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How much bioenergy can Europe produce without harming the environment?

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- Forestry, by Marcus Lindner, Jeannette Meyer, Thies Eggers, Alexander Moiseyev (European Forest Institute, partner of the EEA's European Topic Centre on Biodiversity);
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Executive summary

Increasing the use of renewable energies offers significant opportunities for Europe to reduce greenhouse gas emissions and secure its energy supply. However, the substantial rise in the use of biomass from agriculture, forestry and waste for producing energy might put additional pressure on farmland and forest biodiversity as well as on soil and water resources. It may also counteract other current and potential future environmental policies and objectives, such as waste minimisation or environmentally-oriented farming.

The purpose of this report is to assess how much biomass could technically be available for energy production without increasing pressures on the environment. As such, it develops a number of environmental criteria for bioenergy production, which are then used as assumptions for modelling the primary potential. These criteria were developed on a European scale. Complementary assessments at more regional and local scale are recommended as a follow-up of this work. Further analysis is also needed to take into account the impacts of climate change on the availability of bioenergy, which was beyond the scope of this study.

The scenarios used for each of the sectors (agriculture, forestry and waste) use a common set of general assumptions and projections from the EEA report *European Environment Outlook*. These include a further liberalisation of agricultural markets. It was also assumed that the EU would reach future greenhouse gas emission reductions of 40 % below 1990 levels in 2030, resulting in an increasing carbon permit price. Furthermore, the scenario storylines have additional implications, such as an increase in wood demand. The present study supplements these projections in order to take into account environmental assumptions (see box).

The study concludes that significant amounts of biomass can technically be available to support ambitious renewable energy targets, even if strict environmental constraints are applied. The *environmentally-compatible* primary biomass potential increases from around 190 million tons of oil equivalent (MtOE) in 2010 to around 295 MtOE in 2030. This compares to a use of 69 MtOE in 2003 (of which the *environmentally-compatible part* is included in the 295 MtOE). The potential is sufficient to reach the European renewable energy target in 2010, which requires an estimated 150 MtOE of biomass use. It also allows ambitious future renewable energy targets beyond 2010. The bioenergy potential in 2030 represents around 15–16 % of the projected primary energy requirements of the EU-25 in 2030, and 17 % of the current energy consumption, compared to a 4 % share of bioenergy in 2003.

This study does not analyse the amount of greenhouse gas emissions that can be avoided through the exploitation of the *environmentally-compatible* potential. This strongly depends on the way in which biomass is converted into heat,

Environmental assumptions used in this study:

- At least 30 % of the agricultural land is dedicated to 'environmentally-oriented farming' in 2030 in every Member State (except for Belgium, Luxembourg, Malta, the Netherlands, where 20 % was assumed).
- Extensively cultivated agricultural areas are maintained: grassland, olive groves and dehesas are not transformed into arable land.
- Approximately 3 % of the intensively cultivated agricultural land is set aside for establishing ecological compensation areas by 2030.
- Bioenergy crops with low environmental pressures are used.
- Current protected forest areas are maintained; residue removal or complementary fellings are excluded in these areas.
- The forest residue removal rate is adapted to local site suitability. Foliage and roots are not removed at all.
- Complementary fellings are restricted by an increased share of protected forest areas and deadwood.
- Ambitious waste minimisation strategies are applied.

electricity, and transport fuels and which fossil fuels are replaced. Nevertheless, a rough estimate indicates that the use of the entire potential calculated in this study saves direct greenhouse emissions in the range of 400 to more than 600 Mt CO_2 in 2030 (part of this are already realised by today's bioenergy use). The avoided life-cycle emissions will be lower as some emissions occur during the production of biomass through e.g. the production of fertilizers. A detailed analysis of the avoided greenhouse gas emissions would be useful in completing the environmental assessment of different bioenergy production options.

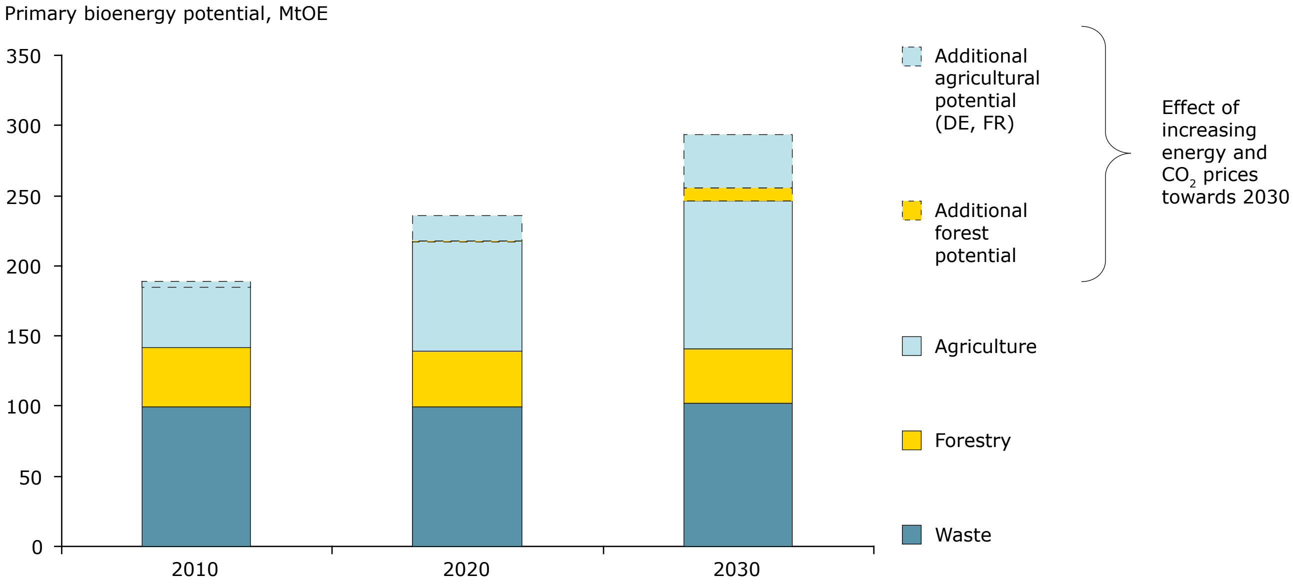
The main factors driving the increase in bioenergy potential are productivity increases and the assumed liberalisation of the agricultural sector, which results in additional area available for dedicated bioenergy farming. Furthermore, with an increase in carbon prices together with high fossil fuel prices, bioenergy feedstock becomes competitive over time compared with traditional wood industries or food crops.

Nevertheless, this study made some value judgments which limit the available potential, including the assumption that bioenergy crops should not be grown at the expense of food crops for domestic food supply. Many of the strict environmental assumptions also act to reduce the available potential. Overall, the outcome of this study can therefore be seen as a **conservative estimate** of the technically available *environmentally-compatible* bioenergy potential in Europe.

However, unless the correct incentives and safeguards are in place to mobilise the potential in an environmentally-friendly way, even a significantly lower exploitation of the biomass resource than projected could lead to increased environmental pressures.

To ensure that bioenergy production develops in an *environmentally-compatible* way and to further explore co-benefits with nature conservation, environmental guidelines need to become an integral part of planning processes at the local, national and European level. The national Biomass Action Plans (as proposed in the recent EU Biomass Action Plan) could be a first step in this direction. Furthermore, wider involvement of European society in stakeholder participation processes (i.e. from policy makers, local governments, to businesses, researchers, NGOs and consumers)

Figure 1 ***Environmentally-compatible* primary bioenergy potential in the EU**



Note: The agricultural potential comprises dedicated bioenergy crops plus cuttings from grassland and was calculated for EU-25 without Cyprus, Luxembourg and Malta. Agricultural residues, such as straw and manures, are included in the category 'waste' (covering all EU-25 Member States). The forestry potential was calculated for EU-25 except Cyprus, Greece, Luxembourg and Malta. It consists of residues from fellings and complementary fellings. The additional forestry potential takes into account the reductions in the black liquor potential as a result of wood redirected from pulp and paper to energy production. It strongly depends on the assumed carbon permit and oil price. The additional agricultural potential due to higher prices paid for bioenergy was modeled only for Germany (DE), France (FR).

could help to enable bioenergy production to fulfil its 'green potential'. An appropriate policy framework, combined with advice and guidance to bioenergy planners, farmers and forest owners on environmental considerations, needs to be in place to steer bioenergy production in the right direction.

In the short-term, the largest potential for bioenergy comes from the waste sector with around 100 MtOE. This remains more or less constant over the time horizon (96 MtOE in 2030) due to environmental considerations, in particular the assumed reduction of household waste generation and the reduction in the black liquor potential. In 2030, the impact of these environmental considerations reduces the biowaste resource by about 18 % compared to a business-as-usual scenario.

The main biowaste streams contributing to this potential are solid agricultural residues (e.g. straw), wet manures, wood processing residues, the biodegradable part of municipal solid waste and black liquor from the pulp and paper industry. At country level, Germany and France have by far the largest potential for bioenergy from waste. Their combined potential level accounts for about one-third of the EU-25 total. Other countries with large populations and land area also have significant resources (such as the United Kingdom, Italy, Poland). Sweden and Finland possess significant resources due to the availability of black liquor from the pulp and paper industry. This potential might, however, decline over time, as a result of a decrease in pulp and paper production. This might happen if more wood is directed from pulp and paper to energy production as a result of higher energy and carbon permit prices.

In the long-term, bioenergy crops from agriculture provide the largest potential. This development will be driven by: additional productivity increases; further liberalisation of agricultural markets; and the introduction of high-yield bioenergy crops. The *environmentally-compatible* bioenergy potential from agriculture can reach up to 142 MtOE by 2030, compared to 47 MtOE in 2010. About 85 % of the potential is to be found in only seven Member States (Spain, France, Germany, Italy, the United Kingdom, Lithuania and Poland). This potential is contingent upon assumptions regarding the farmland area available for bioenergy crop production and the yield of the assumed bioenergy crops.

The area assumed to be available for bioenergy production comprises the areas that are released from food and fodder production (as a consequence of a further reform of the common agricultural policy and productivity increases) and set-aside areas. In addition, as the energy value of bioenergy crops is assumed to reach or exceed food commodity prices towards 2030, some land area that is projected to be used for producing export surplus might become available for bioenergy production (1).

In order to prevent increased environmental pressure from the agricultural sector due to more intensive farming, this study assumed that there will be a high share of environmentally-oriented farming with lower crop yields. While increasing bioenergy production might provide incentives to transform extensively used grassland into arable land, ploughing up these permanent grasslands would lead to a loss of their high biodiversity value and a release of soil carbon. Thus, the almost 6 million ha of released permanent grassland (as well as parts of the olive grove and 'dehesa' area) were assumed to be excluded from dedicated bioenergy production in 2030. Overall, the available *environmentally-compatible* arable land area will rise by 50 % over the time period to reach 19 million ha in 2030.

Crops dedicated to bioenergy production differ from conventional food and fodder crops as they are optimised for their energy content rather than for food production. Innovative bioenergy crops (such as perennials) and cropping systems (such as double cropping) can thus in some cases add to crop diversity and combine a high yield with lower environmental pressures, when compared to intensive food farming systems. They are assumed to be introduced rapidly only after 2010 in this study in order to allow for a 'transition period' from conventional farming systems. As the energy yield from these crops is usually above that of conventional bioenergy crops, they contribute to the rising agricultural bioenergy potential beyond 2010. In addition, such a trend also benefits the environment, as perennial bioenergy crops and short rotation forestry generally have less impact on: soil erosion and compaction, nutrient inputs into ground

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(1) This was analysed for Germany and France, only. Nevertheless, it can be assumed that much of the competition effect for the EU-25 is included by focusing on these two countries, as Germany and France are Member States which are projected combine a very high export surplus for cereals with a large agricultural land area. Competition between the production of bioenergy and food for domestic use was disregarded.

and surface water, pesticide pollution, and water abstraction.

The *environmentally-compatible* bioenergy potential from forestry is estimated to be almost constant at around 40 MtOE throughout the period analysed. **An additional potential of more than 16 MtOE is released from competing industries by 2030** as a result of increasing energy and CO_2 permit prices. These will increase the market value of energy wood over time. At the same time, this effect reduces the black liquor potential by 6 MtOE due to reduced production of pulp and paper.

Without increasing prices paid for bioenergy, the forestry bioenergy potential is determined by the demand for stem wood. With stem wood demand projected to increase over time, the amount of residues will rise. At the same time, complementary fellings will fall due to the increase in the harvest needed to satisfy stem wood demand. Countries with the highest potential for bioenergy from forestry residues include Sweden and Finland, due to the high proportion of forest area. The potential in these countries increases even further if ash recycling is assumed. A high potential for increased fellings was found for central Europe, Italy, Spain, France and the United Kingdom.

These figures take into account the important environmental functions of forest residues and deadwood, and therefore lie around 40 % below the unconstrained maximum potential. If the effects of fertilisation through ash recycling and nitrogen deposition are taken into account, the potential rises by around 3 MtOE.

While environmental considerations in most cases restrict the technically available amount of biomass from waste, agriculture and forestry, there can also be co-benefits between biomass production and nature conservation. This study indicates that an increasing demand for bioenergy may create new uses for currently uneconomic outputs of extensive agriculture or forest residues. For example, using grass cuttings could support the management of species-rich grasslands, which otherwise would be at the risk of being abandoned. Also, forest management and the removal of residues could contribute to reducing fire risk, especially in forests that are currently unmanaged. This is particularly important for southern Europe. New bioenergy cropping systems and perennials might also add diversity and require less pesticide or fertiliser input than in current intensive agricultural systems. The introduction of a wider range of crops and new technologies which use cellulose from grass biomass or other feedstock can further promote crop diversification.

1 Introduction

The exploitation of renewable energy sources can help the European Union meet many of its environmental and energy policy goals, including its obligation to reduce greenhouse gases under the Kyoto Protocol (EC, 2002a), and bring down energy import dependency (EC, 2000, 2005a). The European Union has thus set ambitious 2010 indicative targets for the share of renewable energy in both total energy (EC, 1997) and electricity consumption (EC, 2001). Moreover, discussions on targets beyond 2010 have already commenced. In addition, there is a specific target for increasing the share of biofuels in transport (EC, 2003a).

Currently, around 4 % (69 MtOE) of the EU's total primary energy consumption is met from biomass. This makes biomass by far the most important renewable energy source, providing two thirds of the total energy produced from renewables (2). Nevertheless, compared to other renewable energy sources, such as wind and solar power, biomass production has increased at a much slower rate. Achieving the EU's target of a 12 % share of renewable energies in total energy consumption by 2010 will require a substantial rise in the use of biomass (EC, 2004).

Biomass includes a wide range of products and by-products from forestry and agriculture as well as municipal and industrial waste streams. It thus includes: trees, arable crops, algae and other plants, agricultural and forest residues, effluents, sewage sludge, manure, industrial by-products and the organic fraction of municipal solid waste. After a conversion process, the biomass can be used as a fuel to provide heat, electricity or as transport fuel, depending on the conversion technology and the type of primary biomass (EC, 2005c).

In December 2005, the European Commission published a Biomass Action Plan (EC, 2005b), followed by a communication on an EU Strategy for Biofuels (EC, 2006). The Biomass Action Plan aims to increase biomass use to 150 MtOE (in primary energy terms (3)) in 2010 or soon after. This level is consistent with the various targets for renewable energy and would lead to a reduction in greenhouse gas emissions of around 210 million tonnes CO_{2eq} per year. The plan also sets out a coordinated programme for Community action. These measures include improving the supply and increase in the demand for biomass; overcoming technical barriers; and developing research.

In the longer term, a target of about a 20 % share of renewables in total energy consumption in 2020 (4) could require about 230–250 MtOE from primary biomass potential. This number would depend on: assumptions about the growth of total energy consumption; increases in other renewable energy sources; and the end-use of the biomass (EEA, 2005a; Ragwitz *et al.*, 2005).

Using biomass has many advantages over conventional energy sources, as well as over other renewable energies, e.g. often relatively low costs, promotion of regional economic structures and additional income for farmers. The Biomass Action Plan estimates that an increase of biomass use to around 150 MtOE in 2010 could lead to direct employment for up to 250 000–300 000 people, mostly in rural areas (EC, 2005b).

However, agricultural land use in the EU is already intensive in most regions and increased production of biomass could cause additional pressures on agricultural and forestry biodiversity, and on soil and water resources. The purpose of this report is to contribute to the debate on the potential for bioenergy in Europe by providing a comprehensive

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(2) This has been calculated based on Eurostat data. If an alternative approach to calculate the contribution of different energy sources (the 'substitution approach') was used, biomass and wastes would account for 44 % instead of 66 % of all renewable energy in the EU-25 in 2003 (EC, 2005b).

(3) It has to be noted that the 150 MtOE indicated in the Biomass Action Plan comprise the energy content of solid, liquid, and gaseous biofuels. This study accounts for the primary bioenergy potential of solid and gaseous fuels, and assumes that liquid fuels will still have to be converted from bioenergy crops, which is associated with process losses.

(4) On 23 September 2005, the European Parliament called for a binding 20 % target for the share of renewables in total energy consumption by 2020 (EP, 2005). It also noted that a share of 25 % could be provided by renewables in a more integrated approach that simultaneously focused on improving energy efficiency. Recently, the European Council called for an Energy Policy in Europe which looks into longer term targets for the share of renewables in total energy consumption of e.g. 15 % by 2015 (Council, 2006).

picture of an *environmentally-compatible* potential. It develops a number of environmental assumptions, which are used to model the potential for exploiting biomass in an *environmentally-compatible* way. As this assessment focuses on a consistent approach for the whole of Europe, it has not been possible to take account of local circumstances, pressures and possible solutions. Thus, the assumptions and the approach used in this study should be the object of further debate and for complementary assessments on a more regional and local scale.

The added value of this study is that it develops a number of environmental assumptions for bioenergy production, and, on the basis of this, models the available bioenergy potential in a consistent way for the sectors agriculture, forestry and waste. As such, the results not only indicate the environmental aspects that should be looked at when increasing bioenergy production, they also give an indication of how much bioenergy will be available without harming the environment and without counteracting current and potential future EU environmental policies and objectives.

The report does not consider the policies and measures necessary for this potential to be realised. Given the assumptions made, it needs to be pointed out that a substantial use of biomass below this potential is not necessarily *environmentally-compatible*. Unless the correct incentives and safeguards are in place, even a significantly lower exploitation of the biomass resource could lead to increased environmental pressures.

The report is structured as follows: General assumptions on socio-economic developments and the energy sector are presented in Chapter 2. Chapter 3, 4 and 5 describe the environmental criteria, the analytical approach and the *environmentally-compatible* bioenergy potential for agriculture, forestry and waste respectively. These results are then brought together in Chapter 6 in order to show how much bioenergy Europe can produce without harming the environment.

A more detailed description of the approach, the models and the results by Member States will be made available in two technical reports focusing on the forestry and the agricultural *environmentally-compatible* bioenergy potential.

2 Overall assumptions

Many different forms and flows of biomass can be used as a source of bioenergy. These include waste from existing activities, such as the biodegradable fractions of household waste or residues from agriculture and forestry, as well as the dedicated cultivation of different types of crops. The potential for bioenergy in the EU therefore strongly depends on developments in various sectors. Developments in wood demand, agricultural markets and in waste production will all influence the potential bioenergy resource, while at the same time trends in energy and CO_2 prices will influence the future demand for bioenergy.

The *environmentally-compatible* potential of bioenergy is the quantity of primary biomass that is technically available for energy generation based on the assumption that no additional pressures on biodiversity, soil and water resources are exerted compared to a development without increased bioenergy production. Furthermore, the *environmentally-compatible* potential should be in line with other current and potential future environmental policies and objectives.

