

Technology options for feeding 10 billion people

Synthesis report summary

Options for sustainable food and agriculture in the EU

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Abstract of the study

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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CONTENTS

1. INTRODUCTION.....	1
2. MAPPING A FUTURE FOR FOOD AND AGRICULTURE IN EUROPE	2
3. DEVELOPING MORE SUSTAINABLE FARMING SYSTEMS.....	6
4. CHALLENGES FOR PLANT BREEDING AND GENETIC RESOURCES	10
5. TAKING ACCOUNT OF THE ENVIRONMENT	13
6. FOOD WASTE AND DIETS	21
7. MOBILISING WASTE AND RESIDUES FROM AGRICULTURE, FORESTRY AND FOOD SECTORS.....	27
8. CONCLUSIONS	32

1. INTRODUCTION

The global population is expected to reach 10 billion at some point between 2050 and 2100 according to UN projections. What role will Europe play in addressing the continued challenge of feeding a much larger world population in the coming decades? How will a more sustainable agriculture and food supply chain be created at the same time? The goal is not only to eradicate present levels of persistent hunger and to feed a larger population, but also to improve and enrich diets in large parts of the world. As part of this global endeavour it is essential to create sustainable farming systems capable of being maintained within increasingly apparent environmental limits. Current patterns of agriculture are a major source of pollution, loss of biodiversity and deteriorating soil quality in large parts of the world.

Ideas about the future of the global food system are remarkably diverse. Some of these envisage mainly incremental changes to the present systems of food supply and the markets that accompany them. Others are more visionary, exploring options such as significant dietary change, accelerated investment in high tech agriculture, the revival of more traditional farming systems, and the adoption of new patterns of trade. Business as usual, even with a serious effort to increase agricultural productivity, seems unlikely to be sufficient to meet the multiple and sometimes conflicting objectives ahead of us.

This report focuses on just one segment of a very broad canvas. It considers 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. Europe has many resources on which to draw. These include a productive agriculture and food system, relatively robust soils, a mixture of high and low intensity farming systems, strong infrastructure and support services in most countries and a good range of research institutions. However, there are different views as to where the priorities lie. In the recent debate on the reform of the Common Agricultural Policy (CAP) there were contrasting calls for an immediate increase in European production on the one side and for stronger emphasis on sustainability and “greening” on the other.

Against this background, the STOA Panel of the European Parliament commissioned five studies on relevant aspects of the food and related bioenergy equation, each with a European focus. These offer a broad analysis of our likely future production options, and this forward looking context then permits a focused exploration of some pressing contemporary issues. These include: the means of reversing continued declines in farmland biodiversity, the different means of achieving a significant reduction of food waste, and the options for using wastes and residues to meet biomaterial and bioenergy needs in a sustainable way. This report synthesises some of the analysis and results of the five studies, considering the state of play today and some of the key developments on the horizon, looking towards 2050.

It is in two parts, with a short overall synthesis followed by a more extended summary with accompanying references.

2. MAPPING A FUTURE FOR FOOD AND AGRICULTURE IN EUROPE

There is no certainty about precisely how much food production will need to rise in future in order to provide a sufficient and healthy diet for a larger and more affluent global population. It depends partly on the size of the population, whether it levels off at around 10 billion, and when. In addition, the degree of success in eliminating widespread poverty and related malnutrition, future levels of affluence (and consequently levels of meat and dairy consumption), changing dietary preferences, policies adopted on biofuels, bioenergy and other factors, will all have an influence on how much food is required. Recent projections by the FAO recognise the many unknowns but suggest that a 60 per cent increase in food production by 2050 might be required.

More production, while vital, is only one piece of the equation. Currently, at a global aggregate level there is about enough food to provide a sufficient diet for everyone. Despite this, up to one billion people are still chronically undernourished, and perhaps another billion suffer from the “hidden hunger” of having insufficient vitamins and minerals. Poverty is the primary reason for lack of access to food. Addressing poverty and lack of access to both food and health services requires action on development, income distribution, the empowerment of women, appropriate trade and aid policies and many other factors. Producing more food in Europe at present does not solve these problems.

By contrast, in many developing countries investment in improving local agricultural production can be an effective means of reducing hunger and malnutrition because most of the extreme poor depend on farming and related activities for a significant part of their livelihoods. Consequently, investing in smallholder agriculture often is a key means of improving food security in poorer countries with significant rural populations. Investment in food production where it is needed and where it has a role within a broader effort to address poverty and support development is critical to any serious effort to counter malnutrition and feed a growing world. In future years Europe may indeed need to expand its own output as part of a collective effort to produce sufficient food. However, the priority for the present is to increase agricultural production predominantly elsewhere, particularly in Africa and parts of Asia, rather than in the EU, where demand is expected to remain relatively stable, as is the size of the population.

This does not mean that the EU is peripheral to the future of the global food system. Quite the reverse; it has a number of highly significant roles, which are the principle themes of this report. They involve a more fundamental set of preparations to meet new challenges – not a short term burst of additional food production in Europe. They include a significant contribution to efforts in other parts of the world. The new role for the EU can be presented in different ways, but is considered here under six broad headings.

First, it is a priority to conserve the EU’s own productive resources, so that agriculture can remain robust and potentially able to contribute more, or in different ways, to future demands as these arise. If the EU’s key resources of agricultural land, well-managed soils, uncontaminated water supplies, well maintained infrastructure, a highly skilled workforce, sophisticated supply industries and research capacity can be maintained or, in some cases, restored to a healthy state this in itself makes a major contribution to global food security. If agricultural capacity in this broad sense is run down, considerable costs will be incurred in

bringing it back to a state of readiness for a future and possibly larger role in the global food equation. Maintaining and improving the sustainability of European agriculture is no small challenge however. It entails decisive steps to address large scale deterioration of soils, over-exploitation of aquifers for irrigation and a range of other issues as well as measures to control the rate at which agricultural land is developed for urban purposes. Soils are of particular importance. See Box 1.

Box 1 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, salinisation, and acidification, is most pronounced in arable soil. 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. 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. Soil organic carbon (SOC) decline is of particular concern in the Mediterranean region, where high temperatures and droughts can accelerate its decomposition. 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.

Some of the issues involved in strengthening sustainability are addressed in the five studies for STOA and in the remainder of this summary.

Second, is to increase the emphasis on resource efficiency in EU agriculture, so that more can be produced over time with fewer inputs, for example water, agrochemicals and nutrients. This will contribute to both productivity and sustainability in Europe, help increase the viability of agriculture and reduce the EU's global environmental footprint. Research and development should be geared even more strongly towards these priorities.

Third, is the need to foster innovation and the spread of best practice as well as traditional research and development. This should raise productivity and increase aggregate yields where this is compatible with the constraints imposed by environmental sustainability. It should help European agriculture to compete in the world market and maintain a high level of production. Following the decoupling of CAP support there may be significant changes in the pattern of cropping, and the potential to displace some of the 30m tonnes of livestock feed imported annually. However, there are more fundamental questions. European crop yields are relatively high and production is nearer to the theoretical limits of what could be achieved than most other parts of the world. The growth in yields of Europe's main agricultural crops has slowed down, and it is unclear how far it can be raised again, particularly in the face of climate change and limitations in water supply and the use of nutrients. Despite this, there is certainly scope to close the gap between farms achieving higher and lower yields. The potential for increasing yields is greater in parts of central and

Eastern Europe than in the Western part of the continent where more intensive methods have been in place for longer. Creative innovation, giving priority to resource efficiency, has potential everywhere. An intensified focus on both research and innovation should be put in place to assist this new trajectory in agriculture, recognising that innovation has not been a priority in recent decades. This is now changing (see Box 2)

Box 2 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 (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.

Fourth, there is the challenge of reducing European demand over the coming decades. This applies both to the raw materials required for agriculture and production, including nutrients and livestock feed, as well as to agricultural commodities and processed foods. Europe has a large environmental footprint on the global stage and over time this needs to be reduced in order to respect global resource limits, including water supplies and the protection of forests and natural habitats from excessive agricultural incursions. Resources need to be available to allow for higher standards of living and increased dietary standards in other parts of the world. There are several routes to achieve this. One is the development of more resource efficient agriculture, establishing this as a standard model in Europe and elsewhere. Another is the reduction of wastage, both in agriculture and the rest of the supply chain (see section 7 below). In addition there is the potential to make a significant change in European diets so that they are less resource intensive, particularly with respect to meat and other livestock products. There is a growing literature of studies estimating how much difference might be made by changes in diet, showing that significant contributions could be made to reducing Europe's greenhouse gas emissions, for example.

