation to remove any possible conflicts with the goal of food chain efficiency, for example subsidies for the generation of energy from food waste (see Chapter 9 for further discussion).

[94] French National Pact to Combat Food Waste,
see http://www.fnbnews.com/article/detnews.asp?articleid=33853&sectionid=1[95] Netherlands Policy Paper on Sustainable Food 2009, http://www.scp-knowledge.eu/knowledge/policy-agenda-sustainable-food-systems-netherlands

[95] Netherlands Policy Paper on Sustainable Food 2009, http://www.scp-knowledge.eu/knowledge/policy-agenda-sustainable-food-systems-netherlands

[96] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance)

[97] Courtauld Commitment: http://www.wrap.org.uk/category/initiatives/courtauld-commitment

[98] These are apples, citrus fruit, kiwifruit, lettuces, curled-leaved and broad-leaved endives, peaches and nectarines, pears, strawberries, sweet peppers, table grapes, and tomatoes, see http://ec.europa.eu/agriculture/fruit-and-vegetables/marketing-standards/index_en.htm#specific-marketing-standards

Using economic instruments to reduce waste and increase food chain efficiency

A number of economic instruments can impact efficiency in the food chain. In many Member States, the Value Added Tax (VAT) Regulation applies to food products at a reduced rate[99], which can encourage the perception that food is cheap and can thus be used carelessly (Marthinsen et al, 2012). The German Scientific Advisory Board on Agricultural Policy has suggested eliminating the reduced VAT rate on food products, offset by targeted governmental income support for those in social hardship (BMELV Scientific Advisory Board, 2012). Another option is to introduce variable VAT rates according to the environmental impacts of specific food products (Oosterhuis et al, 2008). However, more explicit research to understand the potential impacts of using VAT as a tool to combat food waste, as well as its potential concomitant social and economic impacts, would be necessary before taking this forward.

An alternative to the taxation of food purchasing is the taxation of food wastage, via the separate collection of food waste and pay as you throw (PAYT) schemes for households. These have been demonstrated to be effective, particularly in coordination with food waste prevention messaging, providing waste charges are not so high as to incentivise illegal dumping. Landfill bans on food waste, as implemented in the Republic of Ireland, or high taxes or gate fees for non-household food waste also have very strong potential to impact waste behaviours, by sending the appropriate market signals (EEA, 2013b; Watkins et al, 2012).

Streamlining food date labelling to reduce consumer waste

Food date labelling is a major issue recurrently linked to food wastage across the food chain (Priefer et al, 2013 and references therein). It is suggested that the visual presentation of date labels be improved and harmonised, in order to increase consumer understanding of their meaning. The eradication of retailer-oriented ‘display until’ dates and expiration dates for stable foods, as well as the rollback of use of ‘best before’ dates with no safety risk should be considered. Information campaigns on labelling should be initiated by national governments and the retail sector to improve consumer understanding, and price reductions for products near expiration should be encouraged.

Awareness campaigns to reduce food waste in households, retail and hospitality sector

Awareness about food waste is growing in the EU, but the level of engagement is variable across Member States. National governments are encouraged to initiate attractive awareness campaigns on the topic, adapted to national circumstances and thus preferably based on national research into the social and cultural background in which food is wasted. Campaigns need to be designed to attract attention, stimulate value and respect for food, and provide practical guidance. Campaign reach and impact should be measured regularly. Feedback to participants on their improving performance is especially effective. WRAP in the UK developed a particularly comprehensive and effective awareness campaign entitled Love Food Hate Waste, which is available to licence internationally, through which it could share its expertise with other Member States[100].

Awareness campaigns need to engage the retail and food service sectors, as well as schools, as champions. Supermarkets have a wide range of opportunities to educate consumers on efficient food use, whether explaining optimum storage conditions on food labels, providing leftover ideas on till receipts, explaining date labels next to the produce display, as well as providing broader context through store magazines and websites. In the food service sector, cafeterias are a particularly good environment in which to communicate to customers on this topic, by publicising both measures taken to reduce food waste and the customer’s role in supporting these activities. Where cafeterias undertake measurement activities, communicating on quantified food waste reduction achievements

[99] In the UK, for example, staple foods are exempt from VAT entirely whereas the standard rate has to be paid for luxury goods such as sweets, crisps and ice cream (Stuart, 2009)

[100] Based on direct correspondence of author with WRAP

are particularly useful in motivating participants to keep going. Food education at school is also a key opportunity; the national pact against food waste in France for example has included food waste education provisions in the required curricula both at schools and at agricultural colleges.

Promoting research on innovative technologies to reduce food waste

European and national policy makers may initiate research programmes to evaluate different technological options for reducing food waste. Technologies aimed across the supply chain with good food waste reduction potential that could benefit from further development/adoption include: innovative use of by-products, intelligent labels on packaging, controlled atmosphere packaging, intelligent ordering systems for retail or RFID-technology[101] to collect data during distribution (eg temperature data during transport), and intelligent waste bins for pay-as-you-throw food waste disposal (Priefer et al, 2013; Ruiz-Garcia et al, 2009).

Regulatory bodies could play an active role in promoting novel technologies for food manufacturing (Langelaan et al, 2013). A focus solely on excluding food safety risks will lead to a standstill in innovation. With the implementation of modern risk-management concepts as well as more science-based manufacturing the right balance between ensuring product safety on the one hand and stimulating innovation on the other hand should be found. Regulatory bodies and others could more actively promote operational excellence programmes for Quality Risk Management[102]. These programmes have already proven their success in other sectors of the industry and could potentially lead to large reductions in the costs associated with poor food quality.

8.5 Options to reduce waste and increase efficiency in the food supply chain

The following options concern supply chain actors, presenting options that they can implement to raise awareness of food wastage and to take advantage of innovative or underexploited opportunities to increase efficiency (Langelaan et al, 2013; Priefer et al, 2013). As the largest proportion of food waste in the EU arises from households and from the hospitality sector, this is an important focus for action. The European food processing sector relies on diverse inflows of imported food products from developing countries, including highly perishable products. The sector therefore also has a responsibility to ensure that losses in agricultural production, post-harvest processing and transport in developing countries is reduced as far as possible, through better supply chain management, investment, training and capacity building (Sonigo et al, 2013).

Options to combat food waste in the hospitality sector

Combating food waste in the food service sector calls for a basket of measures, where portion size flexibility is expected to hold the greatest potential. It is recommended that following a trial period to explore different approaches, actors in the sector who fail to take voluntary action be obliged to do so by statutory measures (Priefer et al, 2013 and references therein).

Given varying appetites, a variety of portion sizes should be offered, at differentiated price points if helpful. An open dialogue on food waste would make it easier for customers to ask for less or none of a particular item, even beyond the cafeteria setting. Trayless dining, where accompanied by communication on food waste, relieves pressure to take as much food as possible in one trip, allowing customers to re-serve themselves more accurately according to their appetite. The prioritisation of

[101] RFID-technology (radio frequency identification data) is the wireless non-contact use of radio-frequency electromagnetic fields to transfer data, for the purposes of automatically identifying and tracking tags attached to objects. The tags contain electronically stored information. Unlike a bar code, the tag does not necessarily need to be within line of sight of the reader, and may be embedded in the tracked object.

[102] See for example Lean Manufacturing tools, http://www.mindtools.com/pages/article/newSTR_44.htm, or Six Sigma, http://www.foodprocessing.com/articles/2007/221.html

pay by weight buffets over all you can eat formats, especially where buffets are not expected to remain completely full until the end of service, can make a big difference.

Careful forecasting and stock management are also critical. Not only can historical consumption data and weather patterns provide insight for forecasts, simple mechanisms such as introducing mandatory reservations for cafeteria and other meals, or improving internal communication on client numbers are not yet being fully exploited (for example where a class of children are away for a school trip and the canteen was not notified, or a conference is being held increasing cafeteria traffic)[103]. Waste analysis can further improve forecasting by helping kitchens understand which types of foods are most commonly wasted and adapting menus accordingly. As in the processing sector, stock management can be improved by mixing ingredients and making quantities available to customers progressively and only when the need is clear.

Training staff in food waste prevention (through processes such as that of Lean Path[104]), and creating incentives for continued engagement (through schemes such as Giving Corner[105]) are important, as is the role of the food service sector in raising customer awareness, on food waste in general and on ordering only as much as is needed in the dining room. Integrating food wastage considerations into certification standards and ecolabels applied to the hospitality sector provides an additional option in supporting both education and compliance.

Alternative marketing channels for surplus agricultural products

A number of channels for ensuring that surplus food gets eaten are currently underexploited. The further processing of surplus fruit and vegetables into juice, jams or canned products is one option. Another possibility is the use of decentralised direct marketing systems in the form of farm shops, farmers' markets, delivery of vegetable boxes by subscription, producer co-operatives, solidarity purchasing groups and Community Supported Agriculture (Priefer et al, 2013). Social supermarkets, such as the épiceries solidaires in France and SOMA in Austria, are gaining ground, as a heavily discounted outlet for those in need, which can make use of both surplus agricultural products and retail oversupply. The various models are more or less popular in different European countries.

A final option is the facilitation of gleaning, where crops left unharvested by farmers, due to low market value or non-compliance with aesthetic standards, are made available to individuals and groups who harvest and consume the produce free of charge. These alternative channels should be facilitated in order to prevent possible rebound effects, while further research is needed to assess the pros and cons of these approaches in greater detail.

Promoting food redistribution programmes

Barriers to food donation should be redressed, so that as much food as possible that would otherwise be discarded is able to reach those in need. The Good Samaritan Act, which currently exists in the United States and in Italy, limits donors and redistribution staff from criminal and legal liability on the food donated, and its propagation across the EU should be seriously considered. Fiscal incentives for donation would also encourage uptake. Furthermore, poor transposition of article 74 of the EU VAT Directive that states that VAT on donated food near its 'best before' date should be fairly low or close to zero, is a missed opportunity, with only 13 Member States interpreting and implementing this

[103] O'Connor et al (2012) Cahiers de préconisations pour la réduction du gaspillage alimentaire en restauration collective (Conseil Général de la Gironde): http://www.gironde.fr/upload/docs/application/save/2012-06/cahier_restauration_collective_1806122_95p.pdf

[104] Lean Path food waste prevention system, see http://www.leanpath.com/

[105] Giving Corner offers businesses a platform to engage employees in contributing to non-profit activities, see http://www.en.givingcorner.com/

article in a way that facilitates food donation.[106] Clarification/guidance is likely to encourage uptake. Finally, infrastructural improvements to enable large scale efficient food donation is very much needed. FareShare in the UK provides a good model of how this can be achieved.[107]

Improved workflows and supply chain management to reduce waste and increase efficiency

Increasing flexibility, reactivity, and foresight must be integral to Europe's food chain efficiency strategy. The use of technologically up-to-date production equipment and the optimisation of processes to reduce wastage are important to minimising residues and rejections. The shelf life of many fresh products depends on both the initial product quality and the ambient conditions (temperature and relative humidity) in which they are stored and processed. The optimisation of these two aspects will deliver a strong control of the product quality in the whole chain and reduce wastage (Langelaan et al, 2013). Sensors and monitoring equipment can track, communicate and adjust conditions during transport, storage and handling. There is also a significant potential to reduce energy and water use with intelligent use of technology and quality control processes.[108]

Waste avoidance is supported by arranging production lines to minimise cleaning, for example by moving from preparations that are light to dark, mild to spicy, organic to conventional, vegetarian to meat-based. Mixing of ingredients at the latest possible moment increases flexibility in response to order changes (Priefer et al, 2013). Optimisation of stock management and communication channels across the food chain should be revisited, in order to improve forecasting of needs and eliminate contractual conditions that generate waste. Norwegian food retail group NorgesGruppen for example has recently made significant savings through stock management optimisation, following an initial waste audit.[109] Significant stock management gains are still available, even though there is a common assumption that processes in the EU are already efficiently streamlined.