These future developments are uncertain, as is their likely impact on the environment. This study chooses a scenario approach that uses a common set of general assumptions built on the EEA's work on environmental outlooks (EEA, 2005d), which were supplemented to take into account environmental assumptions. The environmental assumptions were designed to prevent increased bioenergy production counteracting current or future environmental policies. Furthermore, the increased use of bioenergy should not place any additional pressures on soil and water resources or biodiversity.

The results of this study indicate the overall *environmentally-compatible* potential for bioenergy. This is the amount of primary biomass available for bioenergy production under the given assumptions from a technical point of view. It does not include the costs of or the logistics needed for the collection of the biomass. These issues go beyond the scope of this study. The current use of bioenergy is included in the potential calculated to the extent that it is *environmentally-compatible*.

The scenario assumptions can be divided into an overall storyline describing socio-economic developments and a set of environmental criteria. The overall scenario assumptions are consistent with the EEA outlook work (EEA, 2005d) that was used to underpin the report on *The European Environment — State and Outlook 2005* (EEA, 2005b). In these scenarios, the EU economy is assumed to be characterised by further dematerialisation with stronger growth occurring in high value added industrial sectors and services. The following central macro-economic and demographic assumptions were used in the agriculture and waste sectors, while similar assumptions were used for the forestry sector (5):

- The population of the EU-25 is expected to almost stabilise between 2000 and 2030, but the number of households will increase significantly.
- The gross domestic product is expected to grow at an average annual rate of 2.4 % between 2000 and 2030. These assumptions are slightly optimistic, and entail challenging trade-offs in light of achieving sustainable economic development.

As this study adapts a scenario in which high emphasis is put on environmental protection, it assumes that future climate change policies will be in place to reduce emissions in the long term beyond that required by the Kyoto Protocol. In particular, it is assumed that the EU would reach a reduction of 40 % below the 1990 level by 2030, as developed in the EEA Environmental Outlooks. Around half of the emission reductions would be achieved by domestic action, leading to a growing permit price for CO_2, e.g. 30 EUR/t in 2020 and 65 EUR/t in 2030 (6). In addition, the introduction of green certificates would stimulate the growth of renewable energies ('LCEP-renewables expanded scenario'; EEA, 2005a).

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(5) The EEA outlook report does not include projection on stem wood demand. These were thus taken from other sources (see Chapter 4), which compare well to the EEA assumptions.

(6) The concept of a carbon permit price is used as a tool to incorporate an additional relative value of bioenergy compared to fossil fuels. This can also be met by other instruments than tradable carbon permits.

This study assumes a relatively moderate development of fossil fuel prices with an assumed oil price of 35 EUR per barrel in 2030 (see Annex 1). However, if the carbon permit price of 65 EUR/t CO_2 in 2030 is included, oil would cost EUR 62 per barrel in 2030. As the fossil fuel price assumptions do not reflect recent price increases, the expected effects of an oil price of EUR 50 per barrel in 2030 are provided as additional information in some cases. This will mostly affect the additional forest potential that can be mobilised from competing industries. The effect on the agricultural potential as calculated in this study will be lower, as maintaining current European food self-sufficiency level was set as a framework condition. Thus, competition between food and bioenergy production is assumed to be relevant only for that part of agricultural production that corresponds to projected food exports. Furthermore, many bioenergy crops are competitive already at the lower combined carbon and oil price (see Annex 3).

Specific assumptions on future developments in the sectors agriculture, forestry and waste as well as the environmental assumptions used in this study are discussed in detail in the respective chapters. These include: further reforms of the common agricultural policy that will liberalise agricultural markets; a reduced land-filling of waste; and a slight increase in forestry wood demand in accordance with the assumed demographic and macro-economic development.

The study does not analyse the avoided **greenhouse gas emissions** or air pollutant emissions of biomass used in the competing end-use sectors (electricity, heat and transport). Nevertheless, the final pathways will strongly influence the magnitude of the greenhouse gas and air pollutant emissions over the whole 'life-cycle'. Such analysis would be required to draw an overall picture of an *environmentally-optimal* bioenergy production and use chain.

Climate change is likely to have an impact on the availability of bioenergy, but was not assessed in this study. For central and northern Europe, an extension of the growing season in spring and autumn is expected, coupled with higher temperatures during the growing period (EEA, 2004). This appears to enhance the productivity for both bioenergy crops and forests in these regions. Many crops show an increase in potential areas of production and production rate in the medium term. But this may not continue beyond the 2050s. In southern Europe, an increased risk of drought could lead to productivity losses and increase the risk of forest fires (Schröter *et al.*, 2005). It should also be noted that extreme weather events can have an important impact on the supply of primary biomass to the biomass conversion plants. This could lead to economic losses in particular in cases where the plant is dependent on a limited variety of feedstock.

3 Agricultural bioenergy potential

3.1 Introduction

Agricultural land use has shaped landscape and habitat patterns in the European Union over centuries. During the past five decades, the European Union's common agricultural policy (CAP) has been one factor in intensifying agricultural production, alongside technological and socio-economic trends. The increased intensity of farming has caused significant negative impacts on the environment in Europe (e.g. EEA, 2005c; Wadsworth *et al.* 2003; Donald, 2002). These negative impacts include pollution of water by nitrates, phosphate compounds, pesticides and pathogens; habitat degradation and species loss; the over-abstraction of water for irrigation; and substantial greenhouse gas and air pollutant emissions. While reforms of the CAP after 1990 and measures taken by the sector itself have brought about some improvements, a better balance between the need for agricultural production and environmental protection has yet to be achieved.

Agricultural biomass comprises dedicated bioenergy crops. These can be 'conventional' bioenergy crops such as starch crops (e.g. cereals, sugar beets) or oil crops (e.g. rapeseed, sunflower) as well as perennial grasses or short rotation forests on agricultural land. Agricultural residues (e.g. straw, greentops, manure) are assigned to 'biowaste' (Chapter 5), except for cuttings from grassland, which are included in the agricultural bioenergy potential.

The growing demand for bioenergy crops may create further competition for land and water between existing agricultural activities, energy production and the use of agricultural land for nature conservation and urbanisation needs. This could result in additional negative environmental pressures from cultivating bioenergy crops.

The environmental impact of bioenergy production depends to a large extent on the selection of areas that are used for bioenergy production, the crops cultivated and the farming practice. Some crops (e.g. perennials) might even lower the environmental pressures of agriculture and enhance farmland biodiversity. An environmental framework will thus be needed to ensure that the increasing bioenergy production follows an *environmentally-compatible* approach.

Many plant and animal species are dependent on the continuation of extensive farm management. It has been estimated that 50 % of all species in Europe depend on agricultural habitats (EEA, 2005b, p. 185). However, such extensive forms of agriculture are often not economic and so many farmers intensify production or abandon farming altogether, which generally leads to scrub and forestry growth. Both trends threaten semi-natural grasslands and other habitats (Ostermann, 1998) which are important for a large number of threatened species that rely on them (see e.g. Bignal & McCracken, 1996 and 2000). An important agriculture policy challenge is to provide economic incentives and advice to farmers so that they continue wildlife-friendly farming practices. Producing bioenergy from the products of extensive farming systems (e.g. grass cuttings) is a possible additional revenue stream that could cover some of the costs of maintaining such biodiversity-rich areas. This indicates a possible synergy between bioenergy and nature conservation if the right conditions are created through tailored market and policy mechanisms.

The aim of this chapter is to develop and apply a number of environmental criteria to minimise environmental pressures of bioenergy crop production while exploiting synergies between bioenergy and nature conservation. On that basis, the *environmentally-compatible* bioenergy potential was calculated for each EU-25 Member State (except Cyprus, Luxembourg and Malta) in 2010, 2020, and 2030.

The amount of agricultural biomass that can be used to produce energy is primarily determined by the land area available, and by the yield of bioenergy crops cultivated on this land. The *environmentally-compatible* bioenergy potential from agriculture has been calculated using a four-step approach as follows:

1. Formulate a number of environmental criteria;
2. Model based estimation of the future land availability for bioenergy production in each EU Member State for 2010, 2020 and 2030, taking into account the environmental criteria;

3. Determine an *environmentally-compatible* bioenergy crop mix in each environmental zone (7) in the EU-25;
4. Calculate the bioenergy potential in each Member State based on the future land availability, the *environmentally-compatible* crop mix, crop yields, and the net energy content of different crops.

3.2 Environmental considerations

3.2.1 Potential environmental pressures of bioenergy production

Current agricultural practices can have both a negative and positive impact on the environment. For this reason it is important that any move towards more bioenergy production aims to support positive development, while at the same time not exacerbating existing pressures on farmland biodiversity, and water and soil resources. Potential additional pressures of bioenergy production may occur as a result of:

1. Increased demands on agricultural sector output (8), thus causing intensification of farm management across the agricultural land area;
2. Incentives to transform extensively used grassland, olive groves or dehesas, which are released from fodder production, into arable land for growing bioenergy crops;
3. An inappropriate bioenergy crop mix, which does not take account of the specific environmental pressures of different crops in the context of the main environmental problems in a particular region.

The trends listed above would have an additional negative impact with regard to the main environmental problems of agriculture in the different regions of Europe. The key linkages between agriculture and environment in Europe are described in the following sections and explain the selection of the environmental criteria used in this study to calculate the *environmentally-compatible* bioenergy potential from agriculture.

Soil erosion in Europe is a particular problem in the Mediterranean region, which is characterised by long dry periods followed by heavy bursts of rainfall falling on steep slopes with unstable soils (EEA, 2005c). However, wind erosion can be a problem in the flatter landscapes of northern and central Europe with its intensive agriculture.

Soil compaction results from the use of heavy machinery for activities such as ploughing, spreading organic manure and harvesting. Soil compaction has adverse effects on soil biodiversity and soil structure. It may also lead to problems such as water logging.

Leaching of nutrients, in particular nitrate and phosphates from agricultural land to ground and surface waters, can be a significant problem in intensive farmland areas. Measures to prevent leaching of nutrients **and pesticides** include reducing inputs of manures and fertilisers, widening crop rotations and better farm management. Currently, agriculture is responsible for about 56 % of the nitrate contamination found in surface waters in the EU-15 (EEA, 2005c, p. 64).

Agricultural **water use** is a serious concern especially in southern parts of Europe, where water availability is low and varies from year to year. Increases in irrigated land have contributed to water scarcity, with the lowering of water tables and water levels in rivers and lakes. Effects of increased water abstraction include salinisation and water contamination, loss of wetlands and the disappearance of habitats through the creation of dams and reservoirs and the drying-out of rivers. In general, there has been a significant increase in competition for water between agricultural production, urban land uses, tourism and nature conservation in drier regions of Europe over the last couple of decades. The share of agriculture in total water use stands at about 7 % and 50 % in northern and southern EU-15 countries, respectively (EEA, 2005c, p. 49).

Continuing specialisation in farming over recent decades and a simplification of cropping systems have resulted in a loss of **crop diversity**. This was also associated with a decrease in non-cropped habitats, such as grassland, field boundaries and tree lines. Consequently, landscape diversity has been reduced substantially leading to a loss of diversity in farmland habitats and associated farmland flora and fauna (EEA, 2005c).

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(7) For the concept of environmental zones with similar geo-pedo-climatic characteristics see Section 3.2.2.

(8) This study is restricted to today's utilized agricultural area (UAA), thus assuming that no other land currently not in agriculture production is transformed to UAA. This may underestimate the available area, in particular in some new Member States (see Section 3.4.3).

Farmland biodiversity is affected by a combination of all the previously identified pressures. Indirect pressures include soil erosion and compaction, nutrient and pesticide leaching to groundwater and surface water, and water abstraction. Direct pressures include the loss of habitats and farm and pest management practices. For example, as a result of the intensification of agriculture, there has been a substantial decline in the majority of farmland birds between 1980 and 2002 (EEA, 2005c, p. 81).

However, it is not only the intensification of agriculture that can have a severe impact on farmland biodiversity. Given the close link between species richness and extensive farming practices, farm abandonment can lead to a loss of high nature value (HNV) farmland and characteristic agricultural landscapes (EEA/UNEP, 2004).

An increased diversification in crop type and the introduction of structural elements can be beneficial for biodiversity, particularly in intensive agricultural systems. More diverse land cover creates a greater number of habitats for species from different taxa. Some bioenergy crops (in particular perennial grasses and short rotation forestry) can add to landscape and habitat diversity to a certain extent, as these crops have different structural characteristics than current annual crops.

Overall, the introduction of new bioenergy crops as well as well-managed harvesting of bioenergy from grassland can help sustain or even *promote* biodiversity. Nevertheless, there is a risk that a higher demand for bioenergy may actually exacerbate pressures on biodiversity. This would be the case if *intensively* farmed bioenergy crops would replace extensive farming systems, or would lead to a generally higher intensity of land use, and would introduce highly specialised cropping systems (9).

3.2.2 How to avoid increased environmental pressures?

A number of environmental criteria were applied in this study to prevent the additional pressures described above (10). The criteria are:

1a. At least 30 % of the agricultural land in most Member States is dedicated to 'environmentally-oriented farming' in 2030 (defined as HNV farmland or organic farming).
1b. 3 % of the currently intensively cultivated agricultural land is set aside for establishing ecological compensation areas in intensive farming areas.
2. Extensively cultivated agricultural areas (e.g. grassland or olive groves or 'dehesas') are maintained.
3. Bioenergy crops with low environmental pressures are used.

It should be noted that the first two criteria affect the entire utilised agricultural area (UAA), thus both food/fodder and bioenergy production. They are introduced in order to prevent increasing bioenergy production from affecting an environmentally-favourable development of the agricultural sector. The remaining criteria apply to the land which will be released from food/fodder production (with a certain overlap between criteria 1a and 2).

Changes in farming *practices* are important in determining final environmental impacts, but could only partially be considered within the scope of this study. Other environmental criteria than those listed above will be relevant in particular locations, but such local considerations (including those relating to the criteria above) could not be explored in this study.

1a. High share of environmentally-oriented farming (EOF): *Given the environmental importance of the EOF area, the study assumes that the share of EOF will be at least 30 % in all Member States in 2030 (except for Belgium, the Netherlands, Luxembourg and Malta). EOF includes both agricultural area under organic farming, and high nature value (HNV) farmland.*

Both HNV and organic farming have a high biodiversity value. Research has shown that organic farming generally provides benefits to landscape and biodiversity, for example through a greater range of wildlife habitats (Stolze *et al.*, 2000; Hole *et al.*, 2005).

High nature value farmland comprises those areas of Europe where agriculture is a major (usually the dominant) land use and where agriculture supports or is associated with a high species and

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(9) It should be noted however that the market pressure to use cost-competitive (intensive) farming approaches exists even if no bioenergy production is considered, unless specific monetary support schemes (e.g. subsidies, premium product prices) are assumed.

(10) These environmental criteria were formulated at an EEA expert meeting in March 2005 and build on previous studies (e.g. Elbersen *et al.*, 2005; Fritsche *et al.*, 2004; Feehan and Petersen, 2003; Foster, 1997; Hope *et al.*, 2003; and Reijnders, 2006).

habitat diversity and/or the presence of species of European conservation concern. Farming practices of HNV farms are more extensive and also more synchronised with natural processes and the natural fluctuations which take place within these processes from year to year (Andersen, 2003). Low yields are therefore an inherent characteristic of most HNV farming systems.

Setting a *minimum* level of 30 % for the amount of EOF in most Member States by 2030 will provide a safeguard against the loss of current extensive farmland categories, and will prevent bioenergy production counteracting a further introduction of EOF in countries where extensive farmland is currently below 30 %. A significant number of Member States, including most of the countries in the Mediterranean, but also Austria, Ireland, the United Kingdom, Estonia, Latvia, Romania, Slovakia and Slovenia are already reaching this level, or have exceeded it (see Annex 2). Therefore, it is important to preserve such extensive land use due to its contribution to farmland biodiversity (11).

1b. Minimum level of set-aside as 'ecological compensation area': *At least 3 % of intensively used farmland* (12) *is assumed to be set-aside by 2030 for nature conservation purposes. This criterion helps to re-create ecological compensation areas, which increase the survival and/or re-establishment of certain farmland species.*

A number of studies have shown that creating non-cropped habitats field margins and 'grassland pockets' in arable regions can be effective measures towards supporting bird biodiversity (Bruinderink *et al.*, 2003; Foppen *et al.*, 2000; Opdam *et al.*, 2003; Vickery *et al.*, 2004; Vos *et al.*, 2001). It is important, therefore, that such grassland pockets and other habitat elements are established in intensive farmland areas to form ecological compensation areas at a landscape scale. Without measures to exclude some land from agricultural production, it is likely that an increase in bioenergy production would act against the creation of such compensation areas, as it is likely to increase the average pressure on the entire agricultural sector (13).

2. Maintenance of extensive land use categories*: As extensive land use categories (e.g. permanent grassland; olive groves) are released from agriculture, they become potentially available for biomass production. From an environmental point of view, however, it is best not to plough them up for planting biomass crops but rather to maintain them under their original cover (although the grass cuttings and woody residues can be harvested). This criterion supports the target of a 30 % share of environmentally-oriented farming (criterion 1a) but specifies certain land use categories that need to be included in the 30 % share.*

Extensive land use categories, especially extensive semi-natural grasslands, are important habitats for a large number of species of both plants and animals (Bignal and McCracken, 2000; Ostermann, 1998; Tucker and Evans, 1997). The importance of these permanent grasslands is already clearly acknowledged in the mid-term review of the CAP, which aims to retain permanent grassland. However, only in duly justified circumstances may a Member State derogate from the obligation to maintain land under permanent pasture, and then only to the extent that the ratio between permanent pasture and total agricultural area does not decrease by more than 10 % relatively to the same ratio calculated for the reference year (EC, 2003b). At the same time, it is also clear that many of these permanent grasslands are threatened by either the intensification of agricultural activities or by abandonment (EEA/UNEP, 2004; Ostermann, 1998).

An increased demand for biomass can affect these extensive farmland areas negatively (e.g. in terms of environment and farmland biodiversity) if they are not explicitly protected (Elbersen *et al.*, 2005). This is due to possible shifts from existing food and feed production to bioenergy production, particularly to ligno-cellulosic crops on land that is sub-optimal for arable cropping (14).

In addition to the biodiversity impacts, ploughing permanent grassland would release soil carbon. This could offset the potential carbon mitigation of using biomass to replace fossil energy sources (Smith and Conan, 2004; Vellinga, *et al.*, 2005) (15) (16). Given

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(11) Today, approximately 15–25 % of the EU-15 countryside can be categorised as HNV farmland (EEA, 2005c and Annex 2).

(12) See Section 3.3.1.2 for details on the calculation of intensively used farmland.

(13) On the other hand, bioenergy production can also add to structural diversity if new energy crops are cultivated. Furthermore, an occasional harvesting of ecological compensation areas for energy purposes would not counteract their environmental objective.

(14) This may change when prices paid for bioenergy crops are above the commodity prices, see Annex 3.

(15) The joint European Commission JRC, Eucar, Concawe Well-to-Wheel study estimates that ploughing up permanent grassland could negate the greenhouse gas benefits of biofuel use for 17 to 111 years (EUCAR, Concawe, JRC, 2006).

(16) It could also release large amounts of nitrates (Crouzet, 2001).

these existing threats, it is clear that ploughing-up grassland for bioenergy production is undesirable from an environmental standpoint.