Fifth, there is a need to align Europe's bioenergy policies with long term strategies regarding food, agriculture, and biodiversity. Nearly all forms of commercial bioenergy make some demands on limited supplies of land and this particularly applies to those derived from agricultural crops, and to new energy crops, such as short rotation coppice, as well as traditional forest. Currently around 80-85 million tonnes of cereals and around 10

million tonnes of vegetable oils are used for biofuels alone, on a worldwide basis. The EU is one of the largest consumers of biofuels as a result of a policy target which has been introduced to promote the use of renewable energy in the transport sector. The unintended consequence has been to promote the growth of biofuel production from oilseed rape, cereals, and other food crops on a growing scale. This policy is now under review. However, it illustrates that EU energy policies are having a significant impact on the same resource base that is required to feed the planet; much more ambitious bioenergy policies, which some anticipate, could accentuate this impact very greatly. This is all the more important as other countries outside Europe are incentivising biofuel and bioenergy production as well; a large proportion of the entire US maize crop is now devoted to biofuel production. Increasing the proportion of renewable energy in Europe's energy mix is of course essential, but there are now difficult choices to be made about the extent to which bioenergy can be considered a large scale source of energy without creating a major impact on food production and the land available for more natural habitats and biodiversity. Consequently there is a good case, at least in principle, for utilising wastes and residues on a larger scale as a feedstock for bioenergy. These have a far lower effective land requirement and their role is considered below in section 7.

Sixth, the EU needs to engage in a range of different ways in support for sustainable agricultural production in the developing world as well as addressing other threats to food production, such as climate change and excessive use of limited fresh water supplies. The EU exerts influence through its trade policies, the collective role of EU Member States as the largest donors of official development assistance worldwide (together providing €55.2 billion in 2012), its role in global climate, trade, and biodiversity agreements, and various other fora. In many of the world's smaller, poorer and more technologically disadvantaged countries, particularly in sub-Saharan Africa, investments in agriculture have been decreasing over the last decade. It is appropriate that sustainable agriculture is one of the priority areas identified in the EU's most recent development assistance strategy, the Agenda for Change. However, this commitment needs even more weight in future.

Together these six priorities represent a significant change of direction, affecting all the components in the agriculture and food supply chain, as well as in the EU policy framework. They would make a substantive contribution to aligning the EU to longer term global requirements. Nonetheless, they are based on mainstream scenarios for the future and may turn out to be insufficient. There remain very considerable uncertainties which could have an impact on the evolution of the food system and the response required. For example, climate change may depress yields more than many anticipate. On some FAO scenarios for the period up to 2050 yields of rain fed maize in developed countries could fall by 30%. Various limitations on water and nutrient supplies, including phosphates, could result in higher prices and unexpected constraints. Major outbreaks of diseases could make larger impacts than allowed for in business as usual scenarios. It will be important to be alert and ready to adjust if circumstances change in this direction. In all these cases the more prudent course is to build resilience into food supply systems and to give priority to resource efficiency on a sustained basis.

3. DEVELOPING MORE SUSTAINABLE FARMING SYSTEMS

To increase the sustainability and pace of innovation in European agriculture (and its capacity to produce more over time) requires the improved application of existing good practice and a greater focus on innovation and more creative approaches.

This implies:

- The identification and active dissemination of best practice and accumulated knowledge
- The refinement and application of appropriate technologies
- An expanded research and development effort with a wider focus than at present
- Broader systems thinking to guide a changing agenda for agriculture
- More emphasis on the role of extension services and the resources required to enable uptake of a fresh approach

Sometimes the term “sustainable intensification” is used to capture changing objectives, in agriculture referring to the production of more food and useful by-products from a fixed or slightly declining land area, while reducing environmental impacts and respecting social and economic priorities. Whatever term is used, a core principle is the greater application of knowledge per hectare in order to raise resource productivity rather than the intensive use of purchased inputs, which was the model established during the second half of the last century. This leads to a strong emphasis on farm management in the broad sense, covering concepts, practices and technologies as well as on particular technical skills such as plant breeding (see section 4) and waste reduction (see section 7).

Focusing solely on the crop sector in Europe, there are a wide variety of systems in place, with the predominant model of arable cropping being increasingly large scale, usually intensively managed and frequently becoming more specialised. However, some less intensive and more mixed farms remain. Different approaches to productivity, development, and sustainability can be applied according to the systems used and the local conditions, thinking laterally rather than pursuing a single dominant model. As noted already, there remains potential to reduce the considerable gap between higher and lower yielding farms working in apparently similar conditions through more widespread good practice.

Sustainable yields can be raised by a combination of appropriate crop production systems, technologies and specific practices. Site specific yield potential can be increased, with lower or more optimum input use and higher overall efficiency and output. Holistic approaches to arable farm management have particular value here. Crop management is closely linked to longer term soil and ecosystem management above and beyond traditional agronomic and economic concerns. The maintenance and enhancement of soil fertility and finely tuned exploitation of agro-ecological mechanisms would aim to stabilise high yields in the most productive areas and to increase productivity in more extensive systems without compromising the provision of environmental public goods. At the same time the more marginalised and small scale producers should not be excluded from participating in a new agenda and the accompanying research and dissemination effort. These producers are

numerous in some parts of Europe and could contribute more to local production as well as the socio-cultural fabric of rural areas.

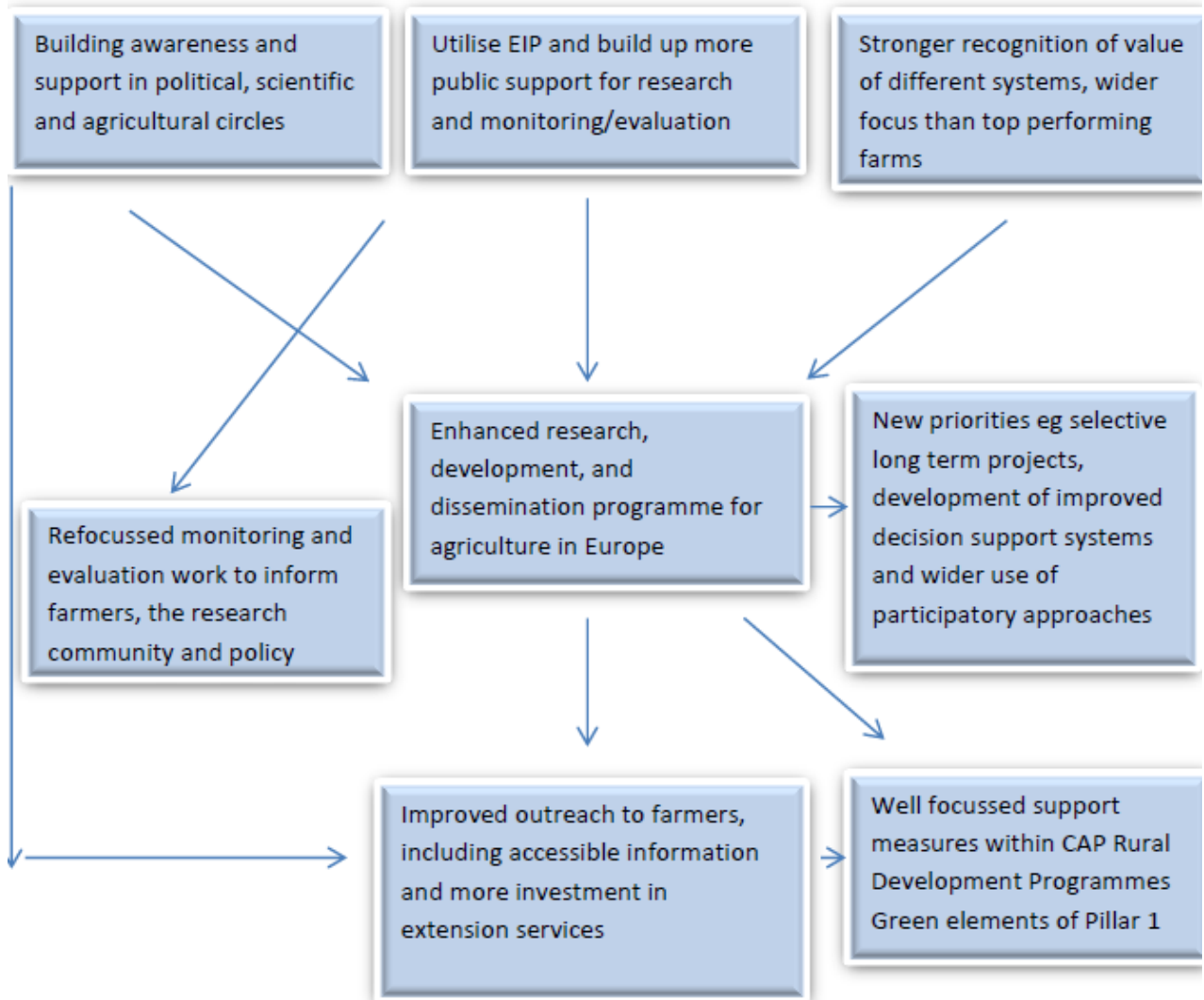
Production systems of particular interest in this context include:

- **Precision agriculture (PA)**, puts the emphasis on information based management of agricultural production, aiming to apply the right treatment in the right place at the right time, taking into account in-field variations of crops and soils. New technologies are used in these systems to determine the variables which guide the use of inputs which are applied in more valuable and precise ways than previous technologies allowed. There are sensor based systems, map based systems and combinations of the two. Specific technologies include yield mapping, remote sensing, geo-information systems, GPS, and sensor technologies for data collection. PA techniques can apply to a range of practices including fertiliser and manure application, weed control, disease management and water management. (Parallel developments in livestock farming use electronic tagging and software to guide decisions about stock feeding, reproduction, slaughter dates etc.) Some precision techniques have been in commercial use for several years, others are still in the process of development. They are mostly used on larger and more intensively managed farms in north west Europe, notably in Denmark, France, Germany, the UK, and the Czech Republic, although the data on the adoption of these systems is rather thin. So far uptake has been constrained by the high cost of the equipment and the need to deploy it over a large area to recuperate the costs. However, over time PA practices are likely to spread to a wider group of farmers and contribute significantly to improved management of many operations.
- **Conservation Agriculture** is a production system based on the three principles of minimal or no mechanical soil disturbance through reduced or zero tillage, soil cover with organic material and diversified crop rotations. The techniques employed are no-till, zone, strip, or row tillage, non-inversion tillage, surface incorporation of crop residues, planting of cover crops and green manures, mulching of crop residues, direct seeding, and weed management with contact herbicides, such as glyphosate. The goal is to prevent soil degradation and to preserve and enhance soil fertility. With little or no cultivation there is reduced energy use and less oxidation of soil carbon. It is not suitable for all soils, requires specialised equipment, and new management skills as well as a willingness to rely on a quite different approach, with persistent use of herbicides. Although its use is relatively popular in some parts of Europe, for example parts of Germany, Eurostat data suggests it accounted for only 3.4% of arable land in the EU in 2011. The potential may be considerably greater.
- **Mixed Farming Systems**, involving livestock and arable production being pursued in an integrated way on the same farm is a far more traditional approach. Nonetheless, some of the basic principles remain highly relevant, including the potential to close loops, for example by producing livestock feed on the farm and utilisation of manure for crop production. These systems have been in decline for many years in Europe. At the present time they may account for only about 12% of the EU agricultural area and about 13% of farms, according to Eurostat, but in many respects they have the potential to improve levels of sustainability if more economically viable systems can be developed and disseminated.

- **Organic Farming** takes these principles considerably further, putting the health of soils and ecosystems into a more central place in a more fully developed management philosophy. A very limited range of manufactured inputs are permitted and there is no use of synthetic pesticides, fertilisers, or GMOs. Organic farms are required to meet certain certification standards if they are to market their produce under this label and there is a well-developed system of farm inspection and control. The produce has much higher recognition amongst consumers than other more holistic or low input systems and is a valuable avenue for increasing awareness and changing consumption patterns. Approximately 5.4% of agricultural land in the EU is registered as organic, and there is support for these systems under nearly all rural development programmes. Expansion could be facilitated by a more ambitious R&D agenda and simultaneous development of the market.
- **Agroforestry** is a less well-known integrated land use system that combines the cultivation of trees and shrubs with annual crops and in some cases livestock on the same land. The object is to utilise complementarities. Some are highly traditional silvoarable systems, such as the Dehesas in Spain and Montados in Portugal, others are modern derivatives, such as systems of alley cropping. Most traditional systems, including wooded pastures and orchards with livestock, are in decline in Europe and now rare in most regions. Some are protected because of their high biodiversity value. Data on their precise extent is not available. Nonetheless, some of the principles employed, such as the maintenance of a tight nutrient cycle, could be highly relevant to sustainable systems in future and they are also a potentially fruitful area for research and development.

The philosophy and practices of these different systems have much to offer to a new agenda and to the formation of new avenues for research and development. To further develop sustainable farming systems and increase their adoption on the ground requires a range of different measures. These are summarised in Figure 1.

Figure 1 Taking Forward Sustainable Farming



4. CHALLENGES FOR PLANT BREEDING AND GENETIC RESOURCES

There are many aspects of agriculture in the EU where a twin focus on sustainability and innovation is particularly important. One of these is plant breeding, which was the topic of one of the five studies for STOA. Over thousands of years plant breeders, including generations of farmers, developed crops with higher and relatively stable yields and increased resistance to pests and diseases. Improvements achieved through breeding are estimated to be responsible for about a quarter to a half of the large increases in EU farm yields since the 1940s. Plant breeding has become a major European industry, with the seed and reproductive material market worth around Euros 6.3 billion a year and the EU established as the world's second largest seed exporter, with an influence far beyond its borders.

While plant breeding has achieved a great deal, especially with the scientific advances of recent decades, there are concerns about its ability to deliver significant further increases in yields against a background of changing climate and increased water stress. For example, wheat yields may be stagnating in Western Europe because of the impact of heat stress on current varieties. Crop yields in the main productive areas of Europe are already high and the environmental impacts of production are considerable and, in some cases, unsustainable. Crop varieties will be needed that maintain yield under more variable weather conditions without increasing use of water and fertiliser.

Plant breeding for increased productivity and sustainability

For many decades plant breeding has aimed primarily for crop varieties which offer increased yield under optimal, often high-input growing conditions. However, alongside these drivers, a new set of requirements is emerging, seeking a stronger emphasis on sustainability as well as yields, requiring plant breeders to seek:

- Evolving forms of pest and disease resistance – as market shifts and climate change bring new challenges to established crops
- Greater drought and salinity tolerance – in response to continued climate change and the need to reduce reliance on conventional irrigation
- Increased efficiency in the use of nitrogen – a topic which has not always had the highest priority in the past, in part because it has been difficult to achieve without compromising on other desired traits
- Enhanced nutritional qualities in many food crops, contributing to healthier diets

Innovation in plant breeding techniques and genetic manipulation

Plant breeding has been transformed in recent decades by scientific advances which allow far more varieties to be created and screened, which speed up the process of bringing improved crops to market and give much greater scope for innovation. Modern plant breeding has opened up the possibility of bringing together the genes of distantly related or even completely unrelated species, including greater uses of landraces and wild relatives of crops.

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. The recent breakthrough in plant breeding has been driven by the ability to use genetic

information (marker-assisted selection), combined with advanced phenotypic characterisation techniques (phenotyping platforms), to identify and track desirable multi-gene (quantitative) traits through the breeding process. Improved tissue culture techniques can be used to grow up and multiply plant cells that combine a wider genetic diversity than can be used in conventional breeding.

Yield stability, the ability of a crop variety to produce a reliably high yield in different years (with potentially significant variations in weather) and in different places, will remain a key objective for plant breeding. Continual investment in plant breeding needs to be maintained while adjusting to new conditions and goals. For example, there may be a bigger role in future for participatory breeding programmes, similar to those widely used in organic farming, to help secure yield stability. Here, farmers and researchers collaborate closely through the entire breeding process, with many on-farm trials of crop varieties taking place and farmers involved in selecting the best performers using their particular knowledge and experience.

Within Europe there is a fierce debate between those who regard genetic manipulation either as unethical or undesirable in social and environmental terms and others who argue that it has real potential for increased yields and lower input use. The latter believe that the EU is losing out in plant breeding innovation due to its overall resistance to GM crops. Only two GM crops have been authorised for cultivation, an insect-resistant Bt maize and a starch-modified potato. Only the first of these is grown on a commercial scale, mainly in Spain. This contrasts with the widespread adoption of a small range of GM soyabean, maize and cotton varieties in the Americas, China, India and Australia, predominantly insect resistant or herbicide resistant crops. GM varieties are regulated separately from seeds produced by conventional plant breeding techniques under the EU definition of genetically modified organisms. But other powerful new plant breeding technologies that use aspects of the GM plant breeding process, such as cisgenesis or directed mutagenesis, also enable the introduction of novel traits into crop varieties; some of these could not be achieved, readily or ever, by conventional plant breeding, though others produce crops with very similar functions to conventionally bred crops. These technologies may present some of the same kinds of risk to the environment and biodiversity as GM crops. However, their status as GM or non-GM varieties has yet to be legally defined within the EU.