Reduced harvest and post-harvest losses through improved guidance to producers and cooperation along the food supply chain

There is a need for increased awareness among European actors in global food supply chains on how to reduce food losses during harvest and post-harvest, particularly in developing countries and transition countries. The food industry needs to provide methods, guidelines and training on good practices, tailored to particular crops (taking into account differences among cultivars), locality, and the human and financial capacities of beneficiaries (ranging from subsistence farmers to commercial farmers) (Meyer et al, 2013). Equally important is the exchange of experience among farmers and information flows along food supply chains as essential elements of crop losses programmes; similarly, horizontal and vertical cooperation is needed.[110] Post-harvest losses often have their origins in the crop production conditions, eg the incidence of fungal disease and associated toxins, which can be reduced through good management practices (see below).

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[106] EC stakeholder meeting of the Working Group on Food Losses/Food Waste of the Advisory Group on the Food Chain, Animal and Plant Health

[107] FareShare: www.fareshare.org.uk/

[108] See for example the Quest II methodology for energy control in refrigerated storage and transport, http://www.wageningenur.nl/en/show/Energy-use-of-refrigerated-containers-further-reduced.htm

[109] NorgesGruppen Stakeholder interview August 2013

[110] It is noted that functioning food supply chains in developing countries also rely on improvements in transport infrastructure, a clean water supply, a reliable energy supply, and ICT (internet, mobile phone)

8.6 Innovation for sustainable food and alternative uses

This section gives options for promoting research and development investment in key innovations in food processing.

Alternative post-harvest processes requiring less energy and water

Most arable farmers in Europe use combine harvesters and large-scale mechanised storage facilities, operated by farmer cooperatives, grain merchants or processors. If machinery is operated well, the harvest and post-harvest losses are generally low. However energy use is high; in particular the use of natural gas to dry grain in silos[111]. Natural air temperature drying is slow but much more efficient, if designed and operated correctly. Solar collector technologies allow drying without fossil fuel use[112].

The post-harvest process is particularly critical for fresh fruit and vegetables, which require a continuous cold chain technology. The cooling, processing, and cold storage of fresh fruit and vegetables significantly reduces raw material losses but the trade-off is that it is very energy intensive. There is however a large potential to increase the energy efficiency of refrigeration technologies. Innovation options include mild technologies for pasteurization and sterilisation that maintain fresh product quality without the need for intensive heating or cooling (such as pulsed electric field processing, cold plasma treatment or advanced heating technologies) (Langelaan et al, 2013).

The lack of basic food storage capabilities in the developing world contributes to enormous wastage. Farmers often carry out harvesting and storage processes manually with very little machinery and losses are generally high. There are many options for improvement using small scale technologies such as small threshing and cleaning engines, together with operator training.[113] Investment in grain storage using locally available materials and research into other simple but effective techniques would have a significant impact on food wastage from the beginning of food chains.

Better techniques and quality control to reduce moulds, mycotoxins and other biotic agents

Biotic contaminants, such as moulds, are another important source of food losses. Fungal infections (moulds) produce mycotoxins, which occur in a variety of crops (grains, roots and tubers, fruits and vegetables) (Meyer et al, 2013). Mycotoxins can be carcinogenic, mutagenic, teratogenic and immunosuppressive, producing a number of short-term and long-term health effects (Wu et al, 2014). The surveillance and control of mycotoxins in food and feed is a major food safety challenge worldwide. Due to the variety of toxins, it is impossible to use one standard technique for analysis or detection, and small businesses are unable to meet the practical requirements for high-sensitivity analysis and the need for a specialist laboratory (Turner et al, 2009).

Mycotoxin control in stored maize and wheat requires rapid and thorough post-harvest drying and storage under controlled humidity and temperature conditions, requiring careful monitoring and quality control. Further options include modified atmospheres, preservatives and biocontrol agents, but the cost of these treatments is prohibitive for most farmers and businesses and would be a target for innovation that reduces costs (Chulze, 2010; Magan et al, 2009). Various sterilisation treatments for food can either control mycotoxins or help avoid mould formation, including warm water, UV radiation, use of fludioxonil, and heat sterilization (Langelaan et al, 2013). However, high costs and sometimes negative impacts on food quality are currently limiting factors for food processors.

[111] Around a third of the EU cereal crop requires post-harvest drying

[112] Eg see http://www.synergysolarsolutions.co.uk/applications/agriculture; though it is noted that usually fossil fuel is used to create the materials and infrastructures needed

[113] Eg see Ethiopian ATA (2013) New Threshing Technologies on Ethiopian Horizon. At http://www.epa.gov/agriculture/tbio.html

Develop more sustainable storage and packaging technologies

Storage and packaging technologies impact resource efficiency by reducing wastage across the food chain, while also contributing in many cases to improved food quality and safety and logistics optimisation (Langelaan et al, 2013; Priefer et al, 2013; Sonigo et al, 2013). Packaging technologies that reduce food wastage by extending the shelf lives of products and improved temperature control systems are the main opportunities in this area (see Box 8-2).

Box 8-2 Defining sustainable food packaging

Sustainable food packaging has been defined by the Sustainable Packaging Coalition as packaging that:

- Is beneficial, safe & healthy for individuals and communities throughout its life cycle,
- meets market criteria for performance and costs;
- Is sourced, manufactured, transported and recycled using renewable energy;
- maximizes the use of renewable or recycled source materials;
- Is manufactured using clean production technologies and best practices;
- Is made from materials healthy in all probably end-of-life scenarios;
- Is physically designed to optimize materials and energy; and
- Is effectively recovered and utilized in biological and / or industrial cradle to cradle cycles.

Source: Sustainable Packaging Coalition,
http://sustainablepackaging.org/content/?type=5&id=design-guidelines.

Vacuum-based skin packages are already contributing to longer shelf lives and reducing retail space requirements per product. **Humidity and ethylene control** are central areas for packaging technology research, in particular modified atmosphere packaging (MAP). Ethylene, a plant hormone central to ripening in many fruits and vegetables, can be blocked or removed via scavengers through MAP technologies. Ethylene blocking can lead in some cases to uneven or ineffective ripening, leading to discard. Improvement of the knowledge base in this area, understanding in particular the relationship of ethylene to temperature, variety and harvesting moment, are key areas for sustainable food packaging research. Temperature control and a well-designed cold chain, furthermore, are integral in maintaining food quality. As cooling cannot be avoided, **energy-saving refrigeration systems** are a research priority.

The use of nano-technologies can increase innovative capacities in food packaging, such as pathogen and toxin sensors. These could contribute to food waste prevention through increased accuracy, for example by avoiding the discard of a whole batch of products when only a handful are affected by a health concern. Nevertheless, rigorous research on safety is essential, due to the very limited current knowledge on potential toxicity, and wider human and environmental health impacts (Blasco and Picó, 2013).

Food packaging is contributing to sustainability and resource efficiency goals through progressive lightweighting of packaging materials. Targets could be set for reducing the use of materials with the greatest environmental impacts and increasing the use of recycled materials in packaging, including the development of economically viable recycling processes for polyethylene and polypropylene. Bio-based materials are increasingly used in packaging, and where they make use of food by-products that would otherwise have become waste, this adds to food chain efficiency (but see Chapter 9 for life cycle impact considerations).

Innovation for sustainable foods and for use of food by-products

Innovations in food processing have the potential to significantly alter agricultural production through changing prices and market demands. For example, in the UK the development of the Chorleywood bread process in the 1960s allowed bakers to increase the proportion of UK wheat within their flour blends, greatly stimulating the increase in UK wheat area and yields (Burgess and Morris, 2009). The development of plant-based meat alternatives that demand significantly lower resource inputs, including certain seaweeds/micro alga, soy, and insects, as well as meat imitators made of pea protein, have very interesting substitution potential as global demand for meat rises (Aiking, 2011)[114]. Consumer acceptance is still a limiting factor for plant-based meat alternatives to make a real contribution to the transition to a more sustainable protein supply. Recent advances in process technology, however, allow for the production of so-called third generation meat replacers which really mimic the taste and feel of animal-derived meat (Langelaan et al, 2013).

Within the food processing sector, substantial quantities of the raw materials that enter the factory are ultimately traded as by-products (Langelaan et al, 2013). By-products are currently mostly exploited in non-food applications (animal feed, technical applications, fertiliser production). Some by-products of food processing, particularly sugar and vegetable oils, have a significant economic role as animal feed. In the Netherlands, for example, around half or more of animal feed originates from the by-products of food production, because of the volume of international trade in food that passes through that country (Nonhebel, 2004).

By-products could be utilised directly as food to a greater extent through the development of innovative processes that meet food safety standards and consumer acceptance. There are increasing examples of this, such as ProValor that uses vegetable by-products in vegetable juices[115]. Animal by-products are transitioning from elementary feed applications to high-value food ingredients, notably due to legislative pressures and increased waste costs, and because of the relatively high economic value of proteins, underlining the impact of cost on innovation (Langelaan et al, 2013). This is likely to spread to other food sectors in the coming years as food prices increase. A promising route for the food industry to find the right balance between ensuring product safety on the one hand and stimulating innovation on the other hand may be to couple a thorough understanding of manufacturing processes to more regulatory freedom, for example in the use of side streams in food applications or in addressing the safety risks associated with the use of novel ingredients (eg new protein sources) for food applications (Langelaan et al, 2013). The Bio-based Industries Joint Technology Initiative (BBI JTI)[116] is one of the public-private partnerships to receive funding under the Horizon 2020 initiative to develop the use of agricultural residues and food waste for biomaterials such as bioplastics (see Chapter 9 for details).

In conclusion, it is important to note that efforts to increase food chain efficiency present a number of trade-offs. One example may be saving food resources by extending shelf life at the cost of more energy input (for cooling) or more packaging material. In this case, life cycle analysis shows that the environmental impacts of food waste are on average fifteen times higher than those of packaging.[117] With regard to food safety, the BSE crisis resulted in a situation where food discards cannot be upgraded via livestock, increasing food safety and health at the cost of wasted materials and resources. The consumption of protein in excess of needs in the EU, and especially the reliance on animal sources, is a consumption-based structural weakness in the food chain from a resource

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[114] See for example a plant-based chicken substitute at http://beyondmeat.com/; a plant-based egg substitute at http://hamptoncreekfoods.com/

[115] http://www.ifr.ac.uk/waste/Reports/Provalor.pdf

[116] See http://www.nnfcc.co.uk/news/eu-and-industry-invest-in-growing-bio-based-products

[117] http://england.lovefoodhatewaste.com/content/naked-truth-about-how-packaging-can-help-you-waste-less-food; http://plana.marksandspencer.com/media/pdf/we_are_doing/waste/Packaging_fact_sheet.pdf

efficiency viewpoint (Sonigo et al, 2013). Such trade-offs try to strike a carefully tuned balance between costs and benefits, but opinions and circumstances may change. The same holds for other trade-offs with legislative roots in the (distant) past. They should all be periodically reviewed and updated by means of explicit multi-criteria methods.

9 REUSING WASTES AND RESIDUES FOR BIOMATERIALS AND BIOENERGY

9.1 Introduction

The use of biomass in a range of industrial sectors is not new. Biomass has a long history of use as an energy source fuelling process and space heating, transport and traction power. Non-energy or 'material' uses of biomass also have a long tradition, eg for construction, furniture, pulp, paper and textiles. The growth of the 'bioeconomy' therefore builds on a strong foundation of well-established uses of biomass.