On the other hand, the ongoing abandonment and/or under-utilisation of grasslands and olive groves is also undesirable, as it will lead to a loss of open and diverse habitats. The continuation of extensive grassland management, such as grazing and cutting, is extremely important for the maintenance of its biodiversity. For farmland birds, appropriate grassland management provides more open types of vegetation, thus providing suitable habitats for them to winter and roost (Angelstamm, 1992; Söderström and Pärt, 2000).

Mechanical removal of biomass may replace both animal grazing and hay cutting on otherwise abandoned grasslands. In this way, the current habitat structure is (partly) maintained while biomass is harvested for energy production. This could thus cover at least some of the costs of maintaining these areas (17).

3. Bioenergy crops with low environmental impacts are used: *The types of bioenergy crops (both perennials and annual crops) to be cultivated should minimise: soil erosion and compaction, nutrients leaching into ground and surface water, water abstraction, pesticide pollution and fire risk. Ideally, they should also have a positive impact on farmed landscapes and biodiversity.*

Different bioenergy crops have different environmental impacts. An *environmentally-compatible* crop mix should aim to reduce the main environmental pressures of the region, in which bioenergy is produced (see Section 3.2.1).

Soil: The main farming practices that prevent soil erosion are: maintaining year round soil coverage (including both winter and autumn); no ploughing and tillage on (steeper) slopes; creating wind-brakes in the landscape by introducing different height crops; maintaining/creating wind brakes as part of field boundaries; and introducing practices that prevent organic matter loss in the soil etc. The increased cultivation of some potential bioenergy crops, in particular sugar beet, provide little protection against soil erosion. In contrast, some other bioenergy crops may help to prevent soil erosion by providing year-round soil coverage, especially in the autumn and winter period. Perennial biomass crops are particularly efficient in soil coverage especially after one or two years of growth.

Crops with high water content and thus a high harvesting weight (such as potatoes and sugar beet) are likely to contribute to soil compaction. On the other hand, some bioenergy crops such as perennials or double-cropping systems can be introduced in no or reduced-tillage systems that minimise the use of heavy machinery. The timing of crop harvesting can also be important, e.g. winter harvest of miscanthus could have significant impacts on soil erosion and compaction.

Water: Some current bioenergy crops, such as oilseed rape, require high pesticide and fertiliser use, and are therefore likely to increase pollution of ground and surface waters. However, other crops, such as certain cereals, may help to reduce the overall inputs to a cropping system if they are exchanged for crops needing higher inputs and/or their introduction leads to a wider crop rotation. If perennial biomass crops are used then these will have better overall nutrient efficiency than conventional arable crops for biomass production. However, irrespective of the type of crops grown, changes in farming practices can be the most significant factor for losses of nutrients and pesticides. However, their exact impact is hard to quantify and is outside the scope of this study.

The choice of biomass crops especially in arid areas should aim for crops with low water demand, which do not need irrigation. In this respect, some perennial biomass crops perform better than the conventional arable crops used for biomass production.

Biological and landscape diversity: Careful selection of biomass crop mixes can help to enhance crop and landscape diversity, by introducing biomass crops with different height and establishment characteristics that create more structural diversity (e.g. perennials and short rotation forestry). Greater crop diversity will be more easily achieved in regions where farming is already very specialised such as the northern and western parts of the EU.

Risk of fires is higher in dry parts of Europe with low rainfall. The effect of any fire can be

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(17) In some cases, where the originally extensive farmland has already lost its biodiversity values because of intensification, it could probably be used for planting of perennial biomass grasses as this would not create any additional pressure on farmland biodiversity or water and soil resources. However, this has not been taken into account in this study as it was not possible to make a realistic estimate of the share of the grasslands affected.

aggravated by a lack of land management (i.e. land abandonment) making the density of dry inflammable biomass high and/or making the accessibility of land to stop fires more problematic. For biomass crop establishment in areas which have high fire risks, it is important to choose crops with low fire spreading characteristics.

3.3 Approach: methodology and scenario development

The amount of bioenergy available is primarily dependent on the available land area and the yields of the cultivated bioenergy crops. These have been modelled and calculated for 2010, 2020 and 2030, taking into account the environmental criteria and assumptions surrounding the potential development of the agricultural sector towards market liberalisation.

3.3.1 Available agricultural land area

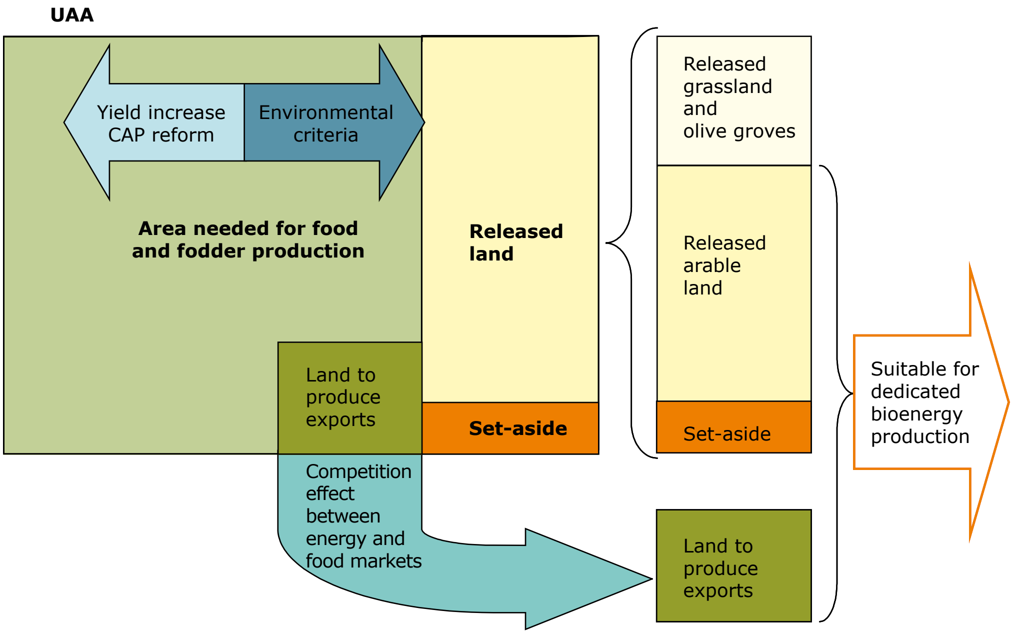
3.3.1.1 Assumptions

This study disregards the effect of competition between bioenergy and food production for domestic food supply. At current market prices, this effect would be limited, but would become more important with the assumed rise of the combined carbon permit and energy prices. Disregarding competition implies that the land available for growing bioenergy crops will be largely determined by the utilised agricultural area (UAA), including set-aside, that can be released from food and fodder production.

The released and set-aside areas were modelled under the assumption of a further reform of the common agricultural policy with total liberalisation of the animal product markets (cattle, dairy, pigs and poultry) by 2025, following the trend of past CAP reforms and international trade negotiations. This includes the abolition of the dairy quota system. In addition, further increases in crop yields were assumed to be realistic (EuroCare, 2004).

With the costs of producing agricultural products being above world-market prices in most Member States (in particular dairy and beef products), the liberalisation will lead to a decrease in production and thus a release of land. This could then be used for dedicated bioenergy production. However, the environmental criterion 1a puts some constraints on productivity growth. More land is needed to produce the same amount of food and fodder, and thus less land is available for bioenergy production. Furthermore, criterion 1b means that less arable land will be available overall. As no transformation of permanent grassland into arable land was assumed to happen (criterion 2) there will be less arable land available for dedicated bioenergy crop production than without such a criterion (see Figure 3.1).

Figure 3.1 Influence of different drivers on land availability



Note: Land that is currently used for bioenergy crop production is assumed to remain available for bioenergy production.

As mentioned before, the approach disregards competition between production of bioenergy and food for domestic use. However, competition was assumed on agricultural land that is used for export production, as it is likely that increasing fossil fuel and carbon permit prices will stimulate bioenergy further at the expense of food and feed production (18). The assumption of limiting competition to these areas would ensure that a growing bioenergy market does not negatively affect the degree of European 'food self-sufficiency'. Within the scope of this study, the analysis of the competition effect was undertaken for Germany and France only. Despite this restriction, the total EU competition effect regarding the land used to produce export products is reflected to a large degree. This is due to the fact that Germany and France are the only Member States which are projected to combine a very high export surplus for cereals with a large agricultural land area.

3.3.1.2 *Models*

The modelling of the released and set-aside land area was based on the CAPSIM model (EuroCare, 2004). CAPSIM is a partial equilibrium model designed to look at agricultural developments in the EU Member States (e.g. cropping and livestock patterns and animal products by country). The model takes account of policy developments, such as changes in the common agricultural policy. As the model results are provided for individual Member States the regional resolution of the agricultural part of this study was limited to the Member State level. The model covers the time horizon up to 2025; an extrapolation of the model results to 2030 was done as part of this study.

The CAPSIM 'Animlib' scenario was used as a starting point to determine how much land will be needed for food and fodder production and thus how much land will be released. This scenario reflects a liberalisation of animal markets in accordance with the assumption of further CAP reform.

The environmental criteria were then applied to convert the Animlib scenario into an *environmentally-compatible* scenario. The 30 % target of environmentally-oriented farming was implemented by assuming that the present share of HNV farmland remains stable until 2030, while the share of organic farming increases to meet the combined target. As the crop yields are lower for organic than for conventional farming, reduced crop yields (taken from Offermann, 2003) were applied to the share of farmland falling under this definition. While it was assumed that the future yield increases for organic faming will be the same as for conventional farming, no increases in yields are assumed for HNV farmland. This is because HNV farming practices are constrained by climatic and topographic factors.

Furthermore, a 3 % set-aside of intensive arable land as compensation area was taken into account. The intensive arable area was assumed to include only the land use categories cereals, oilseeds and other arable crops in 2010. For these categories a rough estimation was made of the part that would be grown very intensively, to which the 3 % rule was applied. This share is assumed to be reached by 2010 and after that the total amount of land for ecological compensation areas is assumed to remain constant.

The land available for bioenergy crop production was then calculated by assuming a certain conversion of (released) farmland to non-agricultural purposes such as urban areas, infrastructure, and recreation. This reduces the released land area by between 0.5 % and 2 %, depending on the Member State (19). On the other hand, land that is currently used for bioenergy crop production and a part of

Table 3.1 Estimated share of intensive farmland in arable land use category in 2010

Member State	Estimated share of intensive land use in arable farmland
Belgium, Czech Republic, Denmark, Germany, the Netherlands, Finland, Sweden and the United Kingdom	70 %
Greece, Spain, France, Austria, Portugal, Ireland and Italy	50 %
Estonia, Hungary, Lithuania, Latvia, Poland, Slovenia and Slovakia	40 %

Note: Arable includes here cereals, oilseed and other arable crops. Cyprus, Luxembourg and Malta were not analysed.

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(18) Towards 2030, the sum of the monetary 'energy value' and CO_2 certificate prices will lead in many cases to similar or higher revenues for bioenergy than for food and feed products under the given assumptions (see Annex 3).

(19) The future land requirement for non-agricultural uses has been estimated roughly at Member State level using a combination of information on passed trends, population density and Gross Domestic Product. It was estimated to be 0.5 % for Estonia, Latvia, Lithuania; 1 % for Hungary, Slovakia, Poland, Spain, Greece, Cyprus, Slovenia, Portugal, Czech Republic, Finland, Sweden, Ireland, Austria; 1.5 % for France, Denmark, Luxembourg, Italy, Malta; and 2 % for Germany, the United Kingdom, Belgium and the Netherlands.

the projected set-aside areas are assumed to remain available for bioenergy crop production.

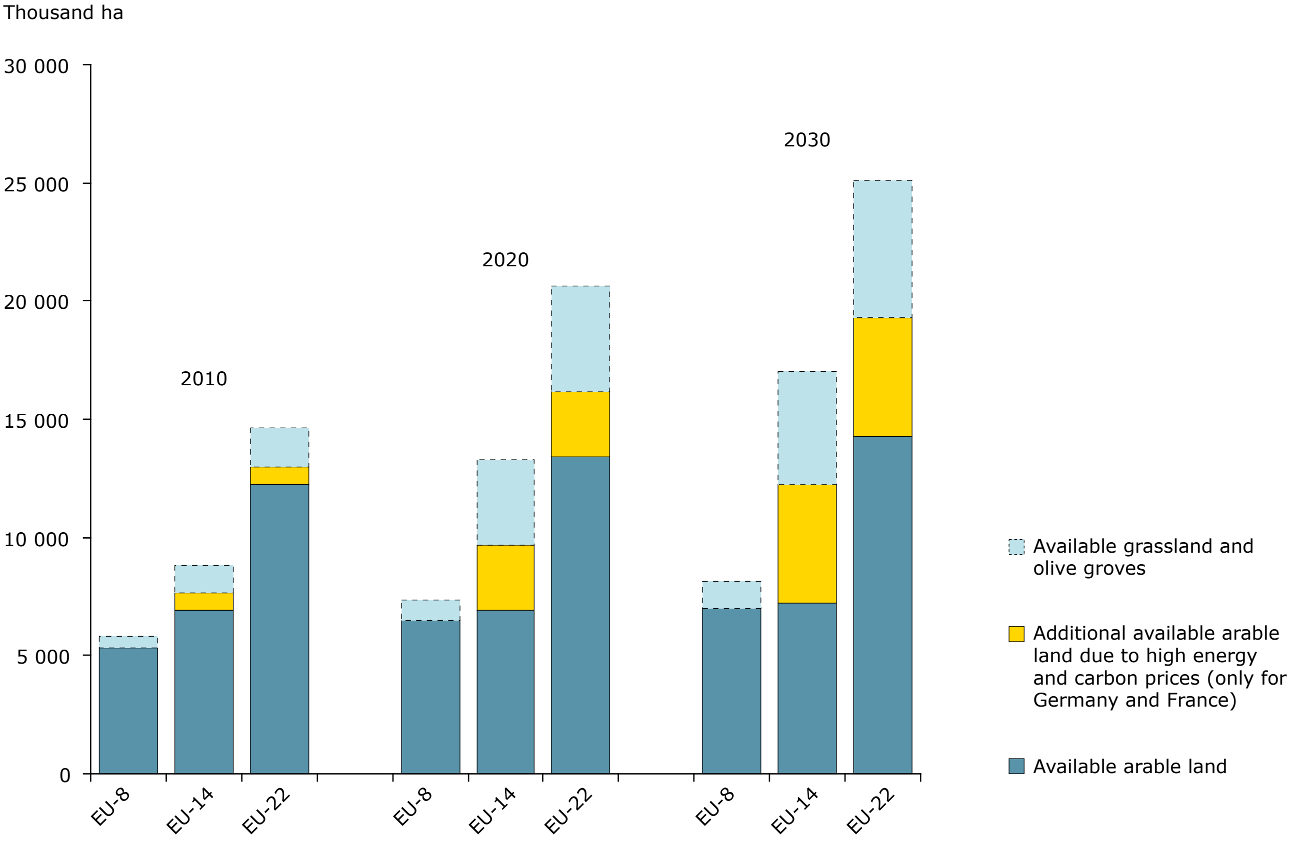
Finally, the competition effect between bioenergy and food production was taken into account in a parallel approach, based on the bottom-up HEKTOR model (Simon, 2005; Fritsche *et al.*, 2004) for Germany and France (20). This model determined the amount of land needed to produce food and fodder to fulfil domestic demands, respecting the described environmental criteria. It was therefore assumed that self-sufficiency rates of food supply in the EU-25 should be ensured while direct and indirect subsidised exports are gradually phased out. The potential land availability for bioenergy crop production is then calculated by subtracting the future land requirements for food production from the land requirements in 2000. This result was then reduced by an amount equal to an estimate of the land that would be needed to respect the environmental criteria and for urbanisation and other non-agricultural activities.

3.3.1.3 Results

The available *arable* land which can be used for dedicated bioenergy production increases from 13 million ha in 2010 to 19.3 million ha in 2030. This is equivalent to 8 % of the UAA in 2010 and 12 % in 2030. Additional land will also be released in the *grassland* and olive grove categories, rising from 1.7 million ha in 2010 to 5.9 Mio ha in 2030. In line with the environmental assumptions, this land should not be ploughed and can thus not be used for intensive bioenergy production. However, the cuttings from grassland can be used to produce bioenergy (21).

Most of the available land is due to the release of land from food and fodder production as a

Figure 3.2 Land available for biomass production for energy



Note: No data for Cyprus, Luxembourg and Malta. The additional available land due to bioenergy prices being above the food commodity prices was calculated for Germany and France with the HEKTOR model. For all other countries, the available land area was calculated with the CAPSIM model.

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(20) Within the scope of this study it was not possible to apply HEKTOR to the whole EU. Nevertheless, as France and Germany are projected to be main export countries of agricultural products in the EU, it is likely to assume that much of the competition effect was included by focusing on these two countries.

(21) The harvesting of wood from olive groves was not considered in this study.

result of the CAP reform and increases in crop productivity. However, out of the available arable area of 19.3 million ha in 2030, around 5 million ha are due to the assumed competition between energy and food production in areas used to produce export commodities in Germany and France. This is triggered by rising fossil fuel and carbon permit prices.

When looking at the individual country results, it becomes clear that the countries with the highest projected land availability do not change much over time. The main 'deliverers' of available land for bioenergy production are Poland, Spain, Italy, the United Kingdom, Lithuania and Hungary. Germany and France are expected to release substantial areas due to the competition effect of bioenergy production versus food/feed production for exports. Countries without any available agricultural area are generally those with currently intensive or very competitive farming systems. This implies that a substantial area of land will be needed to achieve a higher share of environmentally-oriented farming and ecological set-aside area. Also, countries with a high share of grassland have little available arable land, as grassland is assumed not be converted into arable land.

Overall, it is clear that the new Member States deliver a substantial share to the available land for bioenergy, especially if this is related to their share in the total EU UAA. By 2030, around 18 % of their UAA is projected to be available for energy production and 3 % as grassland, while in the EU-15, this share would be around 10 % (including the additional potential in Germany and France).

3.3.2 Environmentally-compatible crop mix

Bioenergy crops need to fulfil different requirements than conventional food crops. They are optimised for their energy content rather than for food production. The range of crops suitable for producing bioenergy thus comprises conventional annual food and fodder crops as well as perennial grasses and short rotation forestry or dedicated 'double cropping systems'.

The **crop prioritisation** by environmental zone was developed as a **tool** to provide a first indication of an *environmentally-compatible* crop mix for biomass production in most environmental zones of Europe. It was used in the context of this study as one of the factors to determine the eventual crop mix, complemented by considerations on the economic efficiency (expressed as energy yield per crop per hectare) and the present land use.

In order to use this ranking for more than its current purpose as a tool, it would have to be set in the context of the existing farming system and farming practices. Other criteria might add to the analysis, such as organic matter content (soil carbon conservation). Similarly, it should be extended to include further bioenergy crops in more details, such as new oil and starch crops or additional sorts of perennials. A complete picture might also include the life-cycle greenhouse gas balance of different crops and their use. Finally, it would have to be applied on a regional and local scale in order to provide more than a rough indication.