Whatever the decision on these technologies, there is an argument that it is the novel trait in a crop variety - the outcome of the breeding process - that should be regulated rather than the technology employed. And while the EU's regulatory stalemate on GM crops must be resolved, there is a need to ensure environmental safeguards apply before novel crop varieties with potentially novel hazards go into use. That requires careful research and evaluation of potentially harmful impacts. Achieving a socially acceptable balance between ensuring environmental safeguards and furthering innovation requires a participatory and broad risk assessment and risk-benefit analysis process.

Strengthening the conservation of plant genetic resources and regulating the seed market

Alongside the development of new seeds runs a different but related priority. This is the loss of plant genetic diversity, which breeding programmes may need to draw from on a significant scale in future, not least in facing sustainability challenges. These plant genetic resources include obsolete cultivars, landraces and wild relatives of crops as well as the

variety of modern cultivars and seeds. Landraces, locally adapted traditional crops, are generally highly genetically diverse and well suited to low-input farming, but today only a few European farmers cultivate them and much of this genetic variation has been lost. It has also been estimated that at least 11.5 per cent of high priority European crop wild relative species are near extinction due to habitat loss, while many are affected by gene flow and hybridisation with crops. A stronger network of gene banks would help (see Box 3).

Strengthening the conservation and use of plant genetic resources in Europe

There are various European initiatives to conserve crop genetic diversity and wild relatives of crops *in situ* and *ex situ*, but together these are insufficient for the task of conserving the range of diversity necessary for conservation and meeting the requirements of plant breeding. Only 6 per cent of European wild relatives of crops have any genetic material conserved *ex situ*, and there is no estimate of what percentage of landraces are conserved. Conserving this heritage is as much about the future as the past.

Box 3 Plant Genetic Resources

A systematic European network of *in situ* genetic reserves for wild relatives of crops and on-farm conservation sites for landraces is needed, together with support measures for farmers to use and conserve this genetic diversity. The approximately 500 gene banks in the EU should also coordinate more. Better marketing of local and traditional crop varieties could contribute to this conservation effort. The European Innovation Partnership for Agricultural Productivity and Sustainability could take a lead here.

One priority is to adopt the current official plant variety registration system within the EU. Currently this works against the use of genetically diverse seed materials, such as those coming from landraces, which can be exchanged informally among farmers who save some of their own seed. The EU could reduce the administrative burden on those plant breeders and farmers using minor crops and varieties and encourage more diversity in the plant breeding cycle.

The Yield Gap

There is potential on most farms to reduce the yield gap – the difference between the seed's yield potential and the average on-farm yield – but opinions differ as to how large a contribution can be made by crop breeding when there are many other variables involved. The performance of farms within closely related agricultural conditions often shows a remarkable heterogeneity, with double the yield on some farms compared to their neighbours.

5. TAKING ACCOUNT OF THE ENVIRONMENT

The environmental impacts of existing levels of agricultural production across Europe are already substantial and in some situations unsustainable. There are serious, overlapping problems with loss of biodiversity and wildlife habitats, degradation of soil resources, over-abstraction of water and damage to water quality.

Much, but not all, of this damage is due to the intensification and greater specialisation of farming in recent decades. There have been large increases in the use of agrochemicals, natural and artificial fertilisers, heavy farm machinery and tillage over the past 60 years in much of Europe. However, in some areas, more recently in southern, eastern, and more remote locations, it is the abandonment of extensive, often traditional, farming methods that has wrought major changes. While some of the land farmed in this way has been converted for intensive agriculture or forestry, much has been left unmanaged and has been invaded by scrub, losing some of its characteristic plant and animal species in the process.

Impacts of climate change

Against this background, anthropogenic (man-made) climate change may reduce current levels of European agricultural output and, in some regions, conflict with attempts to increase total food production. The overall warming seen across the continent in recent decades has already had an impact on farmers and growers. It is not possible to predict with any precision what the changes in climate will be in different regions of Europe and the effects on the many different farming systems. Changes in growing seasons affecting crops and their invertebrate pests, weeds and diseases, extreme rainfall causing flooding and reduced rainfall affecting rain-fed crops and irrigation water reserves will all play a part.

There may be an opportunity to increase arable output in more northern parts of Europe thanks to longer growing seasons and higher CO₂ concentrations in the atmosphere. This could arise partly through increasing yields of existing crops and partly by allowing the establishment of new crops and varieties in areas previously outside their range in northern Europe. However, there is no guarantee of an overall increase in yields in this broad region; they may be outweighed by losses caused by other effects of climate change. And it seems likely that global warming will tend to lower overall farm production in the southern Member States with water stresses and higher summer temperatures playing leading roles in this.

European agriculture's contribution to climate change

Farming is a major contributor to Europe's anthropogenic greenhouse gas emissions (GHGs), and is expected to account for a larger share in the coming decades as emissions from many other sectors fall faster. As with the multi-faceted effects of global warming, determining agriculture's precise overall contribution to European GHG emissions is difficult. It is estimated that farming accounts for some 10% of total EU GHG emissions, but this excludes emissions from land use, land use change and forestry.

While greenhouse gas emissions from European agriculture are estimated to have fallen since 1990, recent increases in farm output may have halted this decline, which was due partly to falling numbers of cattle and sheep. Agriculture is an important source of nitrous oxide (N₂O) and methane (CH₄) emissions to the atmosphere. These two greenhouse gases

cause far more global warming weight for weight than CO₂ (298 and 25 times more warming, respectively, over a 100 year time frame) and together they make up European farming's largest contribution to climate change. Methane comes from livestock farming, particularly cattle, and from manure spreading, while nitrous oxide emissions derive mainly from manure, use of inorganic nitrogen-based fertilisers and from changes in soil caused by cultivation and drainage.

Farming is also responsible for substantial emissions of carbon dioxide (CO₂), the most important anthropogenic greenhouse gas. These CO₂ emissions are both direct - from the burning of fossil fuels on farms in machines, plant and buildings - and indirect, arising from the production of inputs utilised in farming such as fertiliser and electricity. Indirect emissions from "upstream" activities supplying farmers are not accounted for in the official statistics for agriculture. Furthermore, arable farming causes organic carbon in the soil to oxidise to CO₂ through ploughing and erosion, especially when permanent grassland is ploughed. The quantities of crops, such as soyabeans, imported to feed European livestock are responsible for substantial emissions outside the EU, both of CO₂ and other greenhouse gases.

While arable farming adds to CO₂ (and N₂O) emissions, grasslands have acted as an overall carbon sink in the EU in recent decades. Forestry, the other major human use of rural land across Europe, has also been a net absorber of CO₂ from the atmosphere, in part because the total forest area has been expanding. Standing trees and soils store large quantities of carbon, with the continent's threatened peat bogs and fens acting as particularly rich reservoirs of carbon which was once in the atmosphere.

Changes in the overall balance of land uses across the continent caused by expanding agricultural production could drive emissions upwards. To avoid this, those farming and non-farming land uses which act as carbon sinks need to be conserved while wetlands and soils in general need to be better protected against erosion and degradation to retain their carbon storage.

Increasing food production while adapting EU agriculture to climate change and reducing farming's greenhouse gas emissions

Potentially it is possible to reduce agriculture's greenhouse gas emissions and make the necessary adaptations to a changing climate while producing more food in the coming decades. However, this will not be easy and will require changes in policy, practice and technology at all levels.

One of the five studies commissioned by STOA looked at 64 separate agricultural management measures which can help to reduce farm emissions of greenhouse gasses and/or help to adapt agriculture to changes in climate. There were a mixture of well-established techniques, novel and traditional practices, and measures frequently included in agri-environment programmes. Taken together, these measures covered a variety of production systems and land uses as well as agriculture's role in energy and water related consumption and soil conservation.

The study considered the likely costs of these measures, their potential contributions to mitigation, adaptation and farm productivity, and who the prime actors in delivering each measure would be (farmers, research and development organisations, farm advisors,

industry and government). Many measures cannot be implemented by farmers alone, but require some kind of collective action at the local level.