An important context for this study is the Commission's communication on 'A Bioeconomy for Europe' (European Commission, 2012b). This emphasises five 'inter-connected societal challenges' to: ensure food security, manage natural resources sustainably, reduce dependence on non-renewable resources, help mitigate and adapt to climate change and to create jobs and maintain European competitiveness. Kretschmer et al (2013) analyse the contribution the utilisation of certain wastes and residues could make to these objectives. The report quantifies how much material will be available, and how easily and reliably it can be mobilised, and explains the range of technologies available, and under development, to transform these waste and residue streams into useful products, and the nature and potential markets for these products.

The rationale for being interested in wastes and residues is threefold. First, some of these materials have largely been considered a nuisance and a challenge for disposal without polluting the environment. It is highly attractive therefore to be able to switch mind-set and see such materials as useful feedstocks or raw materials. Second, the recent experience of the development of certain renewable energy sources, particularly biofuels from food and feed crops such as cereals, oilseeds and sugar, has stimulated concern that new biorefinery processes must as far as possible be based on non-competing wastes and residues to minimise impacts on food availability and prices. The third interest in the bio-based economy rests on the notion that it is (or should be) fundamentally based on biological processes energised by renewable, current, solar power rather than by the non-renewable stock of fossil fuel. This should, in principle, be far less polluting, particularly in terms of greenhouse gases (GHG). However, this cannot be taken for granted, and so the study looks carefully at the sustainability credentials of biorefinery technologies, especially at their climate protection performance and their potential impacts on biodiversity, water and soil.

The chapter concludes with a summary SWOT analysis (*strengths, weaknesses, opportunities and threats)* of biorefinery development and a consideration of the policies, in use or necessary, to stimulate the sustainable development of bioenergy and biomaterial production from wastes and residues.

9.2 Mobilising waste and residues from agriculture, forestry and food sectors

Three streams of bio-resources are analysed here: food wastes, crop residues and forest residues[118]. Many studies have tried to define these resource streams and attempted to measure the quantities of material which could be available for processing. However, different definitions and different assumptions about how much can safely be extracted have yielded a wide range of estimates of the quantities potentially available. The materials concerned are highly heterogeneous, with varying dry matter, energy content and chemical composition. So expressing their quantities in raw physical tonnes is not very revealing. Therefore Table 9-1 expresses the ranges of availability which have been estimated for the three waste and residue streams (hereafter W&R) in terms of their energy content

[118] The main report explains why other resource streams such as animal manure and human sewage waste have not been considered.

measured in Exajoules, EJ. For reference, the EU-27 final consumption of energy in 2011 was 46.2 EJ[119]. Note that this choice of common unit should not be taken to imply that producing energy, as opposed to materials, from these resource streams is the only or best way to use them.

Table 9-1 Estimates of availability of waste and residue streams in terms of their energy content measured in Exajoules, EJ

Exajoules (EJ) per year	Lower estimate	Upper estimate
Food Waste	0.22	
Agricultural Crop Residues	0.8	3.6
Primary Forest Residues	0.8	2.7
Total	1.82	6.52
Share of EU final energy consumption percent	3.9%	14.1%

These results suggest that the three resource streams could offer a significant contribution of between four and fourteen per cent of total EU energy supplies. The agricultural and forest residues contribute most of this resource (over 90 per cent).

However these estimated ranges are subject to considerable uncertainty. There is no harmonised definition of food waste in Europe (see Chapter 8). There are corresponding differences in definitions of crop and forest residues. There are also wide differences in the estimates of how much of these residues are available given existing uses and what are considered feasible and acceptable extraction rates. These measurement uncertainties themselves inhibit mobilisation of the resources. Other obstacles are the heterogeneity of the materials, their dispersion across the entire territory, on the premises of a very large number of micro-businesses (farms and forests), and, in the case of food waste, millions of individual households. The farm and forest residues are often in remote and inaccessible locations. The collection, separation and utilisation challenges are further tested by the fact that these are generally relatively low-value, high bulk materials which cannot therefore be moved far. Strategic location of first stage processing is therefore vital.

A specific and critical uncertainty for the future availability of food waste is that increasing efforts are being made to ***prevent and reduce*** it through waste-reduction campaigns and initiatives, through the setting of bio-waste targets and possibly even future reduction targets at the EU level. The waste hierarchy defined in the Waste Framework Directive urges that the first best solution for waste is not to create it in the first place. The more successful are efforts to adhere to this principle the more uncertainty about the availability of this resource stream for waste processors. This can only inhibit investment. Conversely, if the utilisation of food waste becomes an attractive business option, it could cause environmental damage as this would work against the efforts to reduce food waste.

For agricultural crop and forest residues a corresponding consideration creating uncertainty is that the extraction of these materials represents a breaking of the carbon cycle in which much of this year's growth is returned to the soil to maintain soil organic matter and thus soil function. In the context of considerable existing concerns about low and falling soil organic matter and soil carbon this is far from a trivial concern.

[119] I EJ = 10^{18} Joules.

9.3 Technology options to convert biomass into biomaterials and bioenergy

Conversion technologies – thermochemical and biochemical routes

Much of the technology for dealing with biomass is well understood and long established. Generally, the biomass raw materials will require some physical pre-treatment, for example to separate components, dry, chop, and pelletise. Then, the processing will either follow a thermochemical pathway characterised by requiring considerable process heat such as hydrogenation, gasification, or pyrolysis. Alternatively it follows a biochemical pathway which utilises biological agents such as yeasts, bacteria, algae, and enzymes to extract or convert the feedstock to the required products. The three main biochemical pathways are transesterification, fermentation and fractionation.

The resulting products are: heating, transport and aviation fuels, power, combined heat and power, fermentation derived chemicals, specialty chemicals, polymers, and a wide range of intermediate chemicals. In turn these chemicals have an equally wide range of applications in: textiles, clothing, packaging, agronomy, personal care, pharmaceuticals, detergents, cosmetics, paints, dispersants, binding agents, dust control, food ingredients, explosives, mouldings, adhesives, barrier films, medical products, biodegradable materials for a wide range of uses, and wood-based panels.

State of the current market and future prospects

The current market of the bio-based chemical and polymer industry is growing rapidly. In 2011, it was estimated that global bio-based chemical and polymer production was around 50 million tonnes with a market size of 3.6 billion US dollars[120], compared to a production volume of chemicals and polymers from petrochemical sources of 330 million tonnes globally (de Jong et al, 2012). Some sectors are experiencing rapid growth; for example between 2003 to the end of 2007, the global average annual growth rate in bio-based plastics was 38 per cent whilst in Europe, the annual growth rate was as high as 48 per cent in the same period. Kretschmer et al (2013) list current commercial plants and biomaterial production technologies.

Several screening exercises have been carried out to ascertain which chemicals have the greatest economic potential in particular regions. Two comprehensive reports have attempted to elucidate the chemicals with the greatest potential, namely the US Department of Energy 'Top Value Added Chemicals from Biomass' study (Holladay et al, 2007; Werpy and Petersen, 2004) and the EU's 'Biotechnological Production of Bulk Chemicals from Renewable Resources' (BREW) study (Patel et al, 2006). More recently, the EU sponsored FP7 BIO-TIC project has identified five bio-based product groups (rather than distinct chemicals) that have the potential to be produced in the EU, are able to substitute for non-bio-based alternatives and help improve EU competitiveness[121]. These are:

- Non drop-in bio-based polymers (PLA and PHA);
- Chemical building blocks (platform chemicals – with a focus on succinic acid, isoprene, furfural, 1.3-PDO & 3-HPA);
- Bioethanol (2nd-generation biofuels from waste) and bio-based jet fuels;
- Bio-surfactants;
- CO_2 as a bio-based feedstock.

It is notable that few of these are indicated to be derived specifically from waste materials. However, several bio-based materials are already produced from wastes and residue materials, for example xylose and furfurals, and there is a growing research and development (R&D) activity into developing bio-based chemicals from waste materials (see Box 9-1).

[120] http://www.nnfcc.co.uk/tools/global-bio-based-chemicals-market-activity-overview-spreadsheet. The $3.6 billion translate into around €2.6 billion using an average 2011 exchange rate of ~0.72 from http://www.oanda.com/currency/historical-rates/.

[121] http://suschem.blogspot.be/2013/03/bio-tic-identifies-five-breakthrough.html

Box 9-1 Some plastics and other chemicals that can be produced from biomass

butanol, isobutanol – primarily used as solvent, as an intermediate to chemical synthesis, and as biofuel. Derived from fermentation of sugars.

furfural – base for production of fuel, fertilisers, plastics, paints, wood treatment oils. Derived from chemical treatment of hemicelluloses.

HDPE (high-density polyethylene) - a polyethylene thermoplastic obtained from petroleum or biomass, with a good chemical resistance and high rigidity. It is widely used in the production of plastic bottles, corrosion-resistant piping, containers, plastic lumber.

isobutene (2-methylpropene) – produced from sugar fermentation, can be converted into fuels, plastics and elastomers.

isoprene – liquid hydrocarbon used to produce polyisoprene rubber and butyl rubber, and to a lesser extent for special chemicals (eg vitamins), perfumes. Derived from fermentation of sugars.

LDPE (low-density polyethylene) - the main plastic used for manufacturing plastic bags, made from MEG.

LLDPE (linear low-density polyethylene) - a plastic primarily used for manufacturing flexible tubing, but also plastic bags and sheets, pipes. It is a linear polymer (polyethylene) with short uniform branches, and has a higher tensile strength and puncture resistance than LDPE.

MEG (monoethylene glycol) - an organic compound and a precursor to polymers, made from ethylene, which in turn is made from ethanol derived from sugar fermentation. It is most commonly used as a raw material for industrial applications, as an automotive antifreeze, and in the production of polyester resins, films and fibres, solvents, etc. Used to make PEF, PET, LDPE, LLDPE, HDPE.

MMA (methyl methacrylate) - used in the manufacture of methacrylate resins and plastics (eg Plexiglas), and also of adhesives and sealants, advertising signs and building panels, textile finishes, etc. It is synthesised most commonly through the acetone cyanohydrin (ACH) process from methanol, ethylene and carbon monoxide.

PDO (1,3 propanediol) - a building block for polymers, but also used as a solvent and antifreeze agent. It is produced through the fermentation of sugars or glycerol.

PEF (polyethylene furandicarboxylate) - a completely bio-based alternative to PET made using FDCA (2,5-Furan Dicarboxylic Acid) which is derived from chemical dehydration of hexose sugars, in combination with bio-based MEG.

PET (polyethylene terephthalate) - used in the production of synthetic fibres and beverage and food containers (eg plastic bottles). Made from MEG and purified terephthalic acid, which is derived from fossil fuels.

PHA (polyhydroxyalkanoates) - a bio-polymer used in the production of bioplastics; it is biodegradable and relatively heat resistant. Derived from sugar fermentation.

PHB (poly 3-hydroxybutyrate) - a non-toxic biodegradable polymer used in the packaging industry (eg drink cans), in the production of disposable utensils and razors, and also for a variety of medical applications. It is made by fermentation of sugars.

PLA (polylactic acid) - a biodegradable bio-polymer used in the production of bioplastics and fibre applications including textiles. Derived from lactic acid, which is derived from sugar fermentation.

PP (polypropylene) - a thermoplastic polymer with a variety of uses ranging from the packaging and apparel industries, to automotive components and laboratory utensils. Made from propylene, which is made from ethylene or ethanol via chemical treatment.

PUR (polyurethane) - a plastic material with a high potential for technical substitution of petrochemical based plastics, with a variety of end-use applications including car parts, insulation of buildings and refrigerators, adhesives and composite wood panels. It is synthesised from bio-based polyols.