In this study, an *environmentally-compatible* crop mix was identified, based on an assessment of the environmental impacts of different crops in the context of the climatic and environmental characteristics of the site, and their yield. For that reason, an initial selection of bioenergy crop mixes was undertaken. This selection aimed to identify the most versatile crops that are suited to every

Table 3.2 Available arable land for dedicated bioenergy crop cultivation by Member State (1 000 ha)

	Austria	Belgium	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy	Latvia	Lithuania	Netherlands	Poland	Portugal	Slovakia	Slovenia	Spain	Sweden	United Kingdom	**EU-14**	**New Member States (EU-8)**	**EU-22**
2010	204	0	303	74	88	486	536	1 000	356	413	0	1 074	83	525	0	3 823	250	81	3	2 706	135	824	5 320	7 646	12 965
2020	266	0	314	0	154	299	1 000	2 000	298	512	0	1 786	144	882	0	4 321	169	140	16	2 582	168	1 118	6 484	9 686	16 170
2030	298	0	301	0	159	174	2 000	3 000	266	547	0	2 165	183	1 055	0	4 525	125	213	36	2 459	178	1 584	7 019	12 249	19 267

Note: No data for Cyprus, Luxemburg and Malta; land for Germany and France based on HEKTOR-calculations and rounded; other countries on the adapted CAPSIM-calculations.

environmental zone of Europe in an *environmentally-compatible* future.

Complementary to the environmental impacts of different crops, assumptions on the speed of implementation of new crops into the current farming systems (e.g. a change from annual to perennial crops) were considered. Furthermore, the availability of conversion technologies was taken into account as some of the current conversion technologies for transport technologies rely on starch and oil crops. This will change with advanced (second generation) biofuels and also if heat and electricity production technologies are considered, as they can use virtually all bioenergy crops. These factors mean that the *sustainable crop mix* per region will change over time.

As a starting point, the main environmental pressures: soil erosion, soil compaction, nutrient inputs into ground and surface water, pesticide pollution, water abstraction, increased fire risk and farmland biodiversity were analysed for each bioenergy crop. This approach is based on a qualitative analysis of the main pressures exerted on the environment by different crops, as described in existing literature. It builds on an ecological prioritisation study of energy crops for German conditions applying a Delphi expert survey (Reinhardt and Scheurlen, 2004), and was amended by literature review and expert knowledge. Table 3.3 provides an example for an assessment of environmental pressures for a perennial crop; an overview can be found in Annex 4.

The findings of this study indicate that perennial energy crops (e.g. reed canary grass or short rotation coppice) generally have lower environmental pressures than most annual plants (EEA/JRC, 2006). They can avoid erosion and need only little soil treatment, thus reducing nutrient and pesticide input. Due to expanded, deep roots, they reduce soil compaction. Depending on the crop type, they can also substantially reduce water abstraction compared to annual food crops. Some perennials are thus well suited for arid climates, but still require some irrigation. A potentially increased fire risk could be reduced if perennial grasses were harvested before the main summer heat. Furthermore, it can be assumed that most fires on agricultural land would be tackled early on due to the economic value of the crop and early detection of any fires. In general, perennial crops can also add to landscape and crop diversity. Nevertheless, impacts on the landscape structure need to be taken into account.

Amongst conventional annual crops, cereals usually have a better 'environmental performance' than rape seed. Sugar beet and potato have a relatively high negative impact on the environment in most zones as they add to soil erosion (no year-round coverage), and have a high harvesting weight that requires the use of heavy machinery and expedite soil compaction. Nutrient input is generally high for wheat, grain maize, potatoes, sugar beet and oilseed rape, but varies strongly between countries (and farming practices).

As bioenergy cropping is not limited to conventional farming, specific annual cropping systems can be introduced. Extensive multi-cropping systems (i.e. a mixture of several plants, species and varieties within the same field) could combine low environmental pressures with high yields, as the whole plants can be harvested several times a year as green plants. Such multi- or double cropping systems that combine several crops on the same field require little fertiliser and pesticide input or ploughing. They would reduce soil erosion due to year-round coverage and aim at closed cycles of nutrients by using fermentation residues. Furthermore, they might add to structural diversity in the fields. However, these cropping systems are not suitable for southern Europe due to high

Table 3.3 Assessment of pressures per crop — Example: short rotation poplar and willow

Aspect	Score	Reason
Erosion	A	Permanent crop, hence good soil cover
Soil compaction	A	Deep rooting, permanent crop
Nutrient inputs into surface and groundwater	A	Significant nutrient demand but good uptake also; low fertilizer use; permanent soil cover
Pesticide pollution of soils and water	A	In later stage very competitive, hence no pesticide use necessary; during the first years, weed competition has to be tackled
Water abstraction	B	High water demand, but no irrigation expected
Increased fire risk	—	Not suitable for arid conditions
Link to farmland biodiversity	A/B	No/low pesticide use; nesting habitat and provides winter shelter; but can have negative impacts on open landscape structures

Note: A means low risk; B means medium risk; C means high risk; — means that the criterion is not relevant.

water requirements, and require more practical investigation, including field trials in different locations of Europe.

On the basis of this 'environmental ranking of bioenergy crops', an *environmentally-compatible* bioenergy crop mix was determined for different environmental zones in Europe. This comprises the following steps (see Figure 3.3).

1. The *environmentally-compatible* bioenergy crop mix was set into context with the main environmental and socio-economic characteristics of the different regions in Europe. The characteristics incorporated are: climatic suitability, current land use, current farming systems and current environmental problems Only in this way can the optimal mixes be placed in their present and potential future context enabling the assessment of their environmental including their ecological impacts. For this purpose, the concept of environmental zones was used. It divides Europe into 13 zones with a homogeneous pedo-geo-climatic character (22).
2. This results in a selection of a biomass crop mix by environmental zone. This mix is not expected to impose any additional pressure on farmland biodiversity but rather lead to a relative decrease in environmental pressures. Table 3.3 gives an example for the priorisation of annual crops in the Atlantic Central and Lusitanian Zone.

The crop mixes by zone were taken as the starting point for analysing the *environmentally-compatible* bioenergy potential by Member State. This implied that each Member State was allocated to one environmental zone except for France, Germany, Spain, Sweden and the United Kingdom, which were allocated to more than one zone.

Based on this allocation and the environmental crop ranking by zone, a *sustainable crop mix* was identified for every Member State. This is the mix of crops that score well on both environmental ranking and *energy yield* (23). The inclusion of yields is a proxy value for the economic efficiency of the biomass crops. In the Atlantic Central zone, for example, the best options are the double cropping systems and the giant

Table 3.4 Priorisation of annual crops in Atlantic Central and Lusitanian Zone

	Double cropping	Linseed (oil)	Other Cereals	Cultivated grass	Clover. alfalfa	Hemp	Mustard seed	Wheat	Sun flower	Rapeseed	Sugar beet	Potato	Maize
Erosion	A	A	A	A	A	A/B	A (B)	A	B/C	B	C	C	C
Soil compaction	A	A	A	A/B	A/B	A	A	A	A	A	C	C	B
Nutrient inputs ground- and surface water	A	A	A	B	B	A	B	A	A/B	B/C	B	B	C
Pesticide pollution of soils and water	A	B	A	A	A	A	B	A	B	C	B	B	C
Water abstraction	A/B	A	A	A	A	B	B	B	B	B	B	C	B/C
Increased fire risk	—	—	—	C	—	—	—	—	—	—	—	—	—
Link to farmland biodiversity	B	A/B	B	A	A/B	B	B	B/C	A/B	B/C	B	B/C	B/C
Diversity of crop types	A	A	B	A	A	B	A	C	B	A/B	B	A/B	B/C

Note: A means low risk; B means medium risk; C means high risk; — means that the criterion is not relevant for the specific zone or crop. Perennial energy crops are not included as they were assessed separately due to different impacts on the environment and the landscape. The criteria 'link to farmland diversity' is based on the other environmental pressures and does not cover interactions and influences of the biotic and abiotic factors in detail. Mustard seeds are relevant for the Lusitanian zone, only. The criterion 'erosion' is 'A' for mustard seed in general, but 'B' if grown as row culture for oil use.

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(22) The environmental stratification of Europe divides the region in zones with a homogeneous pedo-geo-climate character. This zonation is based on climate data; data on ocean influence, geographical position (northing) and altitude which have been clustered statistically. The result are 84 strata which have again been summarised statistically into 13 major Environmental zones (EnZ). For more information about the environmental zonation see Metzger *et al.* (2005) and Jongman *et al.* (2005).

(23) All yield figures are estimated from long term averages in FAO statistics or, if not available, from other published field research. The assumptions about the future yield increases are differentiated by 'conventional' oil crops, cereals (maize only) and 'dedicated' bioenergy crops (such as whole plant use of common arable crops, short rotation coppice, and perennial energy grasses). For dedicated bioenergy crops, the yield increase (1 %/a in 2000–2010, 1.5 %/a from 2010–2020, and 2 %/a between 2020–2030) is expected to be higher than for traditional agricultural crops (1 %/a for oil seeds and 1.5 %/a for cereals throughout the entire period), especially as the breeding potential of the crops for non-food purposes has only recently. started to be exploited. In contrast, yield increase rates for common arable crops have already been slowing down since the 1980s in Europe and this is why for these crops the increase in yields is assumed to be limited. It was assumed that genetically modified crops are not used.

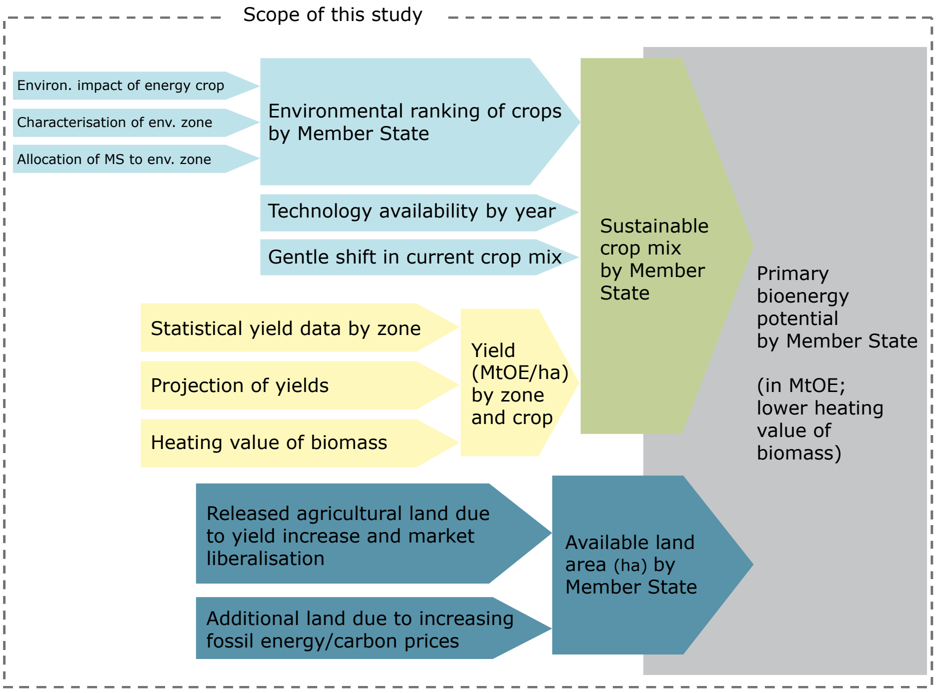
reed. In the Mediterranean, cereals, giant reed, and sorghum would be preferable.

The present crop mix in each country is also taken into consideration together with diversity in land use. The latter implies that if two crops have a similar ranking on environmental and economic performance the crop that occurs less frequent is preferred. In general, a variety of crops with different height and establishment characteristics creates higher structural diversity in the landscape, and more environmental niches in area and time for a large variety of species. On the other hand, the present crop mix and the availability of farming machinery influence the sustainable crop mix. For example, instead of an abrupt change from annual to perennial crops, it is more likely that this will happen continuously over time (phase-in).

Assumptions about *technological development* are also taken into account as they influence the demand for specific bioenergy crops. Today, most agricultural potential comes from oil or starch crops which are converted into biofuels. In future it is expected that there will be a shift from first-generation biofuels (e.g. plant oil, biodiesel and bioethanol from cereals or sugar beets) to second-generation biofuel production by synthetic biofuels (BtL) and ethanol from ligno-cellulosic crops (ethanol+). Furthermore, a larger share of the agricultural bioenergy potential would be used for heat and electricity production. Advanced second-generation biofuel and heat and power production technologies can use various feedstocks, such as perennial grasses, short-rotation forests and whole plants. The shift from traditional ethanol to ligno-cellulosic ethanol+ does not require the establishment of complete new conversion plants. This is why cereals become more attractive than sugar crops as feedstock for future biofuel production, in addition to the relatively low environmental ranking and high costs of sugar beets ([24]).

These steps can be illustrated for the case of perennial crops. These crops are usually characterised by high yields per hectare (and thus a high economic efficiency) and relatively low environmental pressures. They would thus be favourable in many regions to some extent, as long as changes to the landscape structure are

Figure 3.3 Overview of the working steps



Note: MS means Member State.

([24]) Sugar beets were considered not being part of a sustainable bioenergy crop mix. Including sugar beets into the crop mix would, however, not change the bioenergy potential significantly. A sensitivity analysis indicates that the agricultural bioenergy potential in 2010 might be around 3 % higher in the case with sugar beets compared to the *environmentally-compatible* case.

respected. Nevertheless, current farming focuses on annual crops. It can be expected that a change from conventional farming of annual crops, which allows yearly adjustments, towards perennials will take some time. Perennial grasses and short rotation forestry are thus assumed to be phased-in over time, supported by the availability of second generation biofuel conversion technologies after 2010.

In a final step, the *environmentally-compatible* primary agricultural bioenergy potential was calculated on the basis of the released land area, the sustainable crop mixes, current yields and assumptions on future yield increases. The conversion from the biomass potential to an energy potential was achieved using the lower heating value (net calorific value) of the harvested dry biomass (25). The result is energy yields per hectare for each crop and each Member State.

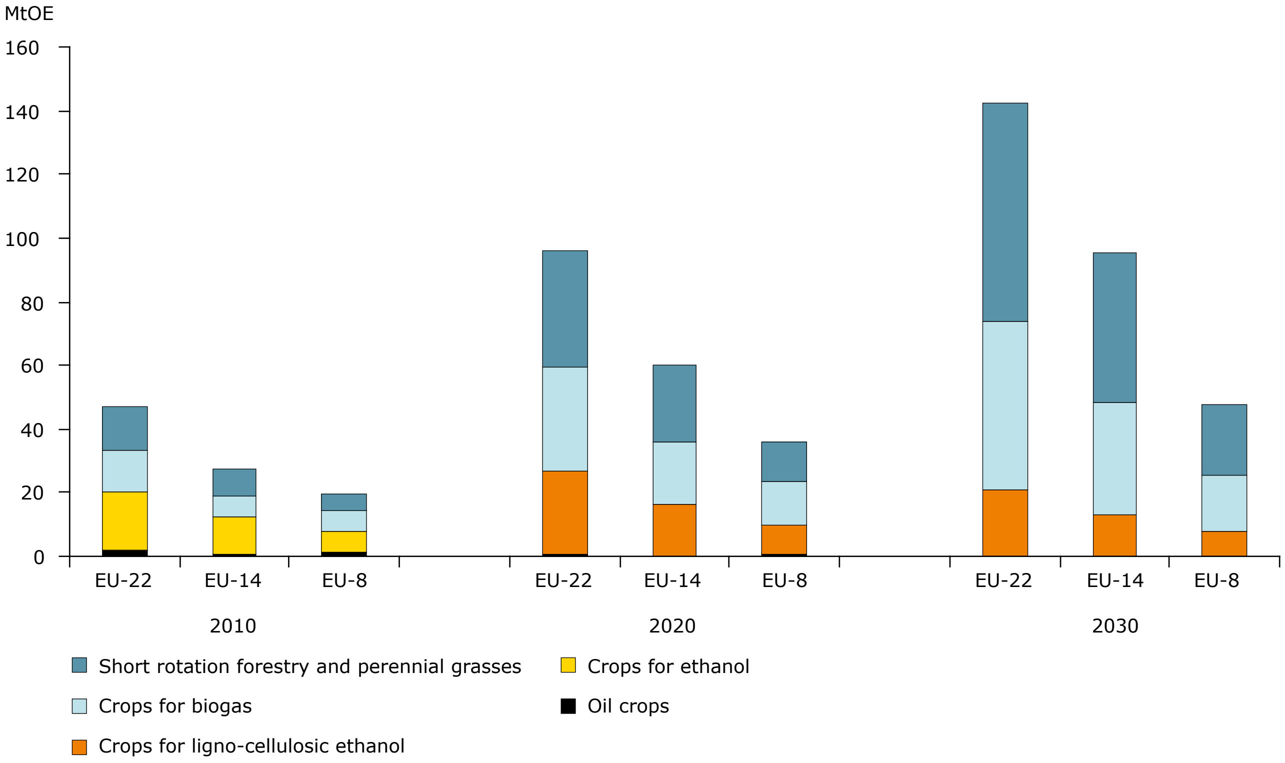
3.4 The *environmentally-compatible* bioenergy potential from agriculture

3.4.1 *Results and assessment*

The assessment shows that around 47 MtOE of bioenergy can be derived from the released agricultural land area in 2010 without creating additional environmental pressures. This could increase to around 95 MtOE in 2020 and 144 MtOE in 2030. The tripling of the potential is due to

- a combination of a steep increase in the available land potential — triggered by the liberalisation of the agricultural markets and productivity increases;
- rising energy and CO_2 permit prices;
- a general energy yield increase per hectare, especially for innovative bioenergy crops.

Figure 3.4 ***Environmentally-compatible*** **agricultural bioenergy potential**



Note: No data available for Cyprus, Luxembourg and Malta. 'Oil crops' comprise rapeseed and sunflower. 'Crops for ethanol' include the potential of grains from maize, wheat, barley/triticale. 'Crops for ligno-cellulosic ethanol' cover the energy value of the whole plant (corn and straw) for wheat and barley/triticale. 'Crops for biogas' are maize (whole plant), double cropping systems, switch grass and the grass cuttings from permanent grassland. 'Short rotation forest and perennial grasses' include poplar, willow, miscanthus, reed canary grass, giant reed and sweet sorghum, which may often be used in whole-plant conversion systems like gasification, or biomass-to-liquid processes.

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(25) In the case of green biomass for fermentation (e.g. double cropping systems or whole maize plant) the lower heating value refers directly to biogas.

The yield increase per hectare is mainly influenced by the assumed introduction of advanced bioenergy conversion technologies after 2010, which allow the use of crops with high energy yields.

While in 2010, the potential in the EU-15 (without Luxembourg) is only 40 % above the potential in the 10 new Member States (without Cyprus and Malta), it will become almost twice the EU-10 potential by 2030. However, both total and transport energy consumption in the EU-10 are much lower than in the EU-15, and a substantial difference is expected to remain despite converging trends (EEA, 2005a). It is thus realistic to assume that some new Member States will export parts of their biomass production (either as biomass or fuel) to EU-15 Member States.

The crop mix is projected to change drastically over time. While in 2010 some 40 % of the agricultural bioenergy potential would be dedicated to bioenergy crops for conventional biofuels production, this would decrease rapidly after 2010. This is the result of both the relatively low environmental ranking of some oil and starch crops (compared to perennials and dedicated bioenergy cropping systems) and the relatively low yield of bioenergy production that focuses on the oil and starch part of the crops instead of the whole plant.

Over time, short rotation forests and perennial energy grasses would increase substantially. These crops combine a generally high energy yield with relatively low environmental pressures. They are phased-in substantially after 2010, reflecting a transition period for the farm sector and the availability of advanced biofuel conversion technologies after 2010. This advanced conversion can make use of a broader range of crops. Crops used as feedstock for biogas installations (e.g. maize or double cropping systems) will increase after 2020 as further technology development increases the efficiency in biogas production (26). As they require sufficient water, they will be particularly important in the countries of the Atlantic and Continental zone.