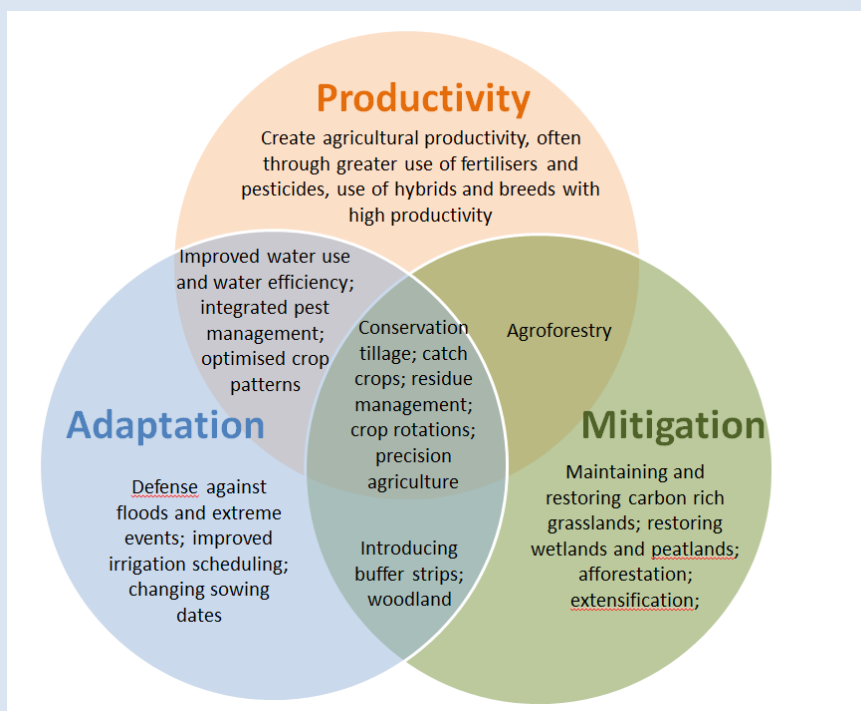
Twenty three of these 64 different measures were assessed as likely to increase agricultural productivity while 34 of them are expected to have a variable, uncertain or neutral impact. Only seven of the 64 are likely to reduce productivity, and most of these measures involve changes in land use such as taking certain types of land out of production or adapting more extensive methods, with reduced nutrient inputs for example. However, if all 64 of the measures considered were applied across Europe on a significant scale, the net effect would probably be to reduce total farm output.

Uptake of these measures needs to be encouraged through policy interventions as well as voluntary measures. Priorities will vary by region and farm type. In many cases it will be logical to focus first on measures which serve all three purposes of increasing food production, mitigating agriculture's contribution to climate change and adapting to it. Such measures include:

- More appropriate arable crop rotations, including better crop residue management and reduced/optimised use of fertilizers.
- More widespread use of precision agriculture
- Improved grassland management, including optimised use of inputs, protection of permanent pasture from ploughing and appropriate grazing regimes
- Improvements in management of both manure and inorganic fertilisers, reducing emissions from manure storage, handling and application, and appropriate use of anaerobic digestion
- Selective use of conservation tillage which minimises the disruption of soil structure, composition and biodiversity, for example by shallow ploughing.
- Promotion of catch crops – fast growing annual crops, typically cereals, adapted to scavenge nitrogen from the soil. They take up surplus nitrogen remaining from fertilisation of the previous crop and are then cut before maturity and left to rot, releasing the captured nitrogen for the next crop.
- Land use change where needed, including conversion of arable to grassland, restoring wetlands and peatlands, selective afforestation
- More emphasis on energy efficiency, appropriate residue use and small scale renewable energy production on farms.

Many of these measures also contribute to climate adaptation but there are also other priorities, including more efficient water use, more contour cultivation and reduced ploughing on slopes, water metering, increased rainwater harvesting, better risk management and disaster information systems, etc. The overlap between measures is shown in a simplified way in Figure 2.

Figure 2 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)

Biodiversity and agriculture

In a different way to climate change, biodiversity, the variety of species and the ecosystems linking them, is also critical to the prospects for European agriculture. Large areas of the continent have been farmed for many hundreds or even thousands of years, and the location and population density of many plant and animal species reflects this. While the biodiversity of Europe has long depended on farming, farming depends on this biodiversity to conserve soils, control pests and pollinate flowering crops.

Biodiversity has been in a rapid and general decline across the EU for decades. For example, since 1980 common farmland bird populations in Europe have fallen by an estimated 51% while grassland butterfly numbers have declined by almost 50% since 1990.

There are many causes of biodiversity loss on farmland with some important ones highlighted in Box 4. Particularly significant has been the loss since the 1950s of traditional large areas of low-intensity farming systems, often involving the grazing of cattle, sheep, or goats, that play a crucial role in maintaining semi-natural habitats and the species they support. Starting in the most industrialised nations, this has spread across the continent. Long established systems have been run down or abandoned, afforested or converted to higher intensity farming, giving particular value to the systems that survive.

Box 4 Widespread changes in agriculture that lead to loss of farmland biodiversity

- Declines in mixed farming systems and greater specialisation
- Removal of natural habitat features such as hedgerows and trees
- Greater application of artificial or organic fertilisers
- Increased pesticide use
- Drainage of grasslands
- Ploughing and reseeded of grasslands
- More intensive systems of livestock grazing and forage management
- Early mowing of grass for silage
- Extended ploughing and other tillage operations
- Expanded irrigation and impacts on ground and surface water

While some forms of agricultural intensification are now being modified or are subject to greater legislative control, for example lower livestock densities in several regions, other forms are appearing, such as the spread of maize onto grassland areas in certain localities. Future pressures could increase intensification, not least if production needs to rise to meet greater global demand. For example, if GM crops were grown on a larger scale there would be risks. A key concern here would be that genes from GM crops could flow into feral populations of crop species and their wild relatives, making them invasive and thereby harming biodiversity.

European farming also has major impacts on biodiversity beyond the continent, particularly because it relies on imports for a significant share of livestock feed. Expanding soyabean cultivation in Brazil and Argentina, driven largely by European demand, has caused semi-natural habitats high in biodiversity to be lost through intensification, and also indirectly caused deforestation – and further biodiversity loss – by displacing livestock farming into forests.

To reverse the decline in biodiversity on farmland requires considered action on a substantial scale. Amongst the priorities are measures to maintain and provide suitable habitats on a sufficient scale for a diverse range of fauna and flora, to ensure sufficiently abundant food resources for animals and to limit mortality factors, for example from pesticides and machinery use. Voluntary agri-environment payment schemes for farmers are the prime measure used to protect biodiversity within the CAP and within the EU budget as a whole. These measures are helpful but need to be targeted more precisely to the type of species groups they are intended to benefit and to the nature of the landscapes of the regions where they are in place. The new round of agri-environment policies that will be in place until 2020 should be more focussed in this way as well as supporting more sustainable systems, including organic farming, and HNV systems.

Stepping up the intensity of effort to serve biodiversity in the wider countryside implies larger scale measures on farmland as well as more focused measures. One study in Germany for example, estimated that active management for biodiversity would be needed over at least 15 per cent of the agricultural area. This would include restoring and maintaining semi-natural landscapes, extensifying 10 per cent of intensive grassland and devoting 7 per cent of arable and grassland to more natural features. In the Netherlands another recent study

suggested that active biodiversity management practices were required on at least 20 per cent of the agricultural area.

Soils, pest control and pollination - why farmland biodiversity loss matters

Addressing biodiversity concerns is not purely an altruistic endeavour for farmers. There are also links to the maintenance of longer term productivity on farmland. Healthy soils have both a key agronomic role and a very high level of biodiversity, most of it found among single celled organisms such as bacteria. This soil life provides critical support to farming; among other things these organisms decompose plant residues, help to supply nutrients to crops and regulate soil pests and diseases. However, soil biodiversity appears to be under pressure across the EU, largely because of the loss of organic matter in soils across most of Europe's arable land.

Above the ground, a large number of vertebrate and invertebrate species which are the natural enemies of farm pests, diseases and weeds and help to keep them in check have been affected, adversely by insecticide use and loss of habitat and food supplies, including nectar and pollen from flowers. The case of bees is one important dimension of this phenomenon, but it is not the only one.

Box 5 Threats to bees and pollinators

Pollinators – domestic honey bees, wild bees and many other insect species bring about the fruit set and reproduction of numerous crops and wildlife plants. They are estimated to play a significant part in growing 35 per cent of Europe's total food production, by weight. The value of this food is estimated at Euros €15 billion per year.