Future prospects for a biorefinery industry based on wastes and residues

Wastes and residues offer a potential route to overcome the concerns over using food materials for non-food purposes. Indeed, glycerine, a co-product of the biodiesel industry, is already a significant feedstock for many bio-based chemicals (such as propylene glycol), in part due to its low price. The use of ligno-cellulosic materials and other wastes is, however, less well developed, except for bioethanol production, albeit one which is being driven by the biofuels industry, and which may be adopted by the chemicals industry in the future. There is a growing recognition of the benefits of using wastes and residues for the production of bio-based chemicals where it is appropriate to do so.

While the use of ligno-cellulosics for the production of bio-chemicals may, in theory, be attractive, it has some significant technical and economic drawbacks. Indeed, the overall growth of the market greatly depends on the continued adoption of biodiesel to provide steady glycerine production and the market growth of new glycerine-based intermediate chemicals. This is problematic, especially for the EU where there is uncertainty over the future of conventional biofuels such as biodiesel. At the current time, mandates in the EU are distorting the market in favour of biofuels, discouraging the scale of investment needed to incentivise the biorefinery sector (Carus et al, 2011).

Technical issues associated with using ligno-cellulosic materials also need to be overcome in order to develop a ligno-cellulosic waste and residues to chemicals capability. One of the key issues here is the heterogeneity of many wastes and residues. One of the most attractive routes for heterogeneous feedstock streams such as mixed wastes and residues, and potentially of great interest to the EU as a whole, is perhaps the use of hybrid thermochemical / biochemical approaches whereby the feedstock is gasified to form a syngas which can then be converted to chemicals using microorganisms which can ferment syngas to economically interesting chemicals. This approach is already being developed for both fuel ethanol (for example by Coskata and Ineos Bio) and several other companies, for the production of PHA, polyols and propylene.

9.4 The sustainability of bio-based products

Because the rationale for bio-based approaches is fundamentally about climate protection, this assessment first considers relevant Life-Cycle Assessments (LCAs) comparing climate impacts of bio-based products to traditional products. It then reviews wider environmental impacts of bio-based products which are not usually covered in LCAs especially on water, soil and biodiversity.

There is a considerable body of literature on the environmental impacts of bioenergy and especially on conventional biofuels. The conclusions are that it is far from clear that they are carbon neutral, let alone generate large GHG savings, compared to fossil based fuels especially if Indirect Land Use Change (ILUC) effects are taken into account. The focus of this chapter is on the emerging evidence on impacts from advanced bioenergy and other biorefinery technologies that are less well understood at present. Some lessons seem to have been learned from the errors made in the premature promotion of first generation biofuels as sustainability is being addressed during the early stages of the development of the bioeconomy. Also, another approach to embrace sustainability is contained in emerging initiatives to establish certification schemes for bio-based materials such as the US National Institute for Standards and Technology's 'Building for Environmental and Economic Sustainability'

(BEES)[122] framework, and in research projects evaluating sustainability aspects, such as in the EU funded BIOCORE project[123].

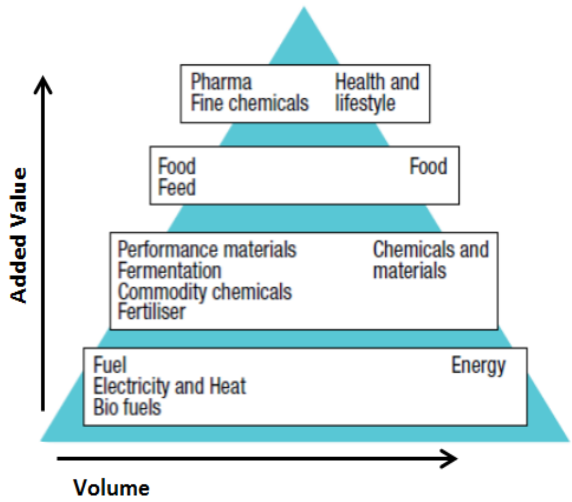
Resource efficient use of biomass via cascading

The resource efficient use of biomass is essential given the anticipated scale-up of biomass to be used for energy purposes and bio-based products along with the growing demand for food and feed. This should prioritise waste and residue sources and combine several biomass applications in a cascade of uses, as illustrated in Figure 9-1.

Such prioritisation should first distinguish between energy and the many non-energy uses of biomass, then between the utilisation of wastes and residues as opposed to food products, and finally between different energy use pathways. Assessing the sustainability of all these pathways must always take into account that some of the wastes and residues to be used as feedstocks were previously used in ways which provided direct environmental benefits. Prime examples are the use of straw as a soil improver, the retention of forestry residues in forests to benefit biodiversity and carbon stocks, and the composting of food waste instead of recovering its energy value via anaerobic digestion.

The driving forces in matching feedstock uses and products in this process should be the level of GHG savings per unit of biomass compared to using fossil based raw materials, and also of course the relative economic value that can be obtained from a given volume of biomass. Put simply, biomass can end up in bulk applications where high volumes of biomass are needed to generate a unit of value added – these include bioenergy but also some biomaterial uses – or in high-value applications where relatively small volumes of biomass generate high-value products.

Figure 9-1 The biomass cascade



Source: Adapted based on Eickhout (Eickhout, 2012) and http://www.biobasedeconomy.nl/themas/bioraffinage_v2/

[122] http://www.nist.gov/el/economics/BEESSoftware.cfm

[123] http://www.biocore-europe.org/page.php?optim=a-worldwide-sustainable-concept

Research findings indicate that biomaterial use does not unambiguously and always outperform solid and gaseous biomass use for electricity and heat production, but a meta-analysis of LCAs indicates that when biomass is used in a cascading way, an additional 10 to 20 tonnes CO_2-equivalent/hectare can be abated on average (Carus et al, 2010). This highlights the importance of cascading biomass use; suggesting that where applicable, non-energy and energy uses for biomass materials should be combined over time.

Wider environmental impacts

There is often a loose presumption that bio-based materials and products are 'natural' and so are bound to be 'greener' and kind to the environment. Such a presumption is not correct. Apart from a thorough GHG account, when dealing with terrestrial bio-resources whose origins and extraction involve deep interventions and management of ecosystems by man, it is imperative also to consider the environmental impacts on soil, water and biodiversity.

Soil: the main consideration for soil is that increased removal of both agricultural crop and forestry residues can impact negatively on soil organic matter, soil structure and soil biodiversity. This represents significant additional environmental pressures given that many European soils are already degraded.[124] The risk of potential negative impacts on soil function and quality as a result of straw removal varies greatly and differs on a regional and even a farm scale. These risks depend on many factors including the local climatic and soil conditions as well as the level of incorporation of straw into the soil and the resultant humus balance prior to residue removal. In some instances, good levels of soil humus availability may mean removal of the straw would not have any detrimental impacts on soil carbon levels. However, in other areas of the EU such as in the Czech Republic, where there has been a decrease in availability of manure due to a decline in the livestock industry, or in Slovenia, where the soils are of particularly poor quality, straw plays an important role as a soil improver (Scarlat et al, 2008). In these areas, diversion of straw from such a use could have negative impacts on soil function and quality.

Forestry soils account for around twice the amount of organic carbon found compared to the above ground biomass. There is a wide range of factors that influence SOC and SOM in EU forests, including acidification, nitrogen deposition, management approach (including residue management), and differences in soil horizon profiles. Like agricultural land, residues (including leaves, branches, bark and stumps) form an important and interlinked relationship with forest soils, helping to stabilise and increase SOC and SOM, contribute to regulation of carbon to nitrogen ratios, reduce erosion events and provide nutrients for soil biota and saproxylic species.[125] Changes to harvesting patterns and increases in residue extraction rates can have a negative impact on many of these factors. For example, the increase in nutrient export might be significant, with up to six times the removal of nitrogen and phosphorus seen under intensive biomass removal (including stumps and roots) compared to harvesting of stems only (Hansen et al, 2011; Helmisaari and Vanquelova, 2012).

Water: the most important water related impacts from the production of biofuels and bio-based products relate to the cultivation of feedstock (Eickhout, 2012; IEA, 2010; Weiss et al, 2012). Therefore, compared to the use of crops as a feedstock, bio-based products derived from wastes and residues should avoid the majority of such impacts and therefore generally will have a lower 'water footprint'.[126] However, negative impacts may ensue from the increased extraction of residues from both cropland and forests with regard to water erosion and water holding capacity as a result of changes in soil structure. Also some of the bio-refining processes may involve the consumptive use of

[124] http://eusoils.jrc.ec.europa.eu/ESDB_Archive/octop/octop_download.html

[125] ie relating to dead or decaying wood

[126] See Hoekstra & Mekonnen (2012) for a discussion of the water footprint concept.

water at various stages of production, so local impacts on water quality and availability should nevertheless be monitored.

Biodiversity: less is known about the impacts on biodiversity of the processing pathways for agricultural residues under examination here. Potential impacts of agricultural residue extraction on soil faunal, floral and fungal assemblages are closely related to the impacts on soil organic matter (SOM). There is little clear-cut evidence on likely impacts. What is clear is that soil fauna, including invertebrates and those species dependent on invertebrates for food, depend largely on SOM as their main habitat. SOM often constitutes hotspots of soil activity and is fundamental in maintaining fertile and productive soils (see references cited in Turbé et al (2010). This applies equally to agricultural and forest soils.

The main lessons for the sustainability of waste and residue use are:

- Bio-based products, their production, use and disposal, should not be considered automatically sustainable *per se* but subject to scrutiny and a set of safeguards to ensure their sustainability.
- It is imperative to monitor the situation: the Bioeconomy Observatory proposed by the European Commission could play an important role in this.
- There is need for more evidence on LCAs of GHG emissions as more commercial plants for advanced biofuels and bio-based materials become operational.
- There is some evidence to suggest that using biomass for bio-based materials rather than burning them for energy recovery leads to higher GHG savings in many cases. This suggests a reconsideration of the imbalance in the current policy framework that gives significant support to bioenergy but not to other biomass-using product pathways.
- A key sustainability concern is the impact of residue removal on soils and in particular soil carbon stocks. The GHG accounting framework of the Renewable Energy Directive excludes soil carbon stock changes arising from residue extraction, as these are considered ‘zero emission’ up to their collection. This should be reconsidered.

9.5 Summary, conclusions and options

Identifying new uses for what were formerly considered waste products turns a disposal problem into a question of raw material availability. It turns a liability which had to be disposed at least cost into asset to be mobilised and then optimally transformed to valuable products – with environmental gain in the process.

However some of this waste material has alternative uses – whether marketed or not. This certainly applies to many agricultural wastes or residues like straw, or forest and wood processing ‘wastes’. In these situations, the new technology or new set of environmental, economic or policy factors which creates the drive to mobilise the material creates competition with the existing uses. Rational resource use dictates that the resource should be allocated between traditional and new uses such that the marginal revenue in each use is equated, ie normal economic allocation rules apply.

Of course the new uses are likely to start at a low level and generally speaking they involve processing large-volume low-value materials, so economies of scale are likely. Hence, it may take some time before the new uses can compete on level terms with traditional uses. This might, in some circumstances, warrant infant industry assistance to get these processing routes established. Table 9-2 is a summary of the main strengths, weaknesses, opportunities and threats facing the use of food wastes and crop and forestry residues for material and energy substitution in Europe.