In this study, crop mixes were specified at national level. No further assumptions were made about where biomass crops will be grown within a country. However, the overall underlying assumption in this study was that most energy crop production will be spread in a similar way over the countries as arable agriculture is presently divided over area. Most annual bioenergy crops will be part of the cropping rotation of farms and will thus be mixed with conventional food and feed crops. This also implies that biomass crops will be grown on a range of high and low productive lands and that yields and income will also vary accordingly, as is already the case with feed and food products.

The *environmentally-compatible* bioenergy potential for selected Member States is presented in Figure 3.5. About 85 % of the potential will be produced in only seven Member States (Spain, France, Germany, Italy, the United Kingdom; Lithuania and Poland). Together with population size and density, economic competitiveness of the agricultural systems in each Member State are the main factors determining land potential. Countries with no or a small potential are typically those with a high population density, a very competitive agriculture sector, limited UAA and/or an overall high pressure on land (such as Belgium and the Netherlands). In these cases, the options for agricultural land to become available for biomass crop production are limited. In other countries, the low potential is due to the fact that even though a substantial amount of land is released, this is permanent grassland, which — according to the environmental criteria of this study — cannot be transformed into intensive bioenergy potential. This is the case for Ireland. Here, land is released in the permanent grassland category and the grassland cuttings deliver relatively little energy per hectare.

Member States with a large bioenergy potential are those which release large amounts of land due to the liberalisation of the agricultural markets. They will also be the Member States where increased competition leads to lower production quantities. Exceptions will include Germany and France. In these countries, a competitive food production for exports outside the EU is assumed to be possible. The rise in bioenergy production in Germany and France will therefore mainly be the result of the increased carbon permit and oil price that makes a shift to biomass production more attractive on those areas that otherwise are dedicated to export food production.

With regard to the crop mix there will be a tendency towards low-pressure, high yield crops. These are primarily drought resistance perennial biomass

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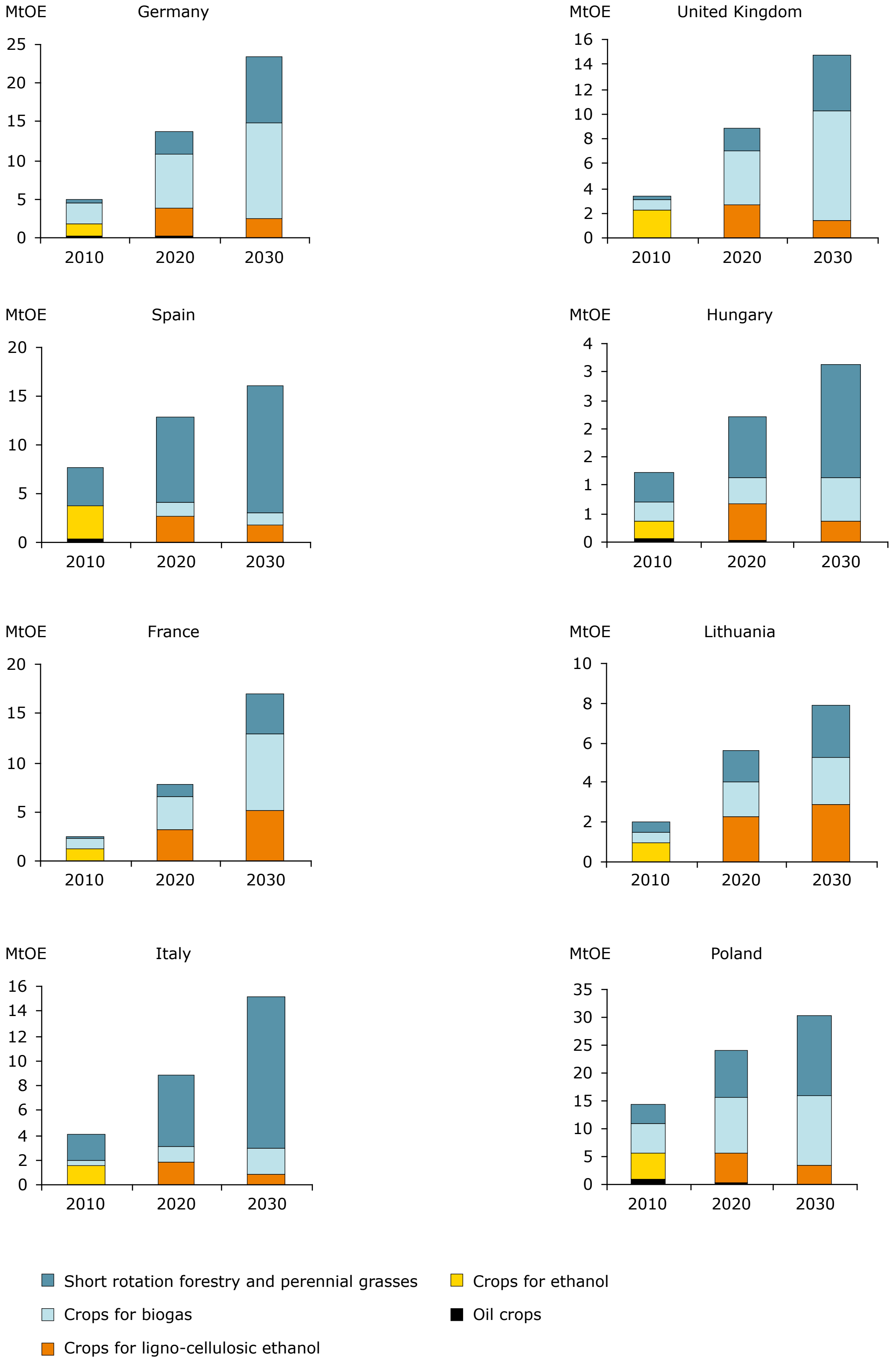
(26) 'Biogas crops' comprise cereals, oil crops, grass (cuttings), maize and perennial grasses. As the residues from biogas production (fermentation) are returned to the field, the nitrogen content is used as fertilizer so that nutrient cycles are nearly closed, thus avoiding fossil-fuel-based fertilizer. The fermentation process is assumed to become more efficient over time by technology learning. In addition, biogas can be processed to natural-gas quality, and be fed into the gas pipeline system, which allows its wide-spread use.

Figure 3.5 ***Environmentally-compatible*** **agricultural bioenergy potential for selected EU Member States**



Note: Figures for France and Germany based on HEKTOR calculations, all other on CAPSIM.

crops in the Mediterranean countries, especially reed canary and switch grass. In northern European countries, they cover both perennials and dedicated annual multi-cropping systems (for biogas production).

3.4.2 Synergies

A higher production of bioenergy could lead to increasing environmental pressures, if no clear environmental guidelines are applied. This would particularly be the case if the currently extensive use of high nature value farmland areas is intensified. On the other hand, the present work indicates that there is some potential for synergies between increased bioenergy production and biodiversity protection, or the conservation of soil and water resources. This potential should be further explored and actively pursued. In this study, the following potential synergies have so far been identified:

- The use of grassland cuttings for energy purposes may be a good opportunity to maintain the management of extensive farmland, which is beneficial for biodiversity. In particular, the harvesting of grass for bioenergy can provide some economic benefit to the management of species-rich grasslands, and thus prevent land abandonment and loss of valuable open habitats (see Section 3.2.2.). Cuttings from grassland contribute some 6–7 % of the estimated overall agricultural potential.
- Bioenergy production can reduce environmental pressure compared to intensive farmland management, if the right crop mix and cropping practice is selected. This can especially be the case in intensively farmed areas, where the introduction of a careful selection of bioenergy crops might minimise some environmental pressures, and could improve landscape structure and land use diversity.

3.4.3 Sensitivities and robustness of approach

The calculation of the bioenergy agricultural potential depends on a number of key scenario assumptions including:

1. the share of environmentally-oriented farming
2. high fossil fuel and carbon permit prices
3. yield increases
4. the restriction of the approach to the current UAA
5. the low spatial resolution
6. the selection of crops.

1) The implementation of a minimum share of environmentally-oriented farming has a significant influence on the land potential for bioenergy, as it reduces productivity and therefore total agricultural production. In 2020 the arable land area in the *environmentally-compatible* scenario is about 80 % of the area that would be available in a development without an increased share of EOF and the ecological compensation areas.

2) The scenario results indicate that most EU Member States will release agricultural land as a consequence of market liberalisation and yield increases. Nevertheless, the effects of market liberalisation may not lead to released land in countries with a competitive agricultural sector. For example, France and Germany show high export rates for a selection of agricultural products.

   This study introduced competition between bioenergy and food markets on those export areas, following the assumption of rising CO_2 permit and energy prices. As a result, the surplus land can be used for bioenergy at the expense of land used for exports of food/feed crops. The impact of this assumed competition increased the land availability for biomass crops in France and Germany by 0.4 million ha in 2010, rising to almost 5 million ha in 2030. This is equivalent to 4 and 41 MtOE of bioenergy in 2010 and 2030, respectively.

   The competition effect is likely to be most pronounced in Germany and France due to their competitive agriculture and large land area. As such, the restriction of the calculation to only two Member States covers the effect for the whole EU-25 to a large extent, but may still be a slight underestimation. Moreover, if competition between production of food for domestic use and bioenergy had been assumed, the bioenergy potential would have increased substantially.

3) Both the land potential and the bioenergy potential depend on the assumed yield increase per year. In this study, conventional arable crops were assumed to have a yield increase of around 1 % per year and for dedicated energy crops the yield increases varied between 1 % and 2.5 % per year. Assuming a lower yield increase of 1 % for *all* crops would reduce the bioenergy potential by 2 % in 2010, and by 13 % in 2030 (see Figure 3.6).

4) In many parts of the EU, especially the new Member States and the Mediterranean, there are significant areas of land no longer used for

agriculture and therefore no longer incorporated in agricultural statistics. This was not taken into account in this study, as the analysis was restricted to the UAA. However, particularly in the new Member States the UAA in 2000 is likely to have been smaller than the area of land that can potentially be used for arable agriculture (EC, 2002b). This implies that the land availability for bioenergy production assessed in this study may well be an underestimate. An additional more detailed analysis should examine the amount and nature of this fallow land.

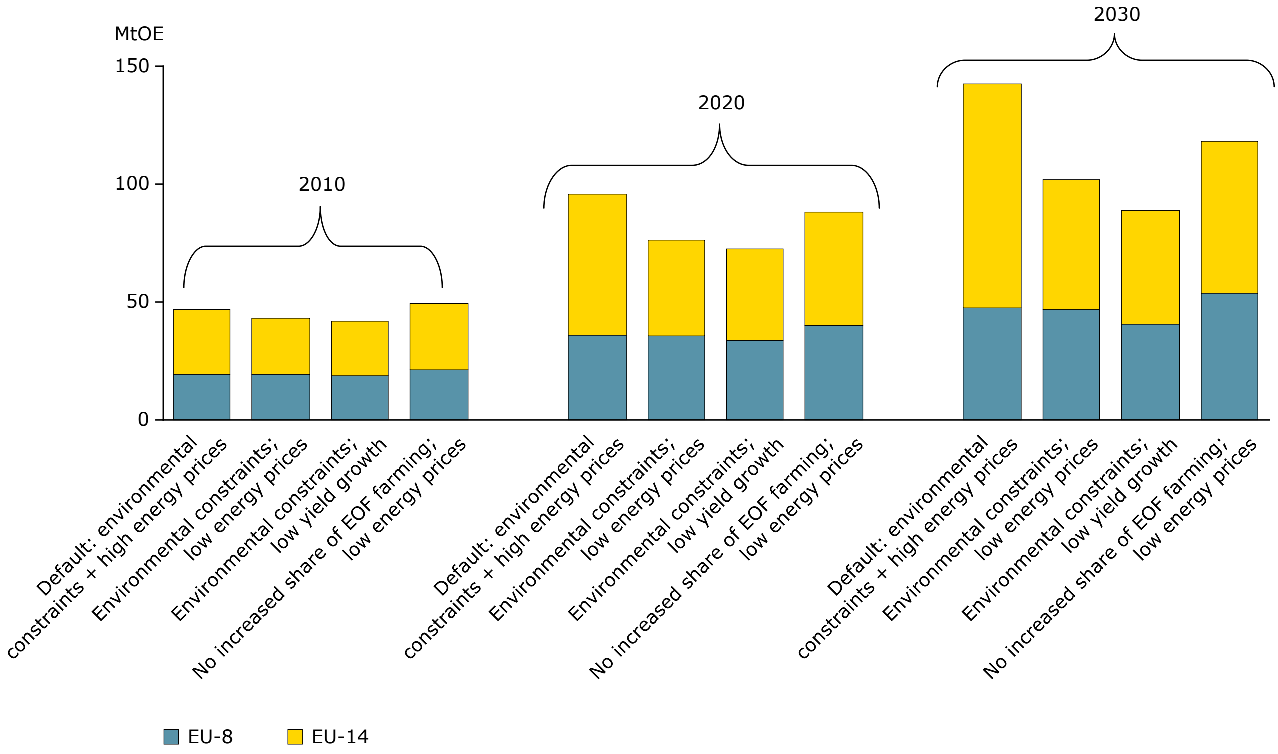
5) Assessments of the *environmentally-compatible* crop mixes or nature conservation aspects need to take local circumstances into account. In this study crop, however, crop mixes were only specified at national level, and no further assumptions were made about where bioenergy crops will be grown within the Member State.

6) The sustainable crop mixes can only be considered as indicative of appropriate mixes for future bioenergy crops and cropping systems. The underlying assessment considers the environmental and — to some extent — the economic performance of different crops via energy yields. Social and rural considerations have not been considered as they were beyond the scope of this study.

For the southern European regions in particular, further research is needed into the suitable biomass crop mixes, as currently there seems to be a limited number of suitable crops for arid regions. In particular, arable biomass crops may increase water abstraction. Even though some perennial biomass crops may not be suited for biomass production under the very arid conditions or increase the risk of fires, they are generally considered a better option in these regions (EEA/JRC, 2006).

Further work is also required on alternative farming practices and new crop mixes. The double cropping practice is just one new approach that needs more practical investigation. Practical investigation should include field trials in different locations all over Europe using very different combinations of crops. Alternative farming systems like agro-forestry should be taken into account as well.

Figure 3.6 Sensitivity of results to changes in key assumptions



Note: No data available for Cyprus, Luxembourg and Malta.

4 Bioenergy potential from forestry

4.1 Introduction

Despite its high population density roughly 30 % of Europe's land area is covered by forests, and these remain a key ecosystem for biodiversity. Natural forests (i.e. those unaffected by humans) often contain a diverse range of both tree and non-tree species, but virtually all forests in Europe have experienced more or less strong anthropogenic influences throughout history. Nonetheless, all forests, even monoculture plantations, are reservoirs of biodiversity (EEA, 2005b).

Most forests are economically productive to some extent. Nevertheless about 25 % of the forest area is subject to management constraints to secure ecosystem services such as nature conservation, soil protection, water supply or recreation (MCPFE, 2003a).

In contrast to many other parts of the world, forestry in Europe extracts timber at a rate slower than or equal to the increment in growing stock. Currently, average felling rates are around two-thirds of the increment. The current level of fellings has advantages for biodiversity as forests of all sorts in Europe are growing older, thus restoring underrepresented late succession stages. Bigger, older trees host a number of species confined to late forest successions and produce deadwood of specific qualities for a number of organisms. In many countries, forestry policies aim to increase the amount of deadwood in the forests and the Ministerial Conference on the Protection of Forests in Europe has identified deadwood as an indicator of forest biodiversity (MCPFE, 2003b).

Recently there has been a trend in several countries towards collecting forest biomass residues after harvest operations for the generation of bioenergy. In addition, the gap between the level of fellings and the increment in growing stock provides an opportunity to use forestry biomass that currently remains unexploited as a source of renewable energy. This opportunity is identified as 'complementary fellings'. Harvest residues and complementary fellings differ significantly in economic terms. Whereas the value of the woody biomass of harvest residues is low in general, mobilising complementary fellings would imply that the forest owner gets at least the current market price for industrial wood. In this report we do not consider biomass from short-rotation forestry as part of forestry as this takes place in most cases on agricultural land and is as such included in Chapter 3.

Forestry biomass in this study comprises residues from harvest operations that are normally left in the forest after stem wood removal, such as stem top and stump, branches, foliage, and roots. Additional sources of forestry bioenergy potential are complementary fellings, which describe the difference between the maximum sustainable harvest level and the actual harvest needed to satisfy round wood demand.

This chapter considers the amount of forest residues and complementary fellings which is available when environmental guidelines are applied to the increased use of forestry biomass. These guidelines ensure that no additional environmental pressures are created. Furthermore, the effect of high bioenergy prices on competing industries is roughly estimated. The approach taken was as follows:

1. Formulate a number of criteria to avoid excess pressure on the environment.
2. Based on these environmental criteria, assess the local site suitability for residue extraction by producing a high resolution suitability map based on spatial data (Figure 4.1) and adapt the extraction rates to the environmental criteria.
3. Determine the regional forestry resource potential from unused forest residues and complementary fellings in the EU. This requires that future wood demand is defined.
4. Combine the suitability classification scheme with information on forest resource projections to calculate *environmentally-compatible* residue extraction potentials.
5. Incorporate the environmental criteria relating to complementary fellings by reducing the maximum sustainable harvest level and calculate the *environmentally-compatible* potential from complementary fellings.
6. Estimate the additional potential which could be re-orientated from competing industries in the case of increasing bioenergy prices.

4.2 Environmental considerations

4.2.1 *Potential environmental pressures of bioenergy production*

Forests, and in particular forest residues and deadwood, have a number of important environmental functions. These include: providing a source of nutrients; regulating water flows; and helping to prevent soil erosion. In addition, they can create habitats. Biomass removal from forestry, whether for timber production or energy use can adversely impact on some of these functions. It is important that any enhanced use of either forest residues or complementary fellings for bioenergy does not increase the existing environmental pressures from forest resource utilisation.

However, as well as negative environmental impacts, biomass removal can also bring positive benefits including reduced fire risk and lower nutrient leakage on eutrophicated sites. The study did not take into account such potential additional positive benefits and the *environmentally-compatible* bioenergy potential from forestry might thus be considered conservative.

Biodiversity: Forest is a key biodiversity repository in Europe, providing a habitat for a large range of plants, animals and fungi. In most European countries, a significant share of the forest land is currently used at a lower intensity than in previous centuries. Also, in a medium time-perspective the industrial forestry is developing favourably from a biodiversity point of view (EEA, 2006a). The principles of Sustainable Forest Management (MCPFE, 2006) and a moderate utilisation in relation to increment have created positive conditions for biological diversity in many cases, and increased the share of deadwood. Increased extraction of forest residues and complementary fellings may result in an intensification of use of forest resources, which can compromise the nature conservation value of such forests. Residue extraction also affects the composition of flora and fauna through habitat homogenisation and more intense soil disturbance. However, there are also some man-made forests that are not thinned due to a lack of market demand and low prices. In such cases thinning for biomass utilisation provides an opportunity to open very dense coniferous forest plantations, and thereby improve the habitat value of these forests for many species.

A certain amount of deadwood per hectare is increasingly recognised as an important factor in the protection of biodiversity in forests (Humphrey *et al.*, 2004, Schuck *et al.*, 2004). Of particular importance is deadwood of a large diameter. Although the removal of fine and small woody debris also has an effect on biodiversity (Kruys and Jonsson, 1999), there are many more species that depend on large dead trees (Schuck *et al.*, 2004). Currently, the amount of deadwood, particularly in commercial forests, is low in many European countries. When extracting forest residues or complementary fellings it is thus important to leave behind a proportion of residues, deadwood and old trees in order not to increase the pressure on biodiversity.