Bees, both domestic and wild species, appear to have been in decline for several decades across large parts of the globe, including many European countries. This threatens both food production and the wild plants which they pollinate. No single, simple cause has been found, and there are regional variations. Multiple factors are involved including pests and pathogens (in particular a virus-carrying parasitic mite, *Varroa destructor*), pesticide use (particularly neonicotinoids) and problems with bees' floral food quantity, quality and diversity, linked to the intensification of grassland and arable farming. For domestic bees, poor beekeeping practice and a lack of genetic diversity also may be involved in the decline. Interactions between different factors may be important. Populations of other wild pollinators are also in decline with similar factors likely to be involved.

A suite of actions is required to address the multiple factors causing losses of European honeybees, and wild pollinator populations. Because the interactive effects can cause greater impacts than each factor in isolation, an integrated response by public authorities, beekeepers, farmers, the pharmaceutical industry and researchers is needed.

This should 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 more abundant flower resources for pollinators in agricultural landscapes.

Recommendations priority options

There are inherent tensions in attempting to increase farm output whilst adapting farming to climate change, reducing its greenhouse gas emissions and conserving biodiversity on and around farms.

Despite the challenges, there is scope for the maintenance of more sustainable production and probably increases over time. Future options and priorities can be considered under four headings.

1. Providing incentives for climate resilient and biodiversity-friendly farmland management

Farmers should be supported, via Pillar 1 of the CAP and the Rural Development Programmes now under development, to use water, soil and energy resources more efficiently and to scale up climate mitigation and adaptation efforts. Many efficiency improvements will yield economic benefits over time and don't need subsidy. However, a significant group of farmers will need help with start-up costs and initial investments. Well designed and adequately funded agri-environment measures are required to reduce greenhouse gas emissions and better adapt farming for climate change, ranging from selectively lowered livestock densities to maintaining unfarmed, flower-rich buffer strips on arable land. Some of the measures required can only be effective if applied to several farms in a locality rather than individual holdings, for example, the restoration of flood plains.

A combination of measures is required to conserve Europe's remaining areas of high nature value (HNV) farming. This should comprise both direct support for selected systems which maintain semi-natural habitats and their characteristic species and also indirect measures which give HNV farmers a viable living, such as help for processing and marketing some of their products.

However, there is also the need for policy and public funding to support habitat recreation in which limited areas are entirely removed from intensive farming, for example rewetting peatlands and pursuing ecological priorities on some intensive arable land and grasslands, in both smaller and larger blocks. The "Ecological Focus Areas" introduced in the new CAP should be utilised by Member States for such purposes.

2. Developing measures which constrain unsustainable farming practices

These would include:

- Ensuring compliance with the Nitrates Directive and other EU legislation that reduces the excessive use of nutrients and improves their management.
- Implementing ambitious pesticide reduction targets of the kind that several Member States have adopted and pursuing full implementation of integrated pest management in line with EU legislation.
- Utilising CAP cross-compliance requirements further, to ensure protection and management of elements of the farmed landscape that benefit biodiversity and climate change adaptation. This baseline of minimum environmental standards needs to be raised.

3. *Ensuring that innovation, research and development aimed at increasing Europe's agricultural productivity takes account of biodiversity conservation and climate change adaptation*

- Integrated approaches are needed. Thus research on increasing yields should also not exclude more extensive farming systems and their role in biodiversity, and less familiar approaches such as good management of rewetted peatlands.
- More intensive research and evaluation of the impacts of new farming technologies on biodiversity, climate change adaptation and mitigation will be necessary.
- Increased research funding is needed urgently to tackle the multiple factors causing honeybee losses and wild pollinator decline.

4. *Reducing the impacts of European agriculture and biofuel imports outside Europe*

Action here would include EU support for intergovernmental initiatives to develop global environmental principles and agreements for food, fibre and energy production. The EU can initiate its own measures also – for example sustainability standards for solid bioenergy and for biofuels and initiatives to increase the sustainability of livestock feed production inside and outside Europe.

6. FOOD WASTE AND DIETS

Major reductions in food waste could play an important role in enabling the EU to contribute more to feeding a world with an expanding population. A large fraction of both the crops that are grown and the food that is consumed in the EU-27 goes to waste. If these overlapping wastages could be curbed significantly, the need to grow more food in Europe and elsewhere – with all of the attendant sustainability challenges – would be reduced correspondingly.

As well as the inefficiency involved, disposal of food waste also causes some direct environmental damage. More than a third of municipal solid waste is still landfilled in the EU countries; food waste is a large fraction of this waste and it rots anaerobically in landfills to produce methane, a powerful greenhouse gas contributing to climate change. There is considerably more indirect environmental damage associated with growing, processing and distributing all of the food which ends up being wasted. It is also responsible for consuming large quantities of natural resources, some of them overstretched, within Europe and beyond.

There have been several national studies of food waste in 27 EU Member States and a small number of pan-European studies, but estimates of how much food is wasted in Europe need improving. The supply chains taking food from farm to fork in industrialised nations are long and complex and the proportion of wastage varies considerably between food types and nations. Food waste in Southern and Eastern Europe has generally been studied far less. Furthermore, experts have used different definitions of what constitutes food waste and measured wastage and loss in different ways along these chains, making comparisons between the various studies difficult.

One lesson from the research is the importance of the distinction between food loss and food waste. ‘Food loss’ refers to food that has been grown for human consumption but falls out of the supply chain for various reasons; it may, however, end up being used for food or for other purposes.. ‘Food waste’ is a subset of ‘food loss’, and it represents food which is suitable for human consumption but which is known to be discarded and never consumed.

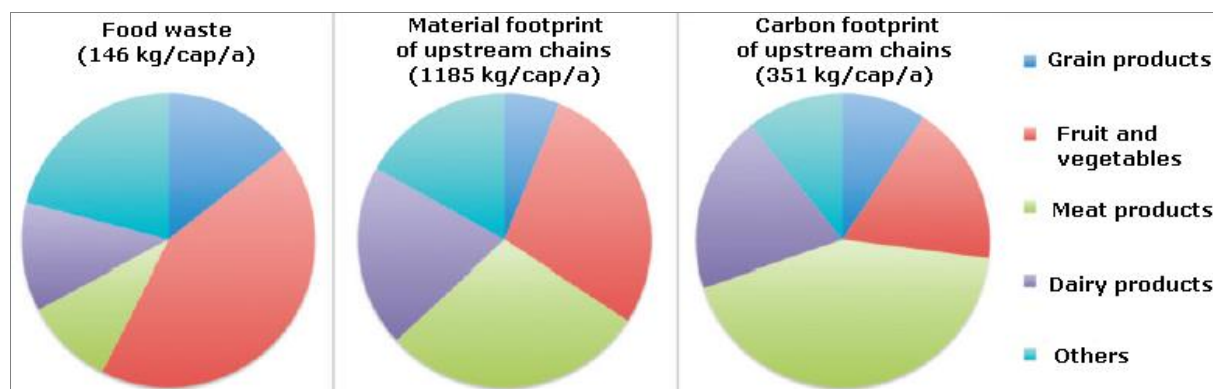
While there is a lack of detailed, comparable data across the EU-27, it is clear that very large quantities of food are lost and wasted in all the main stages of supply chains – during farming and harvesting, during post-harvest handling and storage, during processing and packaging, during distribution by wholesalers and retailers and, finally, after food arrives in people’s homes or in the hands of restaurants, fast-food outlets, hotels and canteens.

The study commissioned by STOA estimated the total amount of food waste along entire supply chains in the 27 EU countries at 138 million tonnes a year, set against a total annual production of primary foodstuffs of some 770 million tonnes a year. This means that the equivalent of roughly a sixth of EU production is wasted, amounting to about 280 kilograms per capita per annum. Estimates for individual Member States ranged from 398 kilograms per capita (the Netherlands) to 171 kg per capita (Slovakia).

One recent estimate for the UK showed that households throw away around €14 million worth of food a year. Meat and fish are associated with the highest economic losses, though they are the smallest share of food types wasted.

Food waste in Germany consists mostly of fruit and vegetable waste, followed by grain and dairy products, especially bread and milk, as shown in figure 2 below. Although meat products are wasted least, their material footprint and especially their carbon footprint is much higher than other products. Dairy products are linked to high resource consumption too.