Table 9-2 SWOT analysis of a European bio-refinery industry based on wastes and residues

STRENGTHS	**WEAKNESSES**
• Bio-based plastics with strong development potential identified (incl bio-PET, PE/PP, PLA, PHA); • The relevant conversion technologies have been successfully demonstrated; • The use of wastes and residues is clearly preferable from a sustainability point of view; • Potential for 'green' jobs and economic activity if sustainability concerns addressed	• Sustainability risks exist even for an industry based on wastes and residues, given prevailing existing uses and environmental functions; • The collection of wastes and residues is constrained by a range of logistical, technical, economic and environmental barriers; • The processing of wastes and residues in biorefineries tends to be more expensive, putting them at a cost disadvantage; • Funding constraints may hinder rapid commercialisation of proven technologies.
OPPORTUNITIES	**THREATS**
• The ongoing revision of EU biofuel policy in an attempt to mitigate ILUC by moving towards biofuels from wastes and residues may provide a stimulus to the wider biorefinery sector; • The Bioeconomy Communication as a high-level policy initiative that stimulates interest among a range of stakeholders; • Private sector initiatives to move towards bio-based sourcing (notably in the food industry).	• The current political focus on bioenergy and biofuels (promoted through renewable energy targets) puts bio-based material uses at competitive disadvantage; • The lack of sustainability criteria for biomaterials (or even for solid biomass energy) in light of the ongoing discussion on conventional biofuels may undermine trust in the sector; • The oil price is an important determinant of the profitability of many bio-based operations but its development is outside of the sector's control.

Source: Own compilation based on the sections below and sources referenced

In conclusion, advanced biofuels and innovative bio-based pathways based on wastes and residues show considerable potential and should be further developed, especially as Europe may have a lead in some of these technologies. There are sound arguments based on infant industry, market failure and dynamising a structurally difficult sector, which justify further collective action to stimulate the development of this sector. However, there are also considerable uncertainties for investors and indeed all market participants, so a major task is to ensure transparency and better information concerning the availabilities of the waste and residue streams, the opportunities for processing, and the benefits to consumers. In addition, because, by definition, bio-based economic developments necessarily interact with ecosystems, there has to be visible assurance that the bio-products are indeed environmentally preferable with respect to GHG emissions, water, soil and biodiversity compared with their fossil-based counterparts. There are persisting uncertainties surrounding the continued availability of wastes and residues, the environmental viability of the sourcing of feedstock, and also the sustainability of the bio-based products resulting from a biorefinery processes. **The conclusion is that policy encouragement should be given to this sector, but with enhanced transparency of all aspects of its development, and with equally strong sustainability safeguards.**

The scale of the potential developments is considerable. The evidence reviewed suggests that the development of the food wastes and the crop and forestry residue streams considered in this report together could account for between three and 14 per cent of current total EU final energy consumption (1.8 EJ - 6.5 EJ out of the total 46.2 EJ/year). These energy based figures are offered as an indicator of orders of magnitude of the potential of the sector but should not be taken to suggest that all this biomass should be used for energy generation. It may well be that producing energy from such resources is not the most efficient way of utilising them. There might be far greater value realisable by decomposing the resources into a cascade of more valuable intermediate chemicals and products.

Given this potential, the main ***barriers and challenges remain to be overcome*** are:

- reliable and cost competitive availability of biomass and, linked to this, the environmental and technical challenges to mobilising waste and residue resources;
- proven technologies at commercial scale by crossing the innovation gap between demonstration and full commercialisation;
- adequate financing to do so by setting up commercial scale demonstration or first of its kind plants;
- sufficient market demand to facilitate investments and make the step towards commercialisation; and
- predictable and stable longer-term policy framework, and for bio-based materials in particular, the public support available for using biomass in the energy sector that is not matched by similar measures for other bio-based products.

Options for the optimal utilisation of wastes and residues

It is emphatically *not* recommended that the EU repeats for biomass use in the wider biorefinery sector the mistakes it has made for biofuels policy based on policy mandates and targets. That experience is not one to repeat. Adequate sustainability criteria were not developed for conventional biofuels before they were put in place and subsequently it has been proposed that the targets are changed. There needs to be an urgent discussion about the role of biofuels and bioenergy as part of renewable energy policy post-2020. Indeed, whilst the next steps for the development of renewable energy policy towards 2030 are being considered, a case can be made to consider integrating biofuel and bioenergy policy with the wider use of biomass by working towards a 'Bio-resources Directive' to provide a more integrated set of objectives and principles for the efficient use of Europe's bio-resources for food, energy and material use. We conclude with a summary of the key policy actions in three areas to stimulate this sector.

To **mobilise waste and residue feedstocks** key options are to:

- Make best use of a***vailable support and advice measures*** available for land managers (eg under CAP Rural Development Policy);
- Improve ***food waste separation and collection*** and revisit legislation on its use for anaerobic digestion;
- Follow a ***regional approach to biomass development*** eg in siting of bioenergy or biorefinery plants.

To **move from demonstration to commercialisation of bio-refineries** using W&R key options are to:

- Provide financing for set-up of large scale demonstration or first-of-its-kind plants (some public money warranted);
- Facilitate market-driven demand for bio-based products through standards and labels for bio-based products;

- Ensure a supportive and stable policy framework by actions to:
    - scale back support for conventional biofuels in particular;
    - consider a ***Bio-resources Directive*** as an integrated set of objectives and principles for the efficient use of biomass for food, energy and material use;
    - introduce incentives to use end-of-life biomass for energy;
    - phase out subsidies for fossil fuels in order to promote bio-based feedstocks.

To **ensure environmental sustainability** of the use of wastes and residues:

- Introduce environmental safeguards to respect the waste hierarchy - the first priority is avoid waste;
- Avoid depleting soil carbon through:
    - standards for biorefinery operators in relation to soils and greenhouse gas emissions (direct and indirect);
    - strengthened soil organic matter protection as part of the cross compliance provisions of the CAP;
    - extension of the Renewable Energy Directive's GHG accounting framework to include soil carbon stock changes;
    - extension of the RED's sustainability criteria to other forms of bioenergy and bio-based products.

These safeguards should not be understood as an attempt to limit the development of a bio-based industry in Europe by imposing additional burdens. Instead, they should be seen as reducing uncertainty about necessary environmental performance. This greater predictability of the environmental ground rules should be beneficial for attracting investment and ensuring the long-term viability of the sector. Indeed, given the experience with first generation biofuels, the lack of well-based and understood sustainability criteria is a barrier to the sector's development. There is a chance to overcome this barrier now and upfront with regards the wider biorefinery sector.

10 CONCLUSIONS AND KEY OPTIONS

This report synthesises the recommendations made in the series of studies that contributed to the STOA "Feeding 10 Billion" project, concentrating on the role of the EU in particular. The studies looked ahead at the coming decades and the ways in which more sustainable food systems could be developed in Europe. Many of the proposals are at a generic level, mapping broad areas of concern and signposting some key actions. Some are relatively specific and short term. The studies recognise the strengths of the EU as a major food producer with diverse and productive agricultural systems, a high level of skills and investment, major research institutions and great potential for innovation over time. While the EU also needs to engage in support for appropriate food production outside Europe, this topic is beyond the remit of this report.

The European Union has strongly developed common environmental and agricultural policies, and a recently reformed Common Agricultural Policy with a greater emphasis on both the environment and innovation, providing Member States with an opportunity to initiate a change in direction. At the same time, there are major challenges to increase productivity in an appropriate way whilst reducing damage to European agricultural and natural resources and biodiversity. It will be important to produce more with less in Europe and to cut wastage.

In the coming decades, the EU needs to determine and then demonstrate:

- How policy can be better arranged to incentivise and require farmers to reduce pollution and pressure on natural resources while increasing their provision of ecosystem services;
- How high yields can be sustainably maintained and even increased, with knowledge intensive land management;
- How to make significant in-roads into reducing waste and harmful over-consumption, and developing healthy diets, including the moderation of consumption of livestock products.

Some of the principal options discussed in the five contributing reports or referred to in this synthesis can be summarised under six headings as follows:

Provide appropriate incentives for climate resilient and biodiversity-friendly forms of farm management that also maintain and increase productivity

- Provide farmers with incentives for the adoption of management actions that have benefits for climate change adaptation and mitigation and avoid significant biodiversity damage, and that are also economically beneficial; this should be prioritised in implementing the current CAP to 2020 and pursued further in the next reform round;
- Couple this with increased financial support for R&D and technology transfer at the EU and national levels;
- Strengthen the protection and management of semi-natural agricultural habitats and the economic viability of the farming systems that maintain them;
- Increase resource efficiency in agriculture by a combination of research, technology transfer, appropriate incentives and legislation;
- Help farmers to deal with risks and uncertainties, including a greater focus on maintaining and enhancing soil fertility and the resilience of farming systems;
- Sharpen the focus of schemes designed to incentivise the delivery of ecosystem services in rural development programmes and elsewhere;
- Increase productivity in extensive as well as more high yielding production systems;
- More discriminating approach to promoting local and high quality products that also demonstrably benefit biodiversity, climate and local economies, for example through rural development programmes;

- Enhance investment in relevant forms of training, information provision and advisory services.

Constrain unsustainable agricultural practices which have damaging environmental effects

- Systematically improve compliance with the Nitrates Directive and other EU legislation that reduces environmental burdens particularly in relation to soil, groundwater, and surface water courses and bodies;
- Push for full implementation of integrated pest management in all Member States and develop further strategies to reduce dependence on agrochemical inputs;
- Use CAP cross-compliance requirements to ensure protection and appropriate management of agricultural soils and those elements of the farmed landscape that benefit biodiversity and climate change adaptation;
- Use CAP measures including cross-compliance to constrain unsustainable forms of irrigation, and to promote progressively more efficient uses of water.

Research & innovation for sustainable agriculture

- Strengthen interdisciplinary and participatory research that addresses the new challenges highlighted in this report and the wider literature, and that encourages local adoption. To scale up advanced crop production systems, new networks among diverse stakeholders are needed to combine top-down and bottom-up knowledge creation and transfer mechanisms, and strengthen institutional learning. This task has to be taken up by the scientific system as well as by funders, not least within Horizon 2020.
- At the European level, a network to promote participatory research for global food security could be established in the frame of the Horizon 2020 programme. Past boundaries between public funded basic research and private funded applied research as well as between research institutes and universities as dominant sources of knowledge and innovation and the farming and commercial sectors as adopters are becoming blurred. This demands new forms of cooperation and knowledge exchange, without which the agricultural knowledge system could become increasingly fragmented.
- Systems approaches and long-term projects, which address different European farming systems, have particular value which needs to be recognised in research programmes;
- Ensure that measures to encourage innovation, including investment and targets, promote areas of greatest potential and knowledge gaps, combining yield improvement with sustainability objectives – here the role of public research funding is critical;
- Strengthen and focus plant breeding and the adoption of crop varieties better suited to more sustainable agricultural systems;
- Ensure that Europe's genetic resources for food and agriculture are better used and conserved;
- Provide increased direct funding for research on tackling the multiple factors causing honeybee losses and wild pollinator decline;
- Further develop sound decision support systems for farmers and others in the food chain to support changes in management and technology that support more sustainable approaches;
- The decline in public extension services for farmers is hindering progress and a new European initiative to revitalise well-focussed and efficient extension services is needed.

Reduce food losses and increase food supply chain sustainability

- Set targets to reduce food waste at the national level following the lead of several Member States and follow up the proposal in the Roadmap for a Resource Efficient Europe;
- Improve food waste monitoring and EU-wide standardised data on food waste;

- Review EU legislation on food safety with respect to waste issues and amend EU marketing standards and food date labelling as necessary;
- Promote more integrated and transparent supply chains, with improved workflows and supply chain management - this could be informed by more systematic assessment of technological developments that aim to reduce food waste whilst increasing food chain efficiency and convenience;
- Promote resource efficient food manufacturing processes at the EU and national levels, for example through Horizon 2020;
- Reduce harvest and post-harvest losses in agriculture, particularly outside Europe, through integrated supply chain management and investment in capacity building, technologies and infrastructure; for poor farmers, innovations in harvest and post-harvest technologies generally should originate in traditional techniques, must be suitable in scale and use as much as possible locally available resources;
- Research the effectiveness of innovative solutions to reduce waste, and strengthen analysis of their relative advantages and disadvantages;
- The innovation power of the EU food industry for increased sustainability needs to be strengthened; Horizon 2020 could play a part here.