Site fertility: Biomass removal from forests always results in the export of nutrients. The various parts of a tree contain different levels of nutrients. The lowest nutrient concentration is generally in the wood and the highest contents are in the foliage. The nutritional impact of biomass extraction from forests is therefore strongly influenced by the rate of extraction and the degree to which foliage and small branches are left on site. The natural replenishment of nutrients from weathering and atmospheric deposition varies between soil types and region. Mineral nutrients are naturally achieved through weathering and the availability is part of the site productivity. It is usually assumed that there are no problems associated with site productivity when removing woody biomass from forests managed with sustainable harvest levels. Utilising forest harvest residues could be detrimental to site productivity without compensatory fertilisation on poor sites such as peatlands (Richardson *et al.*, 2002; Sverdrup and Rosen, 1998). Even on more fertile soil types it is important to retain foliage on the site. Therefore, it is beneficial to exclude small branches and foliage from the biomass removals. In the case of coniferous species this can be realised by extracting dry residues, which allows needles to drop before chipping. In the case of broadleaved species harvesting should take place in the winter months (Richardson *et al.*, 2002).

Part of the European forest land is subject to deposition of long-range transported nitrogen (EEA, 2006a). The extraction of logging residues can remove a significant amount of nitrogen (Samuelsson, 2002). At regional level, nutrient export with forest residues can thus have a positive effect in certain ecosystems on forest land with a high nitrogen load.

Soil erosion: The soil is one of the most fragile components of forest ecosystems. Logging residues decrease the direct exposure of the soil to rainwater, sun or wind, and thereby reduce the risk of erosion.

Modern logging technologies should take into account measures to reduce the damage to forest soils. Negative effects of use of heavy machines can include soil compaction and higher levels of erosion. When harvesting wood for biomass a much larger proportion of the biomass is removed (in comparison with conventional harvesting methods). This inevitably means increased intervention and transportation on the logging sites. Good practice would require the tree roots to be left in the ground and a proportion of branches to be used as 'mats' on forwarder routes to protect the soil. This would place a limit on the maximum rates for extraction of biomass.

Water protection: Logging residues and deadwood have a role to play in regulating the water flows through the forest ecosystem and act as filters to improve water quality. They do this by capturing and storing significant amounts of water and reducing water run-off on slopes. Harvesting for biomass may significantly reduce the potential to regulate water flows.

Forests in water protection areas are usually managed at low intensity. This means that large-scale removal of trees (clear-cuts) are avoided in order to prevent an increase in risk of surface run-off after heavy rainfall and release of nutrients into the groundwater. Nutrient export associated with intensive biomass utilisation could also intensify the acidification of water bodies.

4.2.2 *How to avoid increased environmental pressures?*

In order to avoid increased environmental pressure from bioenergy production from forestry a number of criteria were applied. The main criteria were ([27]):

1. No intensification of use on protected forest areas.
2. Foliage and roots are always left on site.
3. The extraction rate for residues from stem and branches is limited according to the suitability of the site.

For complementary fellings, where dedicated harvesting for bioenergy was considered, additional criteria comprise:

4. A reduction of the area available for wood supply in each Member State by 5 % in order to allow for an increase in protected areas.
5. A set-aside of 5 % of wood volume as individual and small groups of retention trees after harvesting in order to increase the amount of large diameter trees and deadwood.

1. No intensification of use should occur in protected forest areas: A significant proportion of European forest area is protected for conservation purposes, either by national legislation or within the European Community Natura 2000 network. Currently 11.7 % of the European forests are protected (MCPFE, 2003). The legal constraints imposed by this protection vary from a total ban on management to no limitations for sustainable management. In the latter case, it can be assumed that only low-impact management is allowed. This is particularly important in southern Europe where large areas of forest are classified under Natura 2000.

2. Foliage and roots are left on site. Forest residues supply the ecosystem with nutrients, reduce the risk of soil erosion, regulate the water flows through the forest ecosystem and improve water quality. This occurs through the capture and storage of significant amounts of water, and reduced water run-off on slopes. A central assumption was that foliage was left on site as it contains the highest nutrition concentration. They account for approximately 20 % of all the aboveground residues biomass. Furthermore, roots were assumed to be always left on site in order to prevent soil erosion and disturbance of the soil.

3. Site-specific residue extraction rate: The extraction of residues was adapted to the 'environmental suitability' of the site with regard to the functions of residues in the forest ecosystem. On sites with a higher risk of soil erosion — as measured by a combination of soil steepness and elevation — a reduced residue extraction rate is appropriate to protect erosion.

As residues provide nutrients, their extraction should be adapted to the soil fertility of the site. Proxies for soil fertility are different soil types and base saturation. The latter measures the degree of acidity of the soil — a low base saturation corresponds to acidic soils and low nutrient availability. Ash recycling can to some extent increase the suitability for residues extraction on nutrient poor soils. This effect was analysed in a sensitivity case (Section 4.4.3).

([27]) These environmental criteria were formulated at an EEA expert meeting in March 2005 and build on work by WWF Hungary and Solagro on behalf of the EEA European Topic Centre on Biodiversity (see http://www.efi.fi/projects/eea_biodiversity/results/constraints.html) and input from the EEA European Topic Centre on Air and Climate Change.

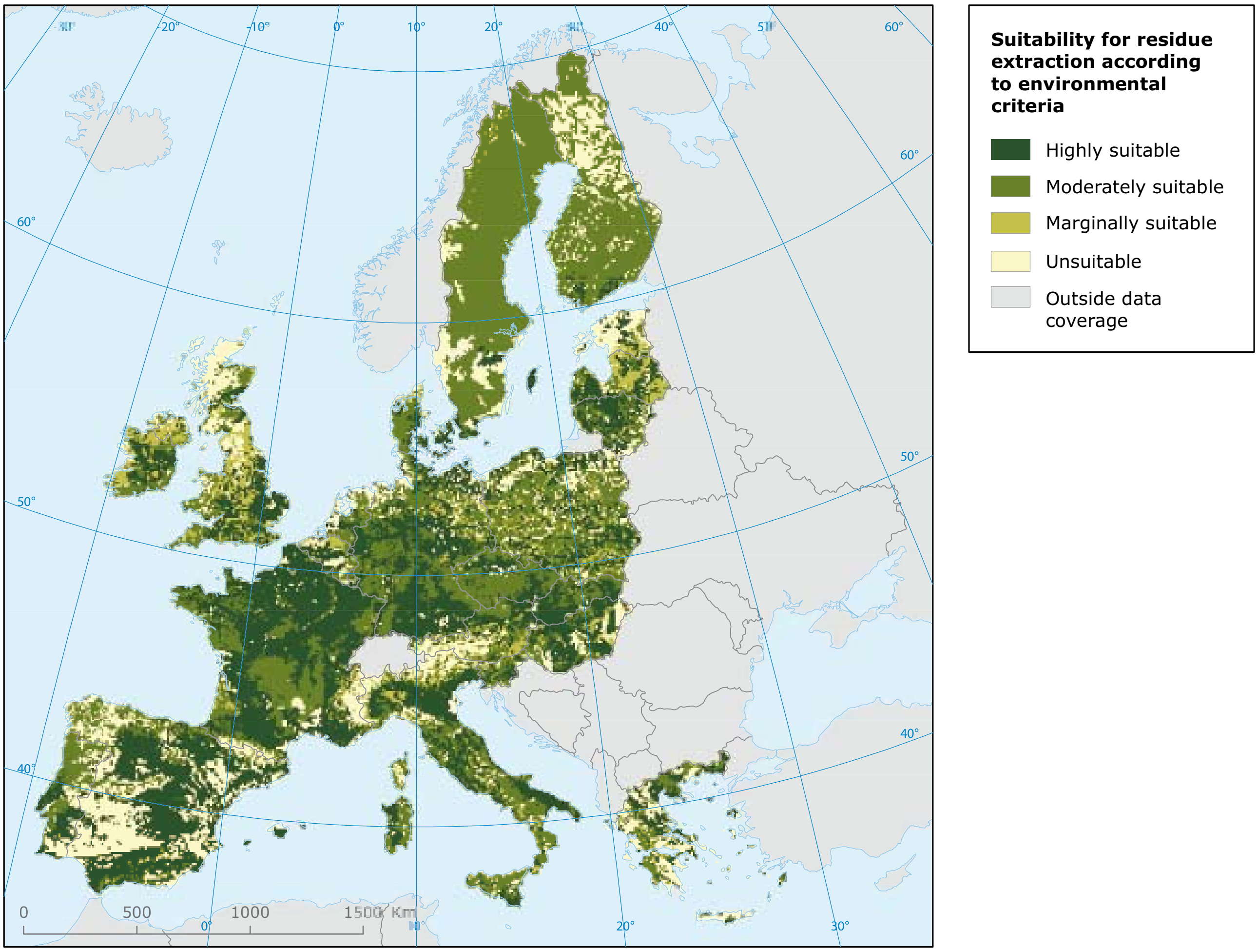
Protecting the soil from compaction was taken into account by analysing the site suitability with regard to the soil water regime and the occurrence of peat land.

The site suitability has to be determined with a high resolution. In this study, this was realised by using various spatial layers in order to produce a suitability map with a resolution of 1 x 1 km for Europe. This suitability map is the result of combining information on soil types with elevation data. It is based on two data sources: spatial data on soil fertility, erosion and compaction from the European Soil Database (grid 10 x 10 km) of the European Soil Bureau Network (http://eusoils.jrc.it/) and elevation data derived from the Shuttle Radar Topography Mission and the U.S. Geological Survey's GTOPO30 data set (around 1 x 1 km).

The maximum extraction potential of residues from stem and branches (excluding foliage) was set at 75 % on highly suitable sites and to 50 % and 15 % on moderately and marginally suitable sites, respectively. 100 % extraction was not assumed, even on highly suitable sites (Table 4.1). This assumption was made in order to take into account the exclusion of sensitive or unsuitable micro-habitats, and also because it is good practice to leave some branches as mats on forwarder routes. Without compensatory fertilisation, foliage should always be left in the forest and so these rates correspond to 60 %, 40 % and 12 % of the total above ground residue biomass.

4. Increased share of protected forest area: Bioenergy production in forests should not counteract a potential future environmentally friendly development of the forestry sector, such as an increasing share of protected forest areas, which is essential for a rich biodiversity. An increase in protected forest areas was thus assumed, reducing the forest area available for wood supply by 5 % in each country.

Figure 4.1 Suitability for residue extraction according to environmental criteria



Note: The above site suitability map does not consider fertilisation as an option on nutrient-poor soils. If ash recycling were considered on podzol areas, the suitability rate would be higher especially in Finland and Sweden. Potential positive environmental effects of nutrient extraction in areas with high nitrogen deposition are also not taken into account, but might increase the suitability for residue extraction particularly in parts of Belgium, Denmark, northern France, Germany, northern Italy, the Netherlands, Poland and southern Sweden.

5. Increased share of deadwood: A substantial amount of biodiversity in European forests depends on deadwood. It was assumed that some mature and dead trees would be retained on the site after harvesting. 5 % of standing volume was assumed to be left as individual and small groups of retention trees after harvesting. This implies an additional deadwood volume in managed forests of 9 m^3/ha as an average for Europe.

In combination, the above two factors reduce the total maximum sustainable harvest volume by 10 %. In some countries this meant that there was no additional potential for complementary fellings compared to current harvest removals.

There are several other environmental considerations or indirect impacts that this work was not able to incorporate into the analysis. These include:

- Amenity values and the protection of traditional landscapes. These could also pose a constraint on the utilisation of certain forest areas for complementary fellings, especially in regions with important recreational values.
- The role of forest residues in protecting natural forest regeneration from browsing in many cases.
- The timing of harvesting can substantially influence the environmental impacts of the management activity. Harvesting in sensitive forest areas should be timed according to the needs of species to be protected from disturbances, or the sensitivity of the soil to compaction in unfavourable conditions (absence of frost, wet conditions).

In addition, forest management practices could, in principle, have a significant impact on the forest biomass potential for bioenergy in the long term. In the time scale analysed in the present study, the impact of environmentally-benign management changes such as increasing shares of broadleaved tree species on the forest resource potential is, however, likely to be small as it will only affect the stand mainly in 30 to 40 years. This is beyond the time scale of this study. The biomass removals until 2030 will mostly come from tree generations that were planted several decades ago.

4.3 Approach: methodology and scenario development

The biomass resource potentials of European forests were quantified for 2010, 2020 and 2030 for an *environmentally-compatible* scenario (i.e. that avoids increased environmental pressures). The biomass potential consists of forest residues from regular fellings, complementary fellings and forest residues from complementary fellings. The bioenergy potential is mainly determined by the market demand for round wood, as competition between bioenergy production and traditional wood use is limited under current prices structures. However, with the assumed increases in energy and CO_2 permit prices towards 2030, this situation may

Table 4.1 Classification thresholds for site suitability for forest residue removal

	Highly suitable	Moderately suitable	Marginally suitable	Unsuitable
Level of residue extraction	**75 %**	**50 %**	**15 %**	**0 %**
Soil erosion				
Slope	< 5 ° (< 9 %)	5 °–10 ° (9–18 %)	10 °–25 ° (18–47 %)	> 25 ° (> 47 %)
Elevation	< 1 500 m	< 1 500 m	< 1 500 m	> 1 500 m
Soil compaction				
Peat land	No	No	Peat	
Soil water regime	Wet to a depth of 80 cm, < 6 months	Wet to a depth of 80 cm, < 6 months	Wet to a depth of 80 cm, > 6 months	Wet to a depth of 40 cm, > 11 months
Soil fertility				
Base saturation				
in topsoil	> 50 %	< 50 %		
in subsoil	> 50 %	< 50 %		
Soil type (FAO85 Lv1)	Cambisol; Chernozem Podzoluvisol; Kastanozem Rendzina; Gleysol Phaeozem; Fluvisol Luvisol; Greyzem Andosol; Vertisol; Town	Podzol Water	Histosol Ferralsol Planosol	Ranker; Arenosol Lithosol; Xerosol Solonchak; Regosol Acrisol; Solonetz Marsh

Note: Grey-shaded cells: criterion must be fulfilled (AND). No shading: criterion is optional (OR).

change. This additional bioenergy potential could only be roughly estimated.

4.3.1 *Scenario assumptions*

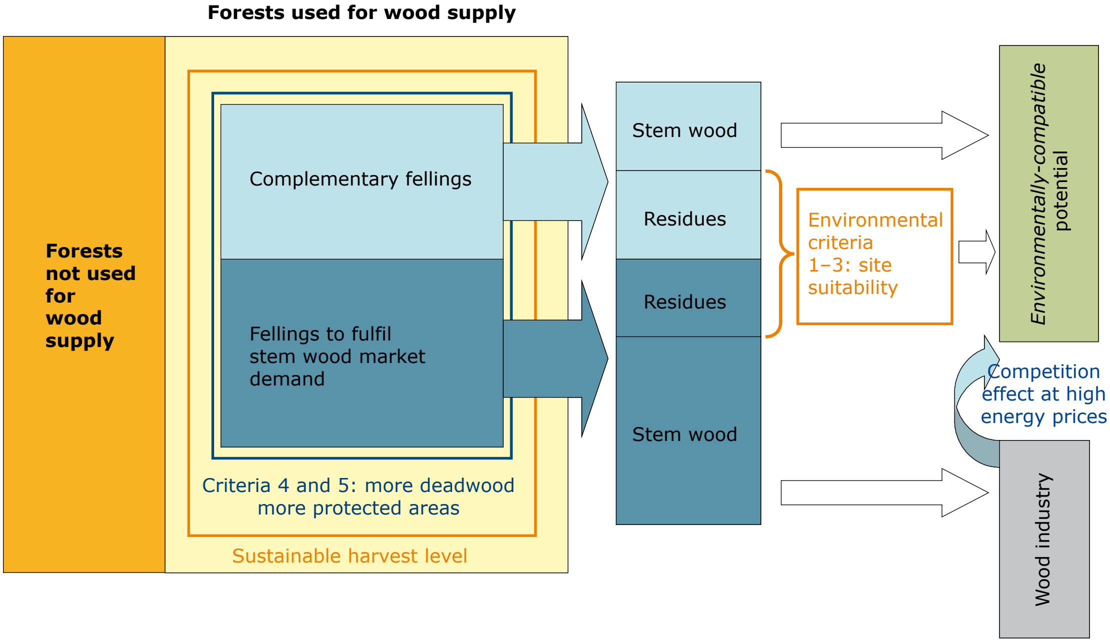
The amount of forest residues is directly dependent on the demand for stem wood. On the other hand, the complementary fellings are inversely-proportional to the demand for stem wood. Thus, this is the most important driver behind the available forestry potential. The demand was based on FAO statistics and a slow increase in demand was implemented from 2006 onwards. This is consistent with the general assumptions of this study (Chapter 2). The further development of the demand was based on the projections for OECD Europe (Image Team, 2001) which in turn were based on the B2 storyline of the Intergovernmental Panel on Climate Change (IPCC). This scenario suggests an increase in wood demand of 20 % between 2000 and 2030.

In order to determine the amount of residues from the projected stem wood demand, the ratio of stem volume to biomass in tree compartments (stem, branches, foliage, coarse and fine roots) is required. This varies considerably between species, age classes and growing conditions. In this study, age- and species-dependent biomass expansion factors were used. These factors were developed in the CarboInvent project (Joanneum *et al.*, 2005) for Germany, Finland, Sweden, Ireland and Austria and were here applied also to additional countries.

The bioenergy potential from complementary fellings is defined as the difference between maximum sustainable harvest level and actual harvest. The maximum sustainable harvest was calculated based on a formula developed by Heyer (1841, 'Nachhaltshiebsatz' — sustainable harvest level), which aims to equalise the age-class distribution (equal areas in each age class), and to provide both constant increment levels and a continuous harvest level. This formula is suggested as a sustainability indicator for example by the Forest Stewardship Council (FSC). This maximum sustainable harvest level was reduced by 10 % to account for an assumed increase in protected forest areas as well as of large diameter trees and deadwood in managed forests.

An increase in the carbon permit and fossil fuel prices is likely to increase the price that people are willing to pay for wood used to generate energy. Some signs of the effect of high energy prices on the forest sector and wood industries can already be seen today. The general storyline assumes an increase in the oil price up to EUR 62 per barrel (comprising the energy price and the assumed carbon permit price). This would lead to an additional forest energy potential as the market value of forest biomass for bioenergy increased (see Annex 3). The competition effect was estimated by allocating wood resources to different industry branches including bioenergy industries according to supply and demand principles within the wood market. The amount of biomass was converted into

Figure 4.2 Schematic presentation of the approach for forestry biomass flows



the bioenergy potential by using the net calorific value (see Annex 5).

4.3.2 Models

The European Forest Information Scenario (EFISCEN) model was used to project the possible future development of forest resources in the European Union (Karjalainen *et al.*; 2002, Nabuurs *et al.*, 2003; Päivinen *et al.*, 1999). The model uses national forest inventory data as input. Only 21 of the EU-25 Member States could be included in the scenario analysis because no suitable inventory data was available for Greece, Luxembourg, Malta and Cyprus.

EFISCEN simulates only forest area that is available for wood supply. Unproductive forests as well as nature conservation areas are excluded from the analysis. In that way, the environmental criteria of no intensification in protected areas was inherently applied (28). The majority of the area not available for wood supply would probably have been classified as marginally suitable or unsuitable for residue extraction. However, part of the area may have constituted an additional resource for biomass utilisation. This means that the results give a conservative estimate of the forest area that can be used for biomass extraction.