Figure 3: Food waste in Germany and its material and carbon footprint, by product group



Source: Göbel et al. 2012, p.105

In Europe today studies show that the greatest loss is in the final, consumption stage, primarily in homes and in the hospitality sector, where around half of all waste occurs. A third is lost within agricultural production, largely at harvest time or on occasions when farmers do not harvest fully grown food crops for various reasons, such as adverse weather, poor crop condition, or very low prices. Smaller shares of losses arise during post-harvest handling and storage, processing and packaging and distribution by wholesalers and retailers. It should be noted, however, that very roughly half of the wastage in the final, consumption stage is generally considered unavoidable – consumers are bound to discard vegetable peelings, egg shells and bones.

In many respects, the complex food systems of advanced industrialised nations are highly efficient. They exploit a wide range of technologies to preserve food and have the infrastructure required to distribute it swiftly to consumers, potentially reducing waste levels. At the same time the sustained deployment by retailers of marketing tools to increase sales, for example “two for one” offers, can lead to increased wastage by consumers.

Consumer expectations for freshness and for food that looks exactly right, mediated by supermarket chains, also can lead to large quantities of food being wasted. If there is no increased consciousness of the topic, European consumers may become more wasteful of food as household size shrinks and as they become more urbanised and affluent, so there are several reasons to give this issue priority.

Ten of the many options for reducing food waste are shown in Box 6. They build on what is already being done to tackle this issue and they involve different actors, ranging from the European Commission to national government, and the food industry. Several have already proven their effectiveness in practice.

The Food Industry

The European food and drink industry is the EU's largest manufacturing sector in terms of economic turnover, people employed, and number of businesses. It has an important role to play in achieving a more sustainable food system, not least by creating more resource efficient manufacturing and distribution businesses. This involves not only reduced wastage and more sparing use of inputs, including water and energy, but also attention to food quality and optimal control of ambient conditions in which the food is stored and transported (temperature and humidity). New technologies are available for this purpose. Much can be achieved by improving food chain management and communication, including the use of modern risk-management and operational excellence tools and systems. There is a common assumption that processes in the EU are already efficiently streamlined, but the innovation leaders in the industry are showing that significant savings can be made.

The remarkable level of innovation in the food industry also could be directed more at the goals of global sustainability and the reduction of diet-related diseases. For example, new generations of plant-based meat alternatives require significantly lower resource inputs and increasingly provide high quality and more palatable protein. Consumer acceptance is still a limiting factor, but it is increasingly possible to mimic the taste and texture of meat.

Transparent and well integrated food supply chains based on responsibly sourced raw materials appear more likely to win consumer confidence as well as improving food security and sustainability. Lack of transparency breeds distrust. A fair deal for suppliers and processors in developing countries will be of increasing importance for building a robust and more equitable supply chain.

Box 6 Ten Means of Reducing Food Waste

Target setting

EU Member States are already obliged to draw up waste prevention plans by 2013 under the Waste Framework Directive. As part of these, they could set mandatory reduction targets for food waste with monitoring of wastes and losses along the entire food chain. The individual sectors, such as manufacturing and retail, should agree to voluntary reduction commitments. These steps could support a Europe wide initiative under the Roadmap for a Resource Efficient Europe.

Improving the data base

Targets cannot be set or implemented effectively without better data. An agreed definition of food waste, differentiating between avoidable and unavoidable waste, should become part of the EUROSTAT framework. Methods for collecting and calculating data on food waste should be standardised throughout the EU-27, with adequate data captured at all the main stages of food chains.

Reviewing EU legislation on food safety

The current regime of food safety related regulations covering pesticides, contaminants, packaging and storage should be reviewed in order to identify any provisions that fail to contribute to protecting lives and health while being the cause of unnecessary food waste. Further research is required to decide where current requirements, including specific standards, may be revised without running any food safety risk.

Amending European Marketing Standards

The repealing of specific EU marketing standards for some foods in 2009 has not succeeded in its objectives of reducing food waste and increasing consumer choice. Further reform should be considered, replacing standards based on the appearance of food with ones related to qualities such as taste, purity, nutritional value and growing conditions.

Streamlining food date labelling

Some consumers are confused about the differences between 'best-before' and 'use-by' dates stamped on packaging and this can lead to safe, edible food being thrown away. The regulations underpinning this labelling should continue to be reviewed with a view to abolishing some types of labels for some foods, alongside information campaigns by governments and retailers. More should be done to offer discount prices on food close to expiry dates.

Improving workflows and supply chain management

Better practice, improved technology, more sophisticated risk management and greater coordination and integration between different parts of the often lengthy supply chain all have a role to play in cutting food waste after it leaves the farm and before it reaches the consumer. Governments need to support more efficient workflows and better coordination, for example with advice programmes.

Awareness campaigns

National governments should join with retailers and the hospitality sector in running awareness campaigns tailored to different groups which make consumers less likely to waste food. For example school curricula should cover the issue more fully than at present.

Assessment of technological developments

A wide range of advanced technologies, including information technology, already play a critical role in organising food chains and these may be able to achieve more in reducing food waste. Developments such as intelligent labels on packaging, intelligent refrigerators, supermarket trolleys and waste bins, all as yet undeveloped or in their infancy, may have a role to play. Research is required to evaluate their potential contribution.

Combating food waste in the hospitality sector

There are several ways in which this sector can cut waste. For example, restaurants and canteens should do more to offer customers the varied portion sizes they actually want rather than a standard – and, for some, excessive – portion size, with suitable variations in prices.

Promotion of food redistribution programmes

Some surplus food at the end of supply chains is inevitable, and, where possible, it should be made available to those in the greatest need through charities and 'food banks'. The case for legal amendments which would protect donor NGOs distributing this food to people in poverty from legal action for unknowingly distributing unsafe food should be considered.

More Sustainable Diets

The average European diet has a large environmental footprint. In the EU, consumption of meat, dairy, eggs and fish is around twice the global average. Food from intensive animal production has much larger environmental impacts than plant-based foods, including greenhouse gas emissions, high water use, and pollution from ammonia emissions and nitrogen leaching. If the population of the EU were to reduce its meat and dairy consumption it would be possible to achieve very substantial environmental gains. However, there are many barriers to intervening in peoples' food choices, and politically acceptable policy measures to bring about change will need to be developed with sensitivity over time. It will require a consistent and long-term combination of measures, including awareness raising, increasing acceptance of economic incentives, and 'nudging' to create meaningful change.

7. MOBILISING WASTE AND RESIDUES FROM AGRICULTURE, FORESTRY AND FOOD SECTORS

Unavoidable wastes and residues are also a resource. One of the five studies commissioned by STOA analysed three streams of bio-resources: food wastes, crop residues and forest residues. Animal manure and human sewage waste, which also have potential, were not included. The materials concerned are highly heterogeneous, with varying dry matter, energy content and chemical composition. Their potential availability in Europe was assessed in terms of their energy content, which amounted to about 46 Exajoules, EJ. Their relative importance is shown in the table below.

The availability of waste and residue streams in terms of their energy content

Availability (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%

Together the three resource streams could offer a significant contribution of between four and fourteen per cent of total EU energy supplies, with a small and declining share from food waste. There are, however, several important uncertainties attached to these estimates. There is no harmonised definition of food waste in Europe, or 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 the level of extraction that might be considered feasible and acceptable, given environmental and economic restraints.

Some important obstacles to the mobilisation of materials on this scale are the following:

- The heterogeneity of the materials and lack of transparent markets.
- Their dispersion across the entire territory, on the premises of a very large number of 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 cost of collection, separation and utilisation are relatively high since these are generally relatively low-value, high bulk materials which therefore cannot be moved far without incurring cost and energy consumption penalties. The relatively close strategic location of first stage processing is therefore vital.

- There are concerns about sustainability, not least because a sufficient volume of residues needs to be returned to the soil to maintain soil organic matter and thus soil function, both on arable and forest land.
- Given the relatively high cost of collecting some of this material and of establishing a first generation of commercial scale biorefineries a strong set of policy signals is required to encourage investors. This has yet to be put in place. Current EU policy distorts the market in favour of bioenergy.

Conversion technologies – thermochemical and biochemical routes

Much of the technology for converting biomass is well understood and long established, but there are also new technologies in the pipeline. Generally, biomass material will require some physical pre-treatment, for example to separate out components, to dry, chop, and pelletise. Then, the processing will either follow a thermochemical pathway, depending on 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.

One interesting option is the use of hybrid thermochemical / biochemical approaches whereby the feedstock is gasified to form a syngas which then can be converted to chemicals using microorganisms which can ferment syngas to economically attractive 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.

The products resulting from these various processes are: heating, transport and aviation fuels, power, fermentation derived chemicals, speciality chemicals, polymers, and a wide range of intermediate chemicals. In turn these chemicals have a wide range of applications. The market for bioplastics is growing particularly fast.