Reuse unavoidable food wastes and residues for biomaterials and bioenergy

- The priority is to ensure sustainable sources of residues from agriculture, forestry, the food sector and related sources; this involves an appropriate EU and associated Member State policy framework for biofuels, forestry, and the expanding bioeconomy;
- Make best use of available support and advice for land and forest managers to mobilise sustainable sources of residues and ensure sustainable residue extraction rates;
- Avoid depleting soil carbon and other nutrients when mobilising agricultural crop residues;
- Improve food waste separation and collection and revisit certain legislation on its use for anaerobic digestion;
- Mobilise sufficient financing at the national level for setting up large scale demonstration or first-of-its-kind plants for biomaterials;
- It is key to ensure a supportive and stable policy framework for biomaterials rather than focusing incentives merely on the energy sector – a regional approach to biomass development is a useful framework for efficient and sustainable resource use;
- Ensure policy coherence in the energy recovery of food waste.

Increase the awareness of producers and consumers in the food chain

- Reduce the negative external impacts of European agriculture and biofuel imports by building up awareness of the key issues and providing clear information on impacts;
- Intensify the EU’s efforts to reduce its global environmental footprint over time in relation to food, feed and bioenergy, encouraging consumer demand for environmentally sustainable food;
- Increase consumer trust in those legitimate labels which provide a guide to sustainability and food security issues for specific products, for example by improving oversight of monitoring and verification procedures;
- Raise awareness of food waste in households and combat food waste in hospitality sector, considering new approaches to policy.

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GLOSSARY

access and benefit sharing	access to genetic resources controlled by another country and equitable sharing of commercial and non-commercial benefits deriving from this access between the provider and the user
accessions (plant genetic resources)	accessions are distinct, uniquely identified samples of seeds, plants, or other germplasm materials that are maintained as an integral part of a germplasm collection
adaptation (to climate change)	adjustment in natural or human systems [ie agricultural management and related socio-economic and policy framework] in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (Easterling et al, 2007)
adventitious presence	the presence of a GM gene and/or GM product in a non-GM crop or seeds or crop product at a low level that is not regarded as damaging (eg below minimum thresholds for conventional or organic produce sales)
allogemic species	Species that cross-fertilise; opposite of autogamic species that self-fertilise.
anaerobic digestion (AD)	Anaerobic digestion is the process by which microorganisms break down biodegradable material in the absence of oxygen (eg in fermentation and silage production); it is used to produce biogas (ie methane plus other gases) as a fuel, using manure, slurry, food waste, and other green residues.
arable land	arable land, in EU agricultural statistics, is land worked (eg ploughed or tilled) regularly, generally under a system of crop rotation (EUROSTAT)
assessment endpoint	a natural resource or natural resource service that needs protection from risks; the valued attribute of a natural resource that is worth protection (EFSA, 2010) – see also measurement endpoint
autogamous species	Species that self-fertilise; opposite of allogamous species that cross-fertilise.
Bacillus thuringiensis	a bacterium that occurs naturally in soils and plant tissues and that produces a range of crystalline (Cry) and vegetative (VIP) proteins that are toxic to certain insects
bee colony	group of bees that is organised in such a way as to support the needs of individuals making it up and the collective life. During the high activity season a honey bee colony has 40,000-60,000 bees; in winter the number of bees decreases to 5,000-15,000. The colony is composed of a queen, her female workers, some males, and by the brood, including eggs, larvae and pupae.
biodiversity	the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (Convention on Biological Diversity 1998, Article 2)
biodiversity (functional)	the quantification of the similarities in phenotypes and ecologies of species (such as their environmental tolerances and how they impact ecosystem function) (Cadotte et al, 2011)
biodiversity proofing	a structured process of ensuring the effective application of tools to avoid or

(of policy)	at least minimize harmful impacts of EU spending and to maximise the biodiversity benefits (IEEP et al, 2012)
bioeconomy	Bioeconomy: 'encompasses the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy'. It is an economy-wide concept in the sense that it 'includes the sectors of agriculture, forestry, fisheries, food and pulp and paper production, as well as parts of chemical, biotechnological and energy industries' and one with a 'strong innovation potential' (European Commission, 2012b). It is worth noting that this definition and others omit from the scope of the bioeconomy non-marketed ecosystem services, such as regulating, supporting and cultural ecosystem services.
bioenergy	bioenergy is energy extracted from biomass (as defined below). This includes biomass used for heat and for electricity generation (via direct combustion of biomass or through biogas from anaerobic digestion) as well as liquid biofuels for transport produced through conventional or advanced conversion routes.
biofuels (liquid)	liquid biofuels consist of bioethanol or biodiesel produced through the processing of biomass using either fermentation or pyrolysis processes. Biofuels can be produced either from conventional feedstocks (food crops and food wastes) or advanced feedstocks (ligno-cellulosic materials including crop and forestry residues)
biological pest control	EITHER 1) the natural control of pest populations through predators, parasitoids, parasites, and disease through the maintenance of a diverse biological control community in and around crop fields; OR 2) the deliberate introduction of a species that controls a pest population, through the release of eggs, larvae, adults, spores, virus, etc.
biomass	biomass is biological material derived from living or recently living organisms. This definition therefore excludes fossil biomass (coal, oil and natural gas).
biomaterials, bio-based materials, bio-based products	biomaterials are non-food products and materials derived from biomass (as defined below). This is to distinguish biomass-based materials from fossil, mineral, and metal-based materials, which are generally derived from non-renewable resources. Bio-based materials are often defined as excluding traditional and established products such as pulp and paper, and wood products, a definition that fits the scope of this report which covers advanced technologies and products. The biomaterials category refers to a broad range of products including high-value added fine chemicals such as pharmaceuticals, cosmetics, food additives, etc, to high volume materials such as general bio-polymers or chemical feedstocks.
biotechnology	any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use.
bitrophic exposure	exposure of an organism to the stressor (eg GM product or pesticide) by feeding on the plant, pollen or exudates (root exudates, guttation fluid etc), or plant residues, containing the stressor

break crop	a secondary crop grown to interrupt the repeated sowing of cereals as part of crop rotation; oilseed rape is the most important break crop in Northern Europe, maize or field beans in Southern Europe.
breeder lines, breeding lines, elite lines	genetic lines bred in a crossing programme before they are named and officially released for commercial cultivation; elite lines are breeding lines that possess most of the characteristics being sought for a particular environment or plant.
Bt	the GM insect resistance trait conferred by a transgene from the bacterium *Bacillus thuringiensis*
buffer strip	A buffer strip is a strip of land alongside a water course or water body that can be designed to deliver particular environmental benefits, for example to protect water against pollution and run-off. Width and management requirements are defined at Member State level (Nitrates Directive, GAEC standard in Council Regulation (EC) 73/2009).
carbon sequestration	the rate of capture and long-term storage of atmospheric carbon dioxide (CO2), which can refer to the natural geochemical cycling of carbon between the atmosphere and reservoirs, eg in trees or soil organic matter, over decades (it can also refer to human-mediated carbon capture and storage or geo-engineering but these processes are not used in this report)
carbon storage	long-term storage of carbon in reservoirs where it cannot affect climate change, ie recalcitrant (long-term) soil organic matter, mature forest stands, underground geological reservoirs, or long-lasting materials such as timber or concrete
case-by-case	a risk assessment approach in which the required information may vary depending on the type of GMOs concerned, their intended use and potential receiving environment, taking into account *inter alia* GMOs already in the environment (Directive 2001/18/EC)
catch crop	a catch crop is a temporary vegetative cover between agricultural crops, typically a cereal, adapted to scavenge nitrogen efficiently from the soil, thereby taking up surplus nitrogen remaining from fertilization of the previous crop, preventing it from being lost through leaching or gaseous denitrification or volatilization. The catch crop is cut before maturity and incorporated into the soil, releasing the captured nitrogen for the next crop. See also cover crop / green manure.
chronic exposure	repeated and continuous contact with a substance that occurs over the organism's life cycle or over a long time
cisgenesis	Cisgenesis is the genetic modification (using recombinant DNA technology) of a recipient organism with a gene from a crossable – sexually compatible – organism (same species or closely related species). The advantage of cisgenesis as compared to conventional cross-breeding is that it enables the insertion of a gene without any linked genetic material that can produce a 'yield drag' effect. The inserted gene includes its introns and is flanked by its native promoter and terminator in the normal sense orientation. Cisgenic plants can harbour one or more cisgenes, but they do not contain any parts of transgenes or inserted foreign sequences. To produce cisgenic plants any suitable technique used for production of transgenic organisms may be used. Genes must be isolated, cloned or synthesized and transferred back

	into a recipient where they are stably integrated and expressed. Sometimes the term cisgenesis is also used to describe an *Agrobacterium*-mediated transfer of a gene from a crossable – sexually compatible – plant where T-DNA borders may remain in the resulting organism after transformation. This is referred to as cisgenesis with T-DNA borders (New Techniques Working Group 2012 Final Report to the European Commission).
clonal variety	Variety that is propagated vegetatively (asexually) (e. g. potato); the individuals of a clonal variety represent genetically identical clones of the donor plant which was propagated.
co-existence (of farming systems)	the ability of farmers to choose between conventional, organic or GM-based crop production, in compliance with the relevant legislation on labelling and/or purity standards
connectivity	the extent to which ecosystems and natural areas are linked together in fragmented landscapes
conservation tillage / reduced tillage	Conservation tillage is any tillage and planting system that minimises the disruption of soil structure, composition and biodiversity by establishing crops in the previous crop's residues; it may include the use of minimum tillage, shallow ploughing at reduced depth (10cm), and/or non-inversion tillage practices (Holland, 2004).
contamination (GM)	the presence of a GM gene and/or GM product in a crop or seeds where it is not wanted and considered damaging, eg in non-GM imports, local varieties, organic crops
conventional tillage	a tillage system in which a deep primary cultivation (30cm depth), such as mouldboard ploughing, is followed by a secondary cultivation to create a seedbed (Holland, 2004)
cover crop / green manure	A cover crop a temporary vegetative cover between agricultural crops, and is ploughed under before reaching full maturity. Cover crops are planted primarily to protect from soil erosion and retain soil water, with additional benefits for soil fertility and control of weeds, pests, and diseases. Leguminous crops such as lucerne and clover are commonly used because of their nitrogen-fixing ability, and these crops are also known as green manure. See also catch crops.
crop diversification	Crop diversification is the introduction of a greater variety of crops at the farm level. It does NOT necessarily imply the adoption of crop rotation. The new CAP Greening component involves the adoption of at least 3 crops at farm level on farms with arable area larger than 10 ha, eg a farmer could farm 25 ha of wheat, 20 ha of maize, and 5 ha of barley to comply.
crop residues	Agricultural crop residues arise on farms in the form of straw, maize stover, residues from sugar beet, oilseeds, grass cuttings, and pruning and cutting materials from permanent crops. Crop residues also arise in the crop processing sector in the form of olive pits, seed husks, nut shells etc.
crop rotation	Crop rotation is the practice of growing a series of dissimilar types of crops in the same area in sequential seasons (as opposed to monoculture). Rotations may include from two to six or more crop types, and ideally should include a balance of crops from different crop groups (cereals, legumes, root crops and broad-leaved arable crops). No one crop group (eg