The resource projections in EFISCEN are driven by the market demand for roundwood, which determines the amount of fellings. Demand equals the supply when enough volume is available for thinnings or final fellings, according to the model projections. If this is not the case, supply will be smaller than the demand. The results are produced on a regional NUTS2 basis for most countries. For Spain, Italy, Portugal, the Baltic countries, Slovenia and Slovakia the national forest inventory data did not allow for a distinction of regions.

Both residues and complementary fellings were calculated using the environmental assumptions described in Section 4.2.2. The calculation of forest residue potentials thus considered only stem residues (tops) and branches as it was assumed that roots and foliage would remain in the forest. Complementary fellings were calculated with the reduced maximum sustainable harvest level.

Applying the site specific suitability map (Figure 4.1) in order to determine the adapted residue extraction rates required that the EFISCEN results were made spatially more explicit. For that purpose, the forest map of Europe was used (Päivinen *et al.*, 2001; Schuck *et al.*, 2002). This provides information on the proportion of forest with a 1 x 1 km resolution. It was assumed that growing stocks and biomass resource potentials per unit of forest area were distributed homogeneously within the EFISCEN regions. This assumption is less problematic in countries where it was possible to distinguish between several regions from the national forest inventory (e.g. in Central Europe). However, for Spain and Italy the countries were modelled as a whole in EFISCEN, and therefore the results for these countries should be treated with caution (both the total potential and the regional distribution).

The suitability map was then overlaid with the forest map. The site-specific extraction potentials were linked to the unconstrained resources as calculated by the EFISCEN model. This resulted in biomass resource potentials for each pixel of the forest map. By aggregating the grid-based energy potentials to the NUTS2 regions level, the *environmentally-compatible* bioenergy potential for forest residues from stem wood demand and complementary fellings for each NUTS2 region was calculated.

The competitive effect of increasing fossil fuel prices was estimated with the EFI-GTM model. EFI-GTM is a regionalised, global partial equilibrium model for forestry and forest industries (Kallio *et al.*, 2004). Its main function is to provide consistent analysis of how and by how much production, consumption, imports, exports, and prices of roundwood and forest industry products might change over time. Changes may take place as a response to changes in external factors, such as economic growth rates, trade regulations, or demand for wood products on the world market. As such, EFI-GTM was able to calculate the competition between wood utilisation for energy generation and for other purposes. With increasing market value for bioenergy, more wood chips that are currently used by board manufacturers and the paper industry would become available for generating bioenergy.

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(28) A country-level comparison showed that the areas of forest *not* available for wood supply were greater than the forest area of the proposed Natura2000 sites for all countries except Germany, the Netherlands and Belgium. This difference was small for Germany and the other two countries only account for a small proportion of EU forest resources. Since some Natura2000 sites may not restrict forest management and no account has been taken of increasing forest areas through afforestation activities, it was concluded that the model appropriately incorporated this criteria. Therefore, no further constraint was applied to account for protected areas in the assessment of forest residues.

4.4 *Environmentally-compatible* bioenergy potential from forestry

4.4.1 *Results and assessment*

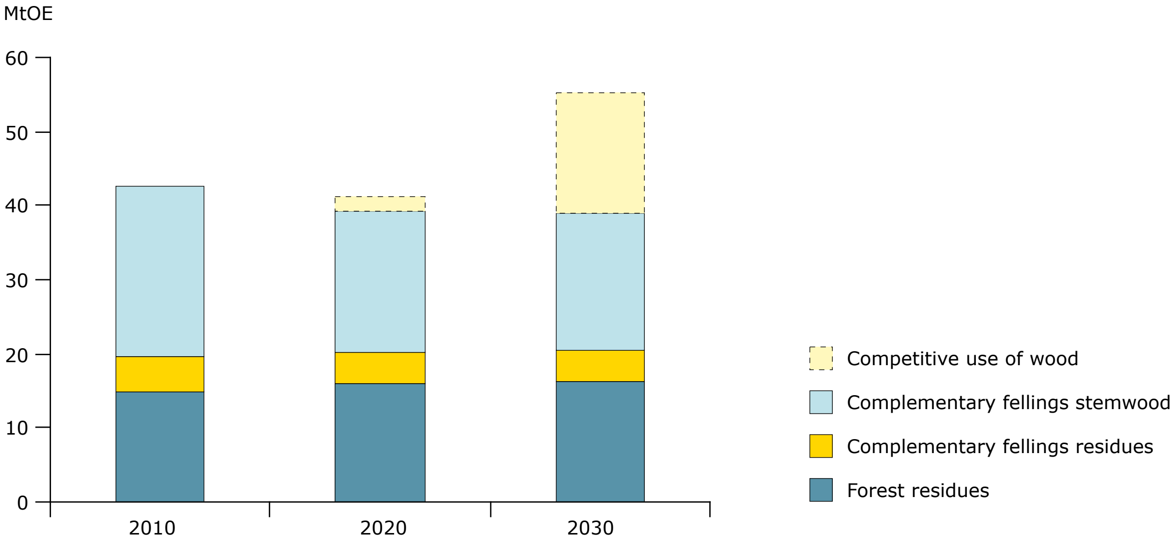
The *environmentally-compatible* bioenergy potential from forestry residues is estimated to be around 15 MtOE in 2010, increasing to 16.3 MtOE in 2030. An additional 28 MtOE in 2010 and approximately 23 MtOE in 2030 could be provided by complementary fellings and their residues. The increase in forest residues from regular fellings is the result of a rising demand for traditional forest products. At the same time, the rise in the harvest level for traditional products implies that the potential for complementary fellings decreases.

If rising fossil energy prices are assumed, substantial additional amounts of wood biomass resources may be used for bioenergy and not in competing industries by 2030. Increasing market values for bioenergy would lead to mobilisation of wood biomass resources for bioenergy from other competing industries currently utilising wood resources. The energy potential from competitive use of wood would increase from around 2 MtOE in 2020 to more than 16 MtOE in 2030 (29), mostly at the expense of pulp and paper production. Pulp and paper production might decline by around 5 % in 2020 and up to 38 % in 2030 under the given price assumptions. This would imply that the black liquor potential from pulp and paper reduction was reduced by a similar amount (see Chapter 5).

Additional forestry biomass potential could be available in Greece, and to a small extent in Luxembourg, Malta and Cyprus, which were not included in the analysis due to lack of data. Also the currently growing forest area in the EU was not taken into account, but could be considered to deliver additional biomass. However, this will become important mainly towards the end of the examined period and beyond. Furthermore, an additional 2 MtOE of forest residues might be extracted if ash recycling was taken into account (see Section 4.4.3).

The analysis did not take into account potential impacts of climate change and increasing atmospheric CO_2 contents on forest growth. Currently these factors seem to stimulate forest growth and could therefore increase the available biomass potential especially from northern and central European forests (see Chapter 2). Improved forest management practices could further increase the productivity of the forests. However, the relative high standard of forest management in Europe means that this potential is relatively small. It should also be noted that with revised management strategies, a certain percentage of

Figure 4.3 ***Environmentally-compatible* bioenergy potential from forests**



Note: Calculations cover EU-25 Member States without Cyprus, Greece, Luxembourg and Malta

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(29) The energy value of wood chips was assumed to be 64 EUR/m^3 in 2020 and 94 EUR/m^3 in 2030 (see Annex 3). If a higher oil price of EUR 50 per barrel was assumed, the potential being redirected from competing industries would increase to 6 and 33 MtOE in 2020 and 2030, respectively.

the complementary fellings could come from pre-commercial thinnings, which do not compete with the traditional forest resource use.

Figure 4.4 shows the spatial distribution of the *environmentally-compatible* energy potential from forest residues at the NUTS2 level. The energy potential by land area is given in the map on the left. The map on the right gives the energy potential for forest residues by forest area, characterising the average resource density in the available forests per unit of forest area.

It can be seen that high resource density per unit of forest area does not necessarily coincide with extensive forest resources in the NUTS2 regions. The highest resource densities for forest residues are located in central Europe and the United Kingdom, but the average share of forest of the total land area is higher in northern Europe. Southern Sweden and Finland are characterised by high energy potential mainly due to the high proportion of forest area in these countries, whereas in central Europe the average biomass volumes in forest stands are higher.

The potential for residue extraction is generally low in the Mediterranean area. This is partly due to existing constraints, such as unproductive soils, and partly due to low biomass density. However, residue extraction can in some cases be beneficial to prevent forest fires. An additional potential as a result of fire prevention measures was not included due to the lack of data about the affected volumes and the regional importance of this practice. Furthermore,

Figure 4.4 ***Environmentally-compatible*** **bioenergy potential from residues in 2030**

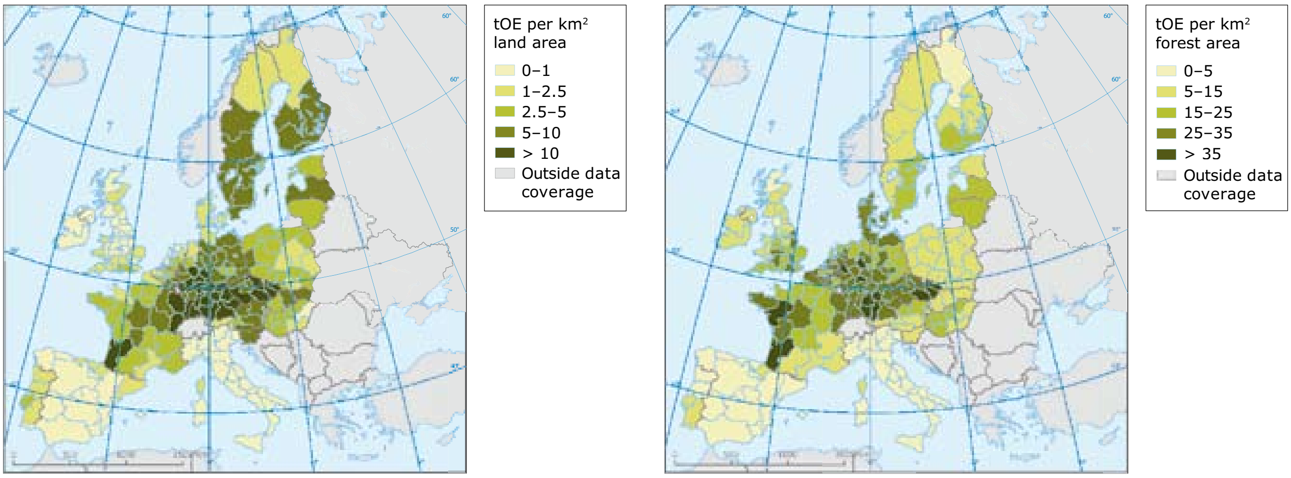
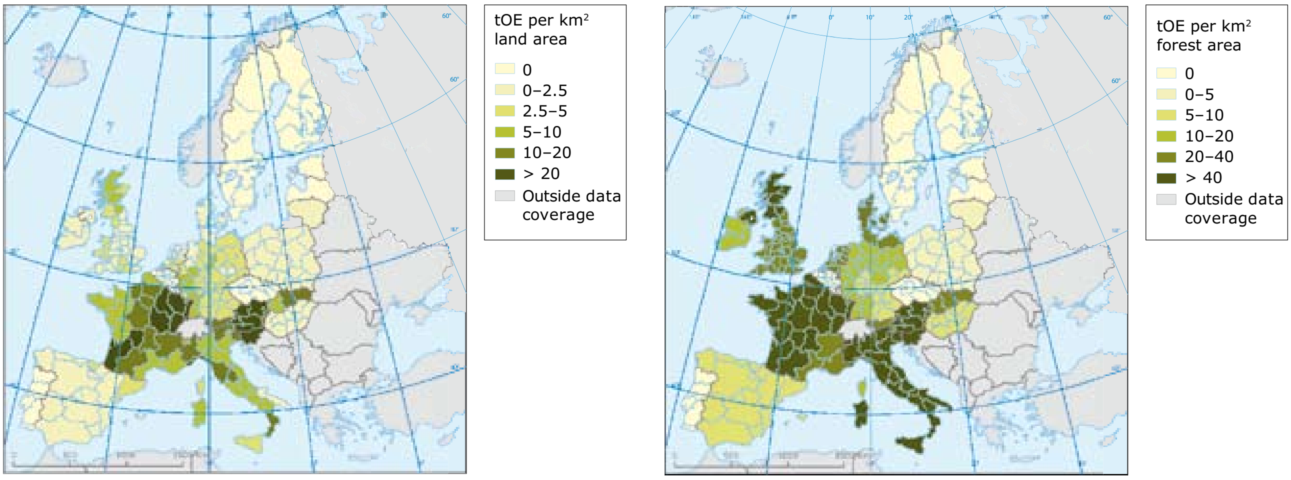


Figure 4.5 ***Environmentally-compatible*** **bioenergy potential from complementary fellings in 2030**



Note: The potential for Cyprus, Greece, Malta and Luxembourg could not be modelled. The regional distribution of the potential within Spain and Italy should be treated with caution due to constraints in regional data.

the total potential in the Mediterranean may be underestimated because the forest resource database excluded other woodland and forest area not available for wood supply. Both land categories could potentially play a significant role in providing biomass for generation of bioenergy in the Mediterranean, where there is a large amount of area classified as 'other woodland'.

Figure 4.5 presents the spatial distribution of the *environmentally-compatible* energy potentials from complementary fellings in 2010. There is considerable potential for an increase in fellings in many parts of Europe, particularly in central Europe, Italy, France, and the United Kingdom. In Spain, only a small share of the increment is currently utilised for felling so the felling level could be increased considerably.

In Portugal, Belgium, Estonia and Latvia, the maximum sustainable harvest level has already been reached or even exceeded by regular felling. Also, in northern Europe — Czech Republic and Hungary — a high share of the increment is already used today. Hence, there would be no additional felling potential available under increased consideration of nature protection and biodiversity.

4.4.2 Synergies

The removal of biomass for energy can also provide other environmental benefits. For example, nutrient export with forest residues can have a positive effect in certain ecosystems on forest land with a high nitrogen load. The extraction of logging residues can remove a significant amount of nitrogen (Samuelsson, 2002). This counteracts the accumulation of nitrogen that can result in nitrogen leaching, soil acidification and changes in vegetation.

The additional potential of this effect was estimated in a sensitivity analysis. Gains in the residue extraction potential due to atmospheric nitrogen deposition were found relevant for countries such as Denmark, the Netherlands, Germany, France, Poland and southern Sweden. The additional bioenergy potential would be in the order of 0.6–0.7 MtOE for the EU throughout the time period analysed.

Woody harvest residues and deadwood constitute a fire risk in Mediterranean countries. Removal of biomass for bioenergy production could thus help to reduce the risk of forest fires and facilitate fire extinction. Also, biomass from creating corridors of fire protection can be utilised which would give an economic value to this operation.

While in general the low utilisation of annual increment has created positive conditions for biological diversity, some man-made forests have not been thinned. This is due to the lack of market demand and low prices. In such cases thinning for biomass utilization could provide an opportunity to open very dense coniferous forest plantations, and thereby improve the habitat value of these forests for many species.

4.4.3 Sensitivities and robustness of approach

This section discusses some of the limitations of the approach used and compares results with those of other studies. Limitations can be separated into three areas:

1. Selection and quantification of environmental constraints (in particular: the effect of fertilisation);
2. Assumed modelling constraints;
3. Data availability.

1. There is relatively little information about the link between management intensity as regards bioenergy extraction and the effects on threatened species and species diversity. The assumptions used in this study may not therefore represent the optimal balance between nature conservation and biomass production. This also applies to other environmental issues such as watershed protection and flood control, where a lack of information made it impossible to include such criteria. Finally, the available European soil map does not cover all the land area in the forest map. Those areas of forest that are not covered were excluded from the analysis.

   The most important environmental constraints for residue extraction were related to: (i) slope and elevation in mountainous regions; (ii) the water regime, especially in northern Finland, the Baltic states, and northern United Kingdom; and (iii) soil fertility in most other regions. Compared to a development without environmental constraints, the *environmentally-compatible* residue potential is about 40 % less.

   Soil fertility was the single criteria which constrained residue extraction most. Almost 20 % of the EU-21 forest area was classified as moderately suitable, based on their low base saturation, and despite their high suitability according to all the other relevant attributes.

   If fertilisation was considered as an option for compensating nutrient export on soils with low base saturation, an additional potential from forest residues would result. This potential was estimated in a sensitivity analysis that assumed the application of fertilizers on soils classified as podzols. These areas would then become highly suitable instead of moderately suitable with a related increase in the extraction potential (if no other constraints applied). The additional potential was found to be 2 MtOE, equivalent to around 12 % of the total potential from harvest residues without compensatory fertilisation. Most of this additional potential would be in Sweden and Finland. While application of inorganic fertilizers can be criticised for the fossil fuel emissions linked to the production process and the negative side effect of enhanced N_2O emissions from the soil, application of wood ash might offer an interesting alternative (Ingerslev *et al.*, 2001).

2. The analysis did not take into account the increase in forest area. Between 1990 and 2000, the annual afforestation rate in the EU has been about 360 000 ha per year. It is expected that this trend will continue (EURuralis, 2004). However, a substantial amount of this area has been planted with slow growing broadleaved species and it would take longer than 30–40 years before significant biomass would be available from these afforestation areas. The situation would be different with fast growing short rotation forest crops. Although this went beyond the scope of this study, it could add an additional potential to the results. About the same gain in European forest area is due to spontaneous regrowth, but is not immediately harvestable.

   Due to modelling constraints, eucalyptus plantations were not included in this study. In Portugal, they constitute about 20 % of the total forest area. If an average productivity of 15 oven-dry tonnes of biomass per hectare with a share of residues of 10 % is assumed, their residues might thus deliver an extra potential of residues in the order of 0.4 MtOE.

3. The underlying forest resources data from the national forest inventories were only available in aggregated form at regional level. The European forest map shows where the forests are located within the regions. The assumption was then made that average growing stocks within EFISCEN regions are distributed homogeneously. This is not the case in reality as there are differences between forest types and management regimes within the regions. Consequently, the local potential for biomass extraction may deviate from the regional average which is represented in the maps and tables.

   Due to incomplete inventory data, Cyprus, Greece, Luxembourg and Malta were not included in this study. While forest areas in Cyprus, Luxembourg and Malta are small, they are widespread in Greece, where half of the land is covered by forest and other wooded land. It is therefore realistic to assume an additional, albeit small, potential in Greece (0.3 MtOE).

   There are also limitations in access to the spatial information needed to specify some environmental criteria. In particular, there is a lack of consistent spatial information about all protected forests in Europe, and information on the management activities allowed in the different protected areas.

   The low spatial resolution of the available data on a European scale often made it difficult to define and quantify the environmental criteria. For example, the soil layer has a 10 km grid and fairly broad class ranges. This was an issue particularly for soil fertility.

   The coarse resolution of the available digital elevation model at the European scale results in an under-representation of forest area with steep slopes. This effect was partly compensated for by the introduction of an elevation filter, which declared the high elevation (> 1 500 m) sites unsuitable for residue extraction. Nevertheless, at a resolution of 0.8 x 0.8 km smaller landscape features cannot be detected. These features restrict the application of technology which enables efficient resource utilisation.

Despite restrictions in the underlying data and model constraints, the results of this study lie in the same range as other studies where similar definitions of the potentials are compared (Table 4.2). The theoretical, *non-environmentally-compatible* residue potential of this study is similar to a study by Siemons *et al.* (2004). The current work reports higher potentials than the EFFECT study (Meuleman *et al.*, 2005), because it focused on the assessment of resource potentials without taking into account the economic viability of extraction or the accessibility of the resources. Both factors would reduce the estimated biomass resource use potential from forest residues.