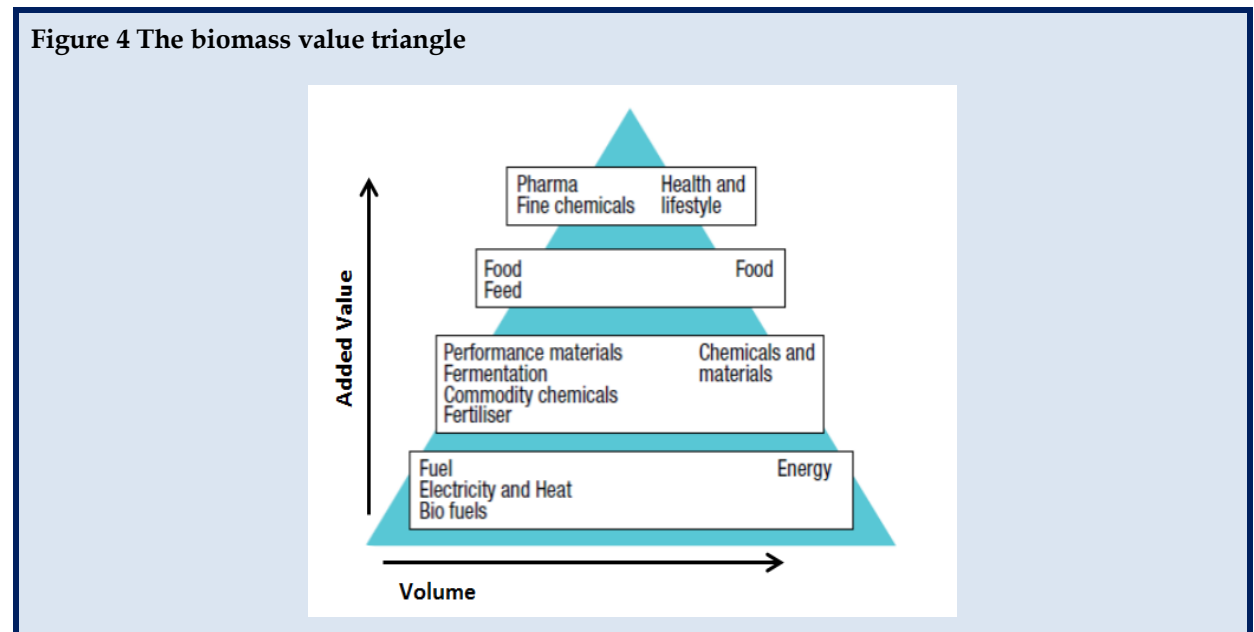
Sustainability Issues

It is important that sustainability issues are fully understood before measures to accelerate the use of wastes and residues in the bioeconomy are put in place. This is an active area of research and debate, with a fast moving and complex agenda. Five issues of significance can be identified.

- **Climate impacts** are of particular interest since much of the rationale for governments to support the use of biomaterials for energy and other applications depends on the contribution that can be made to mitigating climate change. This needs to be measured accurately through the use of well founded Lifecycle Assessments (LCAs) Several conversion pathways for biomass from wastes and residues do produce significant savings in emissions but not all do so and a clear evidence base is essential. The mitigation impact is generally better for wastes and residues than for (food) crops, especially if indirect land use change (ILUC) is taken into account.
- **Overall resource efficiency.** There is some evidence that the scale of GHG savings can be increased, in many cases by using biomass for the production of appropriate bio-based materials rather than burning them for energy recovery. In principle, the preferred approach is to combine several biomass applications in a “cascade” of different uses. This is particularly relevant in the case of forestry biomass. For example,

the first use of wood extracted from a forest would be in a durable application, such as timber in a building. Once obsolete it could be used for secondary purposes, such as panels, and only in a final stage as fuel.

In addition, the Figure below shows that using biomass for energy yields the lowest added value in overall terms as well as in relation to energy and climate impacts. Priority uses are towards pharma and fine chemicals at the peak of the triangle.



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

Research findings indicate that biomaterial use does not unambiguously and always outperform solid and gaseous biomass use for electricity and heat production. However, a meta-analysis of LCAs indicates that when biomass is used in a cascading way, an additional 10 to 20 tonnes CO₂-equivalent/hectare can be abated on average. This highlights the importance of cascading biomass use, suggesting that, where applicable, energy and non-energy uses for biomass materials should be combined over time. For these reasons a reconsideration of the imbalance in the current policy framework is needed. At present it gives significant support to bioenergy but not to other biomass-using product pathways.

- **Soil:** the main consideration for soil is that increased removal of both agricultural crop and forestry residues beyond an appropriate level can impact negatively on soil organic matter, soil structure and soil biodiversity. This is a serious concern given that many European soils are already degraded. Taking account of local conditions is crucial. Acceptable volumes of removal of cereal straw from arable fields will vary considerably, for example. 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.

- **Water:** Bio-based products derived from wastes and residues should avoid the majority of the impacts associated with the production of dedicated crops for use as feedstocks. Generally therefore they will have a lower “water footprint”. However, the increased extraction of residues from both cropland and forests should be managed in such a way as to inhibit water erosion and protect water holding capacity as a result of changes in soil structure.
- **Biodiversity:** less is known about the impacts on biodiversity of the removal of agricultural and forestry residues on a larger scale in Europe. However, inappropriate practices could be damaging to both surface habitats and to soil fauna and flora. The consequences of removal of agricultural residue extraction on soil faunal, floral and fungal assemblages are closely related to the impacts on soil organic matter. More research and appropriate guidelines and standards will be needed to accompany any significant scaling up of residue and waste utilisation.

Ways Forward

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 to justify further collective action to stimulate the development of this sector. However, there are also considerable uncertainties for investors and suppliers, so a key priority 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 well-grounded and visible assurance that the bio-products are indeed environmentally preferable with respect to GHG emissions or other defined environmental variables compared with their fossil-based counterparts. Nor should they entail significant impacts on water, soil and biodiversity. This requires strong sustainability safeguards. Policy actions can be considered under three headings.

To mobilise waste and residue feedstocks key options are to:

- Make best use of available support and advice measures available for land managers (eg under the 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 the siting of new bioenergy or biorefinery plants.

To move from demonstration to commercialisation of those bio-refineries using wastes and residues. Key options are to:

- Provide financing to setup selective large scale demonstrations 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;
- Establish a more supportive policy framework by actions to:
 - scale back support for conventional food crop based 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 to 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.

Clear sustainability safeguards should be seen as reducing uncertainty about necessary environmental performance and so ultimately beneficial for attracting investment.

8. CONCLUSIONS

The five studies synthesised here 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. Together they identified some of the key challenges that will confront Europe as it plays a part in a more robust global agri-food system. This role is not to increase production to fill a food deficit in poorer countries but to establish a strong and sustainable resource base with greater capacity both to produce and to conserve natural resources.

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

- How high yields can be maintained sustainably and even increased, making full use of knowledge intensive land management;
- 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 to make significant in-roads into reducing waste and harmful over-consumption, and developing healthy diets, including the moderation of consumption of livestock products.
- How to reduce Europe's global footprint in the realm of food supply, adjusting the balance of domestic output according to a sustainability logic as well as changes in the market.
- How to align energy policy and the role of bioenergy in particular with the demands of agricultural production and sustainable land use, utilising wastes and residues as a first choice.

The report brings together a sizeable number of options and recommendations which could be taken up by the European institutions and a range of other actors in the public and private sectors. They show that progress can be made on this ambitious agenda and there is a part to be played by farmers, consumers, nutritionists, food processors and retailers, energy suppliers, and waste managers as well as policy makers. Public policy in Europe has a larger role in steering agriculture and the food system than in many other parts of the world and this produces an opportunity for the EU to take a lead if it wishes.

For climate change the European Union is making use of a road map to guide the evolution of policy towards the level of decarbonisation required by 2050. In the sphere of agriculture and food supply the goals and targets are less precise, but there is a role for of longer term scenario building and forward looking policy frames. This would help to guide the many individual policies that will make up the next generation of agri-food measures. They include the actions required to implement the current "greener" CAP and its successor which will follow in 2021. Decisions taken here will send a strong signal as to the direction of travel that the EU has chosen to take.

In the shorter term the European Union can build on an evolving set of common environmental and agricultural policies. The Common Agricultural Policy was recently reformed with the intention of putting greater emphasis on both the environment and innovation. This provides some Member States with the vision to do so an opportunity to initiate a change in direction over the next seven years while funding within the CAP is still substantial.