	cereals) should occupy more than half of the rotation.
crop wild relative	wild species related to crops, including crop progenitors.
Cry toxin	a range of crystalline proteins produced by GM genes from *Bacillus thuringiensis* that are toxic to certain insects, eg Cry1Ab, Cry3Bb, Cry1F (NB the genes themselves are referred to by the name of the toxin in lower case and italics, eg *cry1Ab*)
cultivars	cultivated plant varieties that have been formally approved and registered (see also obsolete cultivars)
ecosystem	an ecosystem is a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit
ecosystem services	the direct and indirect contributions of ecosystems to human wellbeing; categorised in four main types: provisioning services (eg food, water, fuel); regulating services (eg flood and disease control); supporting/habitat services (eg nutrient cycling, pollination, soil formation); and cultural services (eg recreation, cultural, spiritual and aesthetic values) (Millennium Ecosystem Assessment)
ecotype	a population or group of populations genetically adapted to a particular set of environmental conditions where they naturally occur. See also genotype.
eutrophication	excessive richness of nutrients in a lake or other body of water, frequently due to run-off from the land, which causes a dense growth of plant life
ex situ conservation	the conservation of components of biological diversity outside their natural habitats.
fallow (rotational)	Land not used for growing crops during one or two growing seasons, for example as part of a crop rotation. See also set-aside.
feral population	a population of crop plants that is self-propagating outside the crop field itself (ie in field margins, roadsides, waste land etc.). Feral populations may be transient, ie their long-term survival depends on continued seed dispersal from other sources (ie crops or seed transport); or they may be persistent, ie able to reproduce successfully to maintain the population or the meta-population (maybe including seed dormancy).
fitness	the successful survival and reproduction of a particular genotype compared to other genotypes in the population (relative fitness), ie the probable contribution of a genotype to the gene pool of the next generation
food processing	the transformation of raw ingredients and intermediates into products intended for human consumption, with the purpose of improving the digestibility, bio-availability of nutrients and energy, taste, appearance, safety, storability and distribution
forestry residues	forestry residues are woody or wood-derived residues consisting of 1) primary residues accruing from cultivation, harvesting and logging activities on trees within or outside forests (eg hedges, orchards, parks), and 2) secondary residues accruing in the wood processing industry, such as sawdust, wood chips and black liquor.
fragmentation	the division of an ecosystem or habitat into distinct smaller parts, without

	adequate connectivity between the parts. The parts are insufficiently large to retain the full complement of species without connection to other parts. Fragmentation can result from infrastructure development, such as roads and railways, or natural occurrences like forest fires.
gamete cells	Haploid cells produced by sexual propagating organisms; serve as the basis for sexual propagation; by combination of two gamete cells a diploid cell forms from which a new organism can arise.
gene flow	the movement of a gene in and between breeding populations of the crop, feral populations, weedy and wild relatives
genetic erosion	The loss over time of genetic diversity caused by either natural or man-made processes.
genetic map	Shows the linear alignment of known gene loci across chromosomes of an organism; distances between loci are statistically estimated and cannot be equalized with physical distances; only the approximate position of the loci are known but not the DNA sequence.
genetic reserve	A site where the management and monitoring of genetic diversity of natural wild populations within defined areas designated for active, long-term conservation.
genetic resources (plant, animal etc)	Genetic resources are genetic material of actual or potential value; genetic material is any material of plant, animal, microbial or other origin containing functional units of heredity (Convention on Biological Diversity Article 2). Plant genetic resources for food and agriculture are a subset of genetic resources, and are defined as any genetic material of plant origin of actual or potential value for food and agriculture (International Treaty on Plant Genetic Resources for Food and Agriculture Article 3). Genetic resources are a subset of biological resources, which are defined as genetic resources, organisms or parts thereof, populations, or any other biotic component of ecosystems with actual or potential use or value for humanity (Conventional on Biological Diversity Article 2).
genetically modified organism (GMO), living modified organism (LMO)	Genetically modified organism (GMO) means an organism, with the exception of human beings, in which the genetic material has been altered in a way that does not occur naturally by mating and/or natural recombination, by recombinant nucleic acid transformation, or by other techniques involving the direct introduction into an organism of heritable material prepared outside the organism including micro-injection, macro-injection and micro-encapsulation; or by cell fusion (including protoplast fusion) or hybridisation techniques where live cells with new combinations of heritable genetic material are formed through the fusion of two or more cells by means of methods that do not occur naturally (EU Directive 2001/18/EC). Living modified organism (LMO) means any living organism that possesses a novel combination of genetic material obtained through the use of modern biotechnology; 'living organism' means any biological entity capable of transferring or replicating genetic material, including sterile organisms, viruses and viroids; 'modern biotechnology' means the application of in vitro nucleic acid techniques, or fusion of cells beyond the taxonomic family, that overcome natural physiological reproductive or recombination barriers

	and are not techniques used in traditional breeding and selection (Cartagena Protocol on Biosafety to the Convention on Biological Diversity 2000).
genome	an organism's complete set of genes and genetic material (which includes both the DNA in the nucleus and plasmids in the cytoplasm of the cell)
genotype	The genotype is the genetic makeup of a cell, an organism, or an individual (ie the specific allele makeup of the individual) usually with reference to a specific characteristic under consideration. See also ecotype, phenotype and trait.
germplasm	reproductive or vegetative propagating materials of plants
GM event, GM gene construct	the genetic sequence that expresses the GM trait (usually including marker gene, promotor, gene of interest, and terminator), inserted into the GMO using recombinant nucleic acid technology (see definition of GMO/LMO)
GM product	the product (usually a protein, eg an enzyme) that is created (expressed) from the GM gene
green manure	See cover crop
greenhouse gas (GHG)	any of the gases whose absorption of solar radiation is responsible for the greenhouse effect, including carbon dioxide (CO2), methane (NH4), nitrous oxide (NO2), ozone (O3), and the fluorocarbons – usually expressed as CO2 equivalents
habitat banking (conservation banking, biodiversity banking)	A market where credits from actions with beneficial biodiversity outcomes can be purchased to offset the debit from environmental damage (EFTEC and IEEP, 2010). Credits can be produced in advance of, and without ex-ante links to, the debits they compensate for, and stored over time. The term 'habitat banking' can be used to refer to both species and habitats, ie analogous to 'conservation banking' and 'biodiversity banking'.
haploid	Haploid means that a cell core (nucleus) only contains one set of chromosomes.
harm, damage (environmental)	a measurable adverse change in a natural resource or measurable impairment of a natural resource service which may occur directly or indirectly (Directive 2004/35/CE). Harm is generally given more weight when it is irreversible.
hazard	hazard is a potential risk, defined as the potential of an organism or any other stressor to cause harm to or adverse effects on human health and/or the environment (EFSA, 2010)
heterozygous population	A population whose individuals have unequal genomes/unequal gene characteristics.
homozygous population	A population whose individuals have equal genomes/gene characteristics.
horizontal transfer	the transfer of genetic material from a plant or animal genome directly into the genome of viruses, bacteria or fungi, and its expression
hybridization	the process of combining different plant varieties to create a hybrid, through the exchange of pollen (out-crossing); the hybrid then contains genetic material from both parent varieties

hybrid variety	The progeny of a cross of two homozygous inbred lines; hybrid varieties show superior characteristics to their parental lines which is described by the term "heterosis effect".
in situ conservation	the conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings and, in the case of domesticates or cultivated species, in the surroundings where they have developed their distinctive properties.
integrated crop-livestock production / integrated production / integrated farming	Integrated crop-livestock production refers to production systems that combine crops and livestock within a coordinated farm framework that recycles waste products as feed or nutrients and diversifies the farm production and economy. Integrated Production/Farming is a farming system that aims to balance biological, technical and chemical methods of management in order to improve the protection of the environment, farm revenues and animal welfare. It also combines crops and livestock production on-farm.
Integrated Pest Management (IPM)	IPM is the integrated management of pest populations at acceptable levels for a healthy crop using a carefully considered balance of biological, technical and chemical methods that cause the least possible disruption to the biological control provided by the agro-ecosystem, and prevent the evolution of resistant pests.
Integrated Nutrition Management	Integrated nutrition management is the integrated use of diverse plant nutrient resources (organic, mineral, biofertilizer) adapted to site and crop characteristics, in order to achieve the desired level of crop production with maximum use of nutrient recycling on farm, miminisation of losses, and greater sustainability (Roy et al, 2006). However, unlike organic farming it does not aim to completely eliminate the use of mineral fertilisers.
Integrated Soil Fertility Management Plan	plan to optimise a farm's reliance on manufactured fertiliser, making it more resilient under economic or environmental pressures
Integrated Weed Management (IWM)	IWM is a form of IPM for keeping weed populations at an acceptable level for a healthy crop, whilst preventing the evolution of resistant weeds and weed build-up, through the combined use of a diversity of preventative, cultural, mechanical, biological, and chemical control practices. Tactics include crop rotations, early or late planting dates, cover crops, mulching, competitive crop cultivars, the judicious use of tillage, and targeted herbicide applications where necessary.
intercropping / alley cropping	the practice of growing two or more crops in proximity; the goal is usually to produce a greater overall yield on a given piece of land by making use of synergies and by better use of resources such as soil water, nutrients, light and/or space (whilst avoiding the negative effects of crop competition) – see also agroforestry
intragenesis	Intragenesis is a genetic modification of a recipient organism that leads to a combination of different gene fragments from donor organism(s) of the same or a sexually compatible species as the recipient, including promoter and terminator from genes of the same species or a crossable species. It differs from cisgenesis in that the gene sequence combines several elements

	and has been reorganised before insertion. It may be arranged in a sense or antisense orientation compared to the orientation in the donor organism (New Techniques Working Group 2012 Final Report to the European Commission).
introgression (crop-wild gene flow)	the permanent incorporation of the transgene into a reproductively integrated population of another wild or weedy species
landraces	unique varieties of crops that have adapted to local conditions through a process of farmer selection.
LC50	median lethal concentration at which 50% of the exposed population dies within 24h
LD50	median lethal dose at which 50% of the exposed population dies within 24h
line variety	A self-pollinating plant community produced by self-fertilisation techniques; all individuals are genetically identical.
marker (genetic)	Molecular markers are short, clearly detectable sections in the genome whose positions on the chromosomes are defined.
measurement endpoint	a quantifiable indicator of change in the assessment endpoint, that constitutes a measure of hazard and exposure, eg fitness, growth, behaviour, development, fecundity (EFSA, 2010)
mitigation (of climate change)	climate change mitigation encompasses actions being taken to reduce anthropogenic GHG emissions
monogenetic inherited trait	A trait that is only affected by one single gene which determines its expression and characteristic.
mutation / mutagenesis	Spontaneous or via mutagens experimental induced qualitative or quantitative changes in the genome (also called mutagenesis).
nanotechnology	Nanotechnology is the design, characterization, production and application of structures, devices and systems by controlling shape and size at the nanoscale (dimensions of the order of 100 nanometres or less). This definition includes a wide range of fields of science including surface science, organic chemistry, molecular biology, semiconductor physics, microfabrication, and applications in medicine, foods, electronics, information technology, energy supply and distribution and environmental protection. (Source: http://ec.europa.eu/health/nanotechnology/policy/index_en.htm)
no-till / zero-till	see zero till
non-target	a non-target species is a species that is not deliberately killed or affected as part of the GM design or pesticide, but which may nevertheless be affected
novel trait	a novel trait is a form of a character that is not typical of that organism or species, eg herbicide-tolerance would only occur very rarely naturally in plants
obsolete cultivars	plant varieties that are considered of no importance at present or no longer popular or used by the farming community (see also cultivars)
Oilcrops, Oilseeds	Oil-bearing crops include both annual (usually called oilseeds) and perennial plants whose seeds, fruits or mesocarp and nuts are valued mainly