The only other study that reported a separate estimate of the biomass potential from complementary fellings was Karjalainen *et al.* (2004). They report a difference between increment and fellings in EU-25 of approximately 186 million m^3 per year. Without the environmental constraints, the present study calculated a potential for complementary fellings of 162 million m^3 in 2010 (approximately 32 MtOE), which corresponds reasonably well to the above mentioned estimate.

Table 4.2 Comparison of results for forest residues with other studies

Reference	**Geographical coverage**	**Energy potential from forest residues in MtOE**		
		2000/2005	2010	2020
This study, *environmentally-compatible* potential	EU-13	11.0	11.5	12.3
	EU-21	14.3	14.9	15.9
This study, baseline without environmental constraints	EU-13	18.1	18.9	20.3
	EU-21	24.1	25.1	26.8
Bioenergy's role in the EU Energy Market — A view of developments until 2020 (Siemons *et al.*, 2004)	EU-15	17.5	19.3	21.3
Bioenergy's role in the EU Energy Market — Biomass availability in Europe (Nikolaou *et al.*, 2003)	EU-14	14.8		
Estimation of Energy Wood Potential in Europe (Karjalainen *et al.*, 2004)	EU-25	12.4		
Effect: EU forest for renewable energy to mitigate climate (Meuleman *et al.*, 2005)	EU-15	3.2		

Note: EU-13 comprises EU-15 Member States without Greece and Luxembourg; EU-21 comprises EU-25 Member States without Cyprus, Greece, Luxembourg and Malta; EU-14 comprises EU-15 Member States without Luxembourg.

5 Bioenergy potential from wastes

5.1 Introduction

As European society has grown wealthier it has created more and more waste. Over 1.8 billion tonnes of waste are generated each year in Europe. This includes waste and residues from households, the commercial sector, industry, agriculture, construction and demolition, mining and quarry activities, and energy generation. Although data on the generation of waste is incomplete, it is known that the quantities of many important waste streams are increasing and that overall levels of waste generation are rising.

With the generation of such vast quantities of waste, it is vitally important that waste is managed in ways that minimise harm to the environment and human health. To achieve these aims, EU policy sets out overarching principles for waste management ([30]) one of which is a waste management hierarchy. Under this principle, waste management strategies must aim primarily to prevent the generation of waste and to reduce its harmfulness. The target of reducing the volumes of waste generated was strengthened in the 5th environment action programme and constitutes one of the priorities of the 6th environment action programme. Where waste reduction is not possible, waste materials should be reused, recycled or recovered (e.g. composting) or used as a source of energy (e.g. anaerobic digestion, incineration with energy recovery). As a final resort, waste should be disposed of safely.

A significant proportion of the waste generated is biowaste i.e. waste of biological origin. This can be used to generate energy, thus helping to reduce climate change. This chapter considers a range of waste streams arising from agriculture, industry and households. Forestry residues are considered in Chapter 4 while grass cuttings are covered under agriculture in Chapter 3.

Biowaste comprises residues and by-products and wastes of biological origin arising from agriculture, industry and households. The following specific waste streams were considered:

- Solid agricultural residues — cereal and rapeseed straw, stalks from sunflowers and prunings from vineyards and olive trees;
- Other agricultural residues — greentops from potatoes and beets;
- Wet manure — manure from cows, pigs and laying hens;
- Dry manure — manure from fattening hens;
- Municipal solid waste (MSW) — the component of municipal solid waste which is of biological origin (mainly kitchen and garden waste, paper and cardboard, but also the component of other waste fractions which are of biological origin);
- Black liquor — liquid by-products from the pulp and paper production industry;
- Wood-processing waste wood — waste wood in the form of sawdust and off cuts from primary wood processing (sawmills) and secondary wood processing (e.g. furniture manufacture);
- Construction/Demolition wood — wood off cuts from building construction and wood recovered during demolition;
- Packaging waste wood — from the packaging and palettes industry (from palettes, crates, etc);
- Household waste wood — items such as old furniture, fencing;
- Sewage sludge;
- Food processing wastes — wastes from the dairy and sugar industry and wine and beer production.

([30]) See http://europa.eu.int/comm/environment/waste/index.htm.

This chapter assesses the primary potential for energy production from biowastes, while at the same time respecting the waste hierarchy mentioned above. It also ensures that an increased bioenergy demand does not counteract aims for waste reduction. Furthermore, the underlying assumptions are consistent with both the macroeconomic and the environmental criteria used in the agricultural and forestry assessments.

5.2 Environmental considerations

5.2.1 *Potential environmental pressures of bioenergy production*

Unlike dedicated bioenergy crops, biowaste and residues are not produced specifically for use as an energy resource nor do they serve important environmental functions. Biowastes are already produced in significant quantities. They are the result of economic activity and production of goods in almost all sectors of the economy. As the production of biowaste occurs anyway, the diversion of biowaste to energy recovery options does not increase environmental pressures. Indeed the diversion of biowaste away from waste management options, such as landfill, to energy recovery will alleviate some of the environmental pressures associated with landfill. In addition, it will provide benefits associated with production of bioenergy (such as avoided greenhouse gas emissions) (31).

Given the assumed increase in the energy and carbon permit price, the economic value of bioenergy derived from biowaste increases over time. This might reduce incentives to minimise the production of biowastes (e.g. by extending the useful lifetime of bio-based products, minimising packaging). It could also attract portions of the biowaste streams which are currently recycled (e.g. paper from the municipal solid waste stream, demolition wood used for chipboard production) or for which there is another market (e.g. food processing or agricultural residues used for animal feeds into use as an energy resource). This might increase environmental pressures as recycling of some waste products is generally more environmentally beneficial than incineration (e.g. study for paper: EEA, 2006b).

5.2.2 *How to avoid increased environmental pressures?*

The following environmental criteria were assumed when considering the potential for energy from biowaste:

1. Ambitious waste minimisation.
2. No energy recovery from waste currently going to recycling or reuse.
3. All household waste that is currently landfilled or composted will be made available for energy production.
4. Production of timber/wood products and paper declines in line with nature conservation scenarios.
5. More extensive farming practices which influence the availability of agricultural residues.

1. Ambitious waste minimisation: *Household waste is reduced by 25 % compared to a business-as-usual scenario.*

As discussed above, one of the main aims of EU policy on waste is preventing waste generation. In the case of household waste, the EU had a target in its 5th environmental action programme to stabilise the generation of municipal waste per capita per year at the average 1985 EU level of 300 kg by the year 2000. This target has not been met and the average amount of municipal waste generated per capita per year in many western European countries has reached more than 500 kg. Also the 6th environmental action programme identifies waste prevention and management as one of the top priorities, aiming at a significant overall reduction of waste volumes generated.

It was assumed in this analysis that in future significant effort would be directed towards reducing waste generated by households. By 2030, household waste generation would be reduced by 25 % compared to a business as usual scenario (32). This means that the average amount of municipal solid waste per capita and year would be 475 kg instead of 633 kg in a business-as-usual case.

2. No energy recovery from waste currently going to recycling or reuse. The fractions of waste streams that are currently recycled or reused are considered not to be available for use as an energy resource. These streams include waste paper which is

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(31) Combustion of biowaste (as well as other biomass feedstock) can lead to emissions of air pollutants, particularly if mixed with materials contaminated with heavy metals.

(32) This assumption was developed in an EEA expert meeting (see also Gewiese *et al.*, 1988).

recycled; straw which is reused within agriculture; and agricultural and food processing wastes which are reused as animal feed. For example, it was assumed that 37 % of the straw will not be available for energy production in the *environmentally-compatible* scenario (and 33 % in a business-as-usual scenario) as it is used for other purposes such as animal bedding or for ploughing-in. Regarding green tops, 17 % of potato tops and 2 % of sugar beet tops were estimated to be available. Between 10 % and 50 % of food processing waste was considered to be available for energy production (depending on the source), as the remainder is already utilised by industry (e.g. as input to other food products or animal feeds).

3. All household waste that is currently incinerated or landfilled without energy recovery is assumed to be available for incineration with energy recovery. *Similarly waste that is currently composted is assumed to be first anaerobically digested in order to allow energy recover. The digestate is then composted.*

Landfill and incineration without energy recovery are the least favoured options in the waste management hierarchy as they offer no or very limited opportunity for recovering useful resources (either materials or energy) from the waste (33). It is therefore assumed in this study that all waste, which are currently landfilled, become available as a resource for incineration with energy recovery. This moves the treatment of this waste type up the waste hierarchy.

The diversion of the biodegradable content of municipal solid waste is already required by the landfill directive (EC, 1999). The amount of biodegradable municipal waste going to landfill needs to be reduced in the future, so that by 2016 (2020 for countries which currently have a heavy reliance on landfill) only 35 % (34) of biodegradable municipal waste may be disposed of through landfill.

Some Member States have more stringent national legislation, and have banned the disposal of all biodegradable waste to landfill. Some alternatives to landfilling of waste (e.g. mechanical biological treatments and composting) offer opportunities for material recovery but not for energy recovery. It is assumed that all such waste be anaerobically digested instead. The digestate from the process could then be made available (after further curing if necessary) as compost. This allows the recovery of biogas for energy generation from the waste as well as well as material (compost), thus improving overall resource recovery from the waste.

4. Consistency with the forest tree sector*.* The production of timber/wood products and paper (and hence the waste from these processed) are assumed to grow at a reduced rate compared to a business-as-usual scenario. This rate is in line with the nature conservation and increased emphasis on waste prevention, recycling and reuse assumed in the scenario storyline. Moreover, this assumption corresponds with the assumptions made for the forestry sector.

5. Consistency with the agricultural sector. As described in Chapter 3, 30 % of the utilised agricultural area (20 % in a few Member States) should become environmentally-oriented farming (EOF) by 2030. This assumption is also made in estimating agricultural biowastes. This influences the availability of some agricultural residues. For example, an increased use of straw for bedding is assumed in extensive and organic farming systems compared to traditional intensive agriculture (see above).

5.3 Approach: methodology and scenario development

A wide variety of biowaste streams were considered in the study. The availability of the information on the quantities of current biowaste and forecasts of future biowaste production differed significantly across the waste streams. Three different approaches were therefore used (Figure 5.1) to estimate current and future resource availability in an *environmentally-compatible* scenario. In broad terms the three approaches were:

1) For municipal solid waste and construction and demolition waste, forecasts of waste generation were available under a business-as usual scenario. The effects of the environmental criteria on the forecast were then estimated directly to give an estimate of resource availability in the *environmentally-compatible* scenario, e.g. by assuming the 25 % waste reduction compared to a baseline.
2) For agriculture and food wastes the scenario developed for the assessment of the *environmentally-compatible* agricultural bioenergy potential was used. This scenario was combined

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(33) Energy can be recovered from waste that is landfilled, through recovery and combustion of the landfill gas that is produced.

(34) 35 % of biodegradable municipal waste produced in 1995.

with information on the amount of biowaste generated per tonne of product and per animal, and the availability of this waste after other uses. The practices in environmentally-orientated farming were taken into account. For example, yields in environmentally-oriented farming are generally lower, but the use of longer stemmed varieties gives more straw per tonne of product. However, more straw is required for use as bedding.

3) For other biowaste streams, estimates of current quantities were obtained and then projections of the main socio-economic driver for that waste production were used to generate forecasts of future biowaste arising. The impact of the environmental criteria on those drivers (e.g. reduced demand for a product) was then considered in order to produce a forecast of waste quantities.

5.3.1 Scenario assumptions

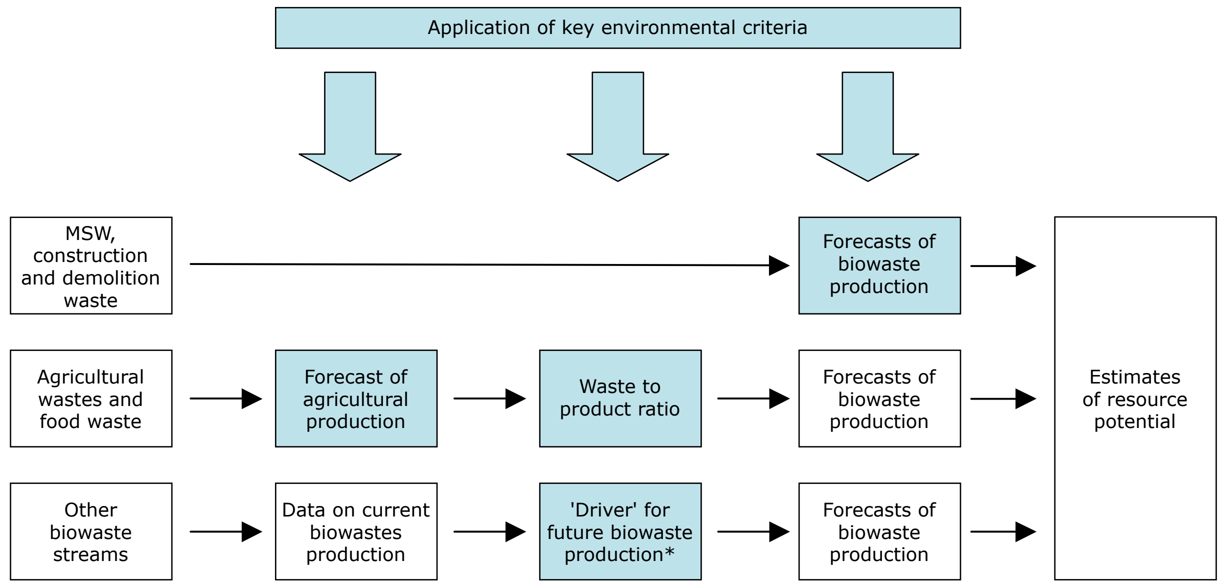
Projections of the amount of biowaste depend on the development of the economy and society. For this study an *environmentally-compatible* scenario was considered in which it is assumed that Europe develops in a more sustainable way. As well as a desire to promote biomass and other renewable energy resources, the scenario assumes that society responds strongly to other environmental concerns, e.g. waste minimisation.

The underlying socio-economic assumptions (e.g. GDP at national and sectoral level, population, number of households etc.) were taken from energy and emissions modelling carried out previously for the EEA using the PRIMES model (LCEP scenario, see Chapter 2 and Annex 1; EEA, 2005a). The same projections of agricultural activity (e.g. crop production and livestock populations) were used to calculate the potential from agricultural residues, animal manures and food processing wastes. In order to be consistent with the agricultural section in Chapter 3, the effects of an increasing share of environmentally-oriented farming were considered.

In the case of the biodegradable component of municipal solid waste, the amount of waste generated is based on projections by the European Topic Centre on Resource and Waste Management (Skovgaard *et al.*, 2005). These were prepared for the EEA outlooks report (EEA, 2005d). However, it is assumed that waste generation can be reduced by 25 % by 2030, due to household waste prevention measures (based on data from Gewiese *et al.*, 1988). The fraction of waste that is biodegradable is assumed to remain constant into the future.

For black liquor, estimates in the growth of pulp and paper production, and hence black liquor production, are taken from the LCEP scenario (see Annex 1). These estimates are then reduced by 25 % in order to bring them more into line with

Figure 5.1 Overview of the modelling approach for biowaste streams



* For example, population, number of households, GDP e.g. population, households, growth in industry, demand for product.

the estimates made by the Food and Agricultural Organisation for wood used for paper and pulp production under a sustainable scenario (FAO, 2005). In the case of high energy and carbon prices, the same assumptions are used as for the forest sector. At an assumed wood chip price of EUR 64 and EUR 94 per m^3 in 2020 and 2030, pulp production would decrease by around 5 and 38 %, respectively. It was assumed that the black liquor potential would decrease similarly. Advanced technologies may increase the energy recovery per tonne of pulp, but were not taken into account.

Estimates in the growth of waste wood from wood processing were also based on the FAO conservation scenario for roundwood, sawnwood and woodbased panels.

Changes in the amount of construction and demolition wood available in the future are based on projections of construction and demolition waste made by the European Topic Centre on Resource and Waste Management (Skovgaard *et al.*, 2005; EEA, 2005d). Packaging waste wood is based on GDP projections, with a 25 % reduction in the growth rate to allow for waste minimisation. The growth in household waste wood is based on projections of household numbers. This is also the main driver for the projections of municipal solid waste.

The growth in sewage sludge production is also based on projections of the number of households. Advanced sewage treatment methods to improve the quality of discharges from sewage treatment works and hence improve water quality may be introduced over the next decades. They are likely to lead to increases in the amount of sewage sludge produced. However, this was not estimated in this study. Nevertheless, the effect on the overall potential would be limited as sewage sludge amounts to only 1.4 % of the biowaste potential.

5.3.2 Models

A number of spreadsheet models were developed to estimate the resource potentials. The main models underpinning key data were:

- Agriculture models such as CAPSIM — for projections of agricultural activity (e.g. crop production and livestock populations) — in order to calculate the potential from agricultural residues, animal manures, and food processing waste.
- Models developed by the EEA's Topic Centre on Resource and Waste Management. These provided projections of waste and material flows. They also examined the historical relationships between waste flows and their driving forces (e.g. the number of households, population, consumption of goods) in order to be able to project future waste flows.

5.4 *Environmentally-compatible* bioenergy potential from waste

5.4.1 Results and assessment

The biowaste resource for the EU-25 is 99 MtOE in 2010 and is dominated by five waste streams: solid agricultural residues (of which almost all the resource is in cereal straws), wet manures, wood processing residues, municipal solid waste and black liquor. These waste streams account for almost 90 % of the resource (Figure 5.2).

The total biowaste resource is projected to remain almost constant between 2010 and 2030. Compared to the year 2000, it increases by 10 %. While a number of the biowaste resources grow significantly, such as wood processing waste and demolition and construction waste, the assumed waste minimisation practices for household waste led to a decline in municipal waste generation. Compared to a business-as-usual development, there are also significant reductions in the wood processing residues resource (3 MtOE in 2030) and the black liquor resource (2 MtOE in 2030). This is due to reduced demand for wood products and paper.

A more important decrease in the black liquor potential would occur as a result of high energy and carbon permit prices. In that case, some wood may be used directly for energy generation instead of pulp and paper production, thus reducing the potential by 0.8 MtOE in 2020 and 6.3 MtOE by 2030. The overall *environmentally-compatible* biowaste potential would then decrease between 2020 and 2030 to 95.8 MtOE, remaining almost at the year 2000 level.

The packaging waste wood resource declines, as it is assumed that waste minimisation measures reduce the amount of packaging waste. For agriculture based resources, the growth in solid agricultural residues and wet manures resources are much smaller than in the business-as-usual scenario. For solid agricultural residues, the lower yields in organic farming give lower crop production. This is then partially offset by the use of longer stemmed varieties of cereals which deliver more straw per tonne of cereal produced. However, organic farming of livestock requires more straw for animal bedding. Therefore, the overall resource is reduced by around

9 % compared to the business-as-usual resource in 2030. The wet manure resource shows only slight growth. This reflects smaller increases in livestock populations in the *environmentally-compatible* scenario. Overall, this meant that the growth rate is under half of that seen in the business-as-usual scenario.

The *environmentally-compatible* biowaste potential by Member State is presented in Figure 5.3. The distribution of the biowaste resources across the Member States varies significantly, and the make up of the biowaste resource within some countries differs significantly from the average across the EU-25. For example, solid agricultural residues are a particularly important biowaste resource for France, Hungary, and Poland. Wood processing residues form the majority of the biowaste resource in Estonia and Latvia, and are also very significant in Austria. Black liquor is an important source for Portugal, Finland and Sweden, but might decrease in the case of high energy and carbon prices.

5.4.2 Synergies