	for the edible or industrial oils that are extracted from them. They include: Castor oil seed, Coconuts, Cottonseed, Groundnuts, Hempseed, Jojoba Seeds, Karite Nuts (Sheanuts), Linseed, Melonseed, Mustard seed, Oil palm fruit, Oilseeds, Nes, Olives, Palm kernels, Palm oil, Poppy seed, Rapeseed, Safflower seed, Seed cotton, Sesame seed, Soybeans, Sunflower seed and Tung Nuts (FAO, 2012b).
on-farm conservation	The sustainable management of the genetic diversity of locally developed traditional animal breeds or crop varieties by farmers (usually within traditional agricultural, horticultural or agri-silvicultural cultivation systems).
open-pollinated variety	An open-pollinated plant community is produced by cross-fertilisation techniques; the individuals of an open-pollinated variety are more or less heterogeneous and heterozygous.
organic soils	soils that contain at least 12% organic carbon (around 20% organic matter) in at least 40cm depth within the upper 100 cm of soil (ie accumulations of partly or completely decomposed plant residues formed under anaerobic conditions), OR organic rich soils under 10cm thick overlying ice or rock (FAO)
paludiculture	sustainable agricultural production on peatland that has undergone rewetting
parasitoid	an insect which reproduces by laying its eggs inside (endoparasitoid) or on (ectoparasitoid) another insect known as the host, either in the eggs or on or in the larvae. The parasitoid larvae develop feeding in or on the insect, and hatch through the skin. Adult parasitoids either do not feed or feed on nectar and/or guttation fluids.
phenotype	the sum of an individual's observable characteristics or traits, such as its morphology, development, biochemical or physiological properties, phenology, behaviour, and products of behaviour (such as a bird's nest); phenotypes result from the expression of an organism's genes as well as the influence of environmental factors and the interactions between the two (see also genotype and ecotype).
plant genetic resources for food and agriculture	see genetic resources
polygamy	Multiplication of the stock of chromosomes of a cell.
polygenic inherited trait	A trait that is affected by several or numerous genes that interact amongst each other and/or with the environment; these interactions determine the expression and characteristic of the trait.
precision agriculture	Precision agriculture is a production system that focuses on the precise application of fertilisers at the right time of the crop development as well as controlled application of pesticides only in case of attacks by pests, based on detailed mapping of fields and the use of GPS technology.
primitive forms (of crops)	crop varieties that have not been subjected to intensive breeding or growers' selection; they have features or traits that are similar to wild relatives.
problem formulation	the "what could go wrong" step of risk analysis. This involves: identifying

	the scope of the assessment; identifying the boundaries (temporal, spatial, organisational), identifying the stressor (pesticide, metabolites, GM gene, GM product, GM plant, crop & cultivation practices); identifying potential adverse effects; identifying stakeholders; and identifying the risk analysis strategy, including risk hypotheses. EFSA uses a narrower definition as the process of identification of characteristics of the GM plant capable of causing potential adverse effects (hazards) and of the nature of these effects (hazard characterisation); the identification of pathways of exposure through which the GM plant may adversely affect the environment (exposure identification); and defining assessment endpoints and setting up specific hypotheses (EFSA, 2010).
process/quality control and monitoring (food)	process to control of the different individual unit operations of food processing, as well as to assess the quality evolution of the raw materials, intermediates and final products throughout the entire food production-to-consumption chain
productivity – Labour Productivity	Labour Productivity is the ratio of output to labour input in a production process and represents a partial productivity index. Agricultural labour productivity is measured as aggregated output per agricultural worker.
productivity - Land Productivity	Land Productivity measures the aggregated output per harvested area. Land Productivity is a partial productivity index.
productivity - Total Factor Productivity	Total Factor Productivity is usually defined as the ratio of total output to total input in a production process. In agriculture, output is composed of multiple commodities produced by multiple inputs in a joint production process.
promoter	the genetic sequence in front of the GM gene that acts as a "switch" telling the plant when and how to read the gene
protoplast	Protoplasts are cells without a cell wall; the degradation of the cell wall is carried out by special enzymes.
Pulses	Pulses are annual leguminous crops yielding from one to 12 grains or seeds of variable size, shape and colour within a pod. They are used for both food and feed. The term "pulses" is limited to crops harvested solely for dry grain, thereby excluding crops harvested green for food (green peas, green beans, etc.) which are classified as vegetable crops. Also excluded are those crops used mainly for oil extraction (e.g. soybean and groundnuts) and leguminous crops (e.g. seeds of clover and alfalfa) that are used exclusively for sowing purposes. They include Bambara beans, Beans, dry, Broad beans, horse beans, Chick peas, Cow peas, Lentils, Lupins, Peas, Pigeon peas, Pulses, and Vetches (FAO, 2012b).
quantitative trait loci	A region in the genome that has an effect on the expression of a polygenic trait; the calculated effect results from statistical estimations based on genetic analyses (eg marker analysis).

resilience	Resilience is the capacity of a system to absorb disturbance and reorganise whilst undergoing change so as to still retain essentially the same function, structure, identity and feedbacks (Walker et al, 2004). This recognises that ecosystems can exist in multiple stable states – thus, some species interchange may occur as a result of perturbation without significant impacts on ecosystem resilience, providing that the new species fulfil the same ecological functions as the lost species (Mazza et al, 2012). Resilience usually needs to be specified in terms of the identity (boundaries) of the ecosystem and its valued properties and functions.
resistance (to stressor eg pests, diseases, herbicides, insecticides, GM product)	resistance is the inherited ability of a plant or animal genotype to survive and reproduce following exposure to a dose of a pesticide (or GM product) normally lethal to the wild or normal genotype of the species. Resistance is the result of evolution by mutation and/or cross-breeding with naturally resistant individuals plus intense selection pressure.
restoration	the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed
rhizosphere	The rhizosphere is the narrow region of soil around plant roots that is directly influenced by root secretions and biomass. It is much richer in soil micro-organisms than the bulk soil. Much of the nutrient cycling and disease suppression needed by plants is carried out by these micro-organisms and thus occurs immediately adjacent to roots. Plant secretions determine the composition and function of the rhizosphere community; some plants secrete allelochemicals from their roots which inhibit the growth of other organisms (allelopathy).
risk	the combination of the magnitude of the consequences of a hazard, if it occurs, and the likelihood that the consequences occur (Directive 2001/18/EC). Risk is a probability of a harm occurring, which is quantified as far as is possible, but is always associated with a degree of uncertainty that should be specified with the risk statement.
salinisation (of soil)	the accumulation of soluble salts of sodium, magnesium and calcium in soil to the extent that soil fertility is severely reduced
set-aside	land temporarily taken out of agricultural production; Set-aside also refers to a scheme to lay fallow a proportion of the EU arable crop introduced under the Common Agricultural Policy in 1988 to help reduce over-production. Set-aside was abolished in 2008.
shelterbelt / windbreak	one or more rows of trees and/or shrubs planted in such a way as to provide shelter from the wind and/or sun and/or snow for crops, livestock and/or grassland; this report refers only to 'field shelterbelts' ie rows of trees or shrubs on agricultural fields, not shelterbelts around farmyards or livestock facilities, on marginal lands to change land use, or in block plantings to provide woodlots
short-rotation coppice (SRC)	high-yield varieties of tree (generally poplar and willow) grown as an energy crop; planted at a high density, cut at the base (coppiced) after one to two years, and re-harvested on a two to five year cycle for up to thirty years
silage	Silage is fermented, high-moisture stored fodder which can be fed to cattle and sheep or used as a biofuel feedstock for anaerobic digesters. It is

	fermented and stored in a process called ensilage, ensiling or silaging, and is usually made from grass, maize, sorghum or other cereals, using the entire green plant (not just the grain).
soil organic carbon (SOC)	the total carbon stored in soil organic matter expressed as % C per 100 g of soil – in general soil organic matter contains approximately 58% C, therefore a factor of 1.72 can be used to convert SOC to SOM (NB calcareous soils contain much more inorganic C than SOM)
soil organic matter (SOM)	Soil organic matter is the non-living product of the decomposition of plant and animal substances and residues. It consists of 1) partly decomposed residues (active SOM), 2) microbial biomass and decomposition products, 3) humus (a well-decomposed stable mix of complex carbon molecules), and 4) inert organic matter. SOM does not include living soil organisms (other than microbes), undecayed residues or surface litter, or inorganic (mineral) soil components.
soil sealing	the loss of soil resources due to the permanent covering of land for housing, roads or other infrastructure
Standard Gross Margin (SGM)	The SGM is the difference between the value of the agricultural output (crops or livestock) and the cost of inputs required to produce that output. The sum of all the margins per hectare of crop and per head of livestock in a farm is a measure of its overall economic size.
sterilization (of food) including pasteurisation	the use of heat and/or high pressure to destroy bacteria and other pathogens that cause decay in food and/or transmit diseases or toxins
sub-lethal	an negative effect on individuals that survive exposure to a toxin, ie a decrease in fitness through changes in physiology and/or behaviour, for example by decreasing fecundity or lifespan or flying behaviour (Desneux et al, 2007)
synergistic impact	effect of the interaction of several components/factors/organisms that causes higher impacts than the sum of their individual impacts
target	a target species is a species that is deliberately killed as part of the GM or pesticide design, eg insects killed by the toxin in GM insect-resistant crops, weeds killed in GM herbicide-tolerant crops
terracing (bench)	bench terraces are series of (nearly) levelled platforms built along contour lines, at suitable intervals, usually sustained by stone walls. Bench terracing is particularly beneficial for soil retention and infiltration, but requires high maintenance, and is therefore increasingly frequently replaced by earth terraces.
tissue culture techniques	All tissue culture based methods follow the principle to cultivate single plant cells, tissues or organs in special culture medium in vitro in order to generate plant organs or whole plants.
tolerance (to stressor eg herbicides, insecticides, GM product)	tolerance is the inherent ability of a species to survive and reproduce after exposure to a pesticide or other stressor, for example because it has a naturally low susceptibility

trait (GM trait)	a trait is the particular form of a character of an organism, eg red flower colour or herbicide resistance; most GM traits are expressed by a single gene (whereas most traits eg yield are the result of a complex interaction of many genes); see also genotype
transgene	the genetic sequence that expresses the transgenic trait, taken from an unrelated species and inserted into the GMO (as opposed to cisgene)
transgenesis	the transfer of one or more genes between organisms which cannot naturally interbreed (and which belong to species in different gene pools); see definition of cisgenesis
tritrophic exposure	exposure of an organism to the stressor (pesticide, metabolite or GM product) via another organism on which it feeds or parasitizes, and which has fed on the plant and/or stressor; exposure of an organism to the stressor (pesticide, metabolite or GM product) via the faeces of another organism that has fed on the plant and/or stressor (see also bitrophic exposure)
UAA (Utilized Agricultural Area)	Utilised agricultural area (UAA) describes the area used for farming. It includes the land categories arable land, permanent grassland, permanent crops and other agricultural land such as kitchen gardens. The term does not include unused agricultural land, woodland and land occupied by buildings, farmyards, tracks, ponds, etc (EUROSTAT).
volunteer population	a population of crop plants that has propagated in the crop field itself (ie within the subsequent crop or crops) from previous plantings of that crop
water scarcity	Water scarcity is a man-made phenomenon. It is a recurrent imbalance that arises from an overuse of water resources, caused by consumption being significantly higher than the natural renewable availability.
weedy races (of crops)	crop varieties that are no longer cultivated and have become naturalized in the wild
yield potential	the ideal yield for a crop under a specific climate where the crop develops without any biophysical limitations other than uncontrollable factors, such as solar radiation, air temperature, and rainfall (in rainfed cropping systems); achieving yield potential therefore requires optimal management of all yield-restricting production factors such as seeding date, plant population, nutrient supply, protection against pest and disease damage and weed competition
yield gap	the difference between yield potential and average farmers' yields, for a specified spatial and temporal scale of interest
zero tillage (no-till)	Zero till (no-till) is a way of growing crops without disturbing the soil. This practice involves leaving the residue from last year's crop undisturbed and planting directly by drilling seeds through the residue. See also conservation tillage.

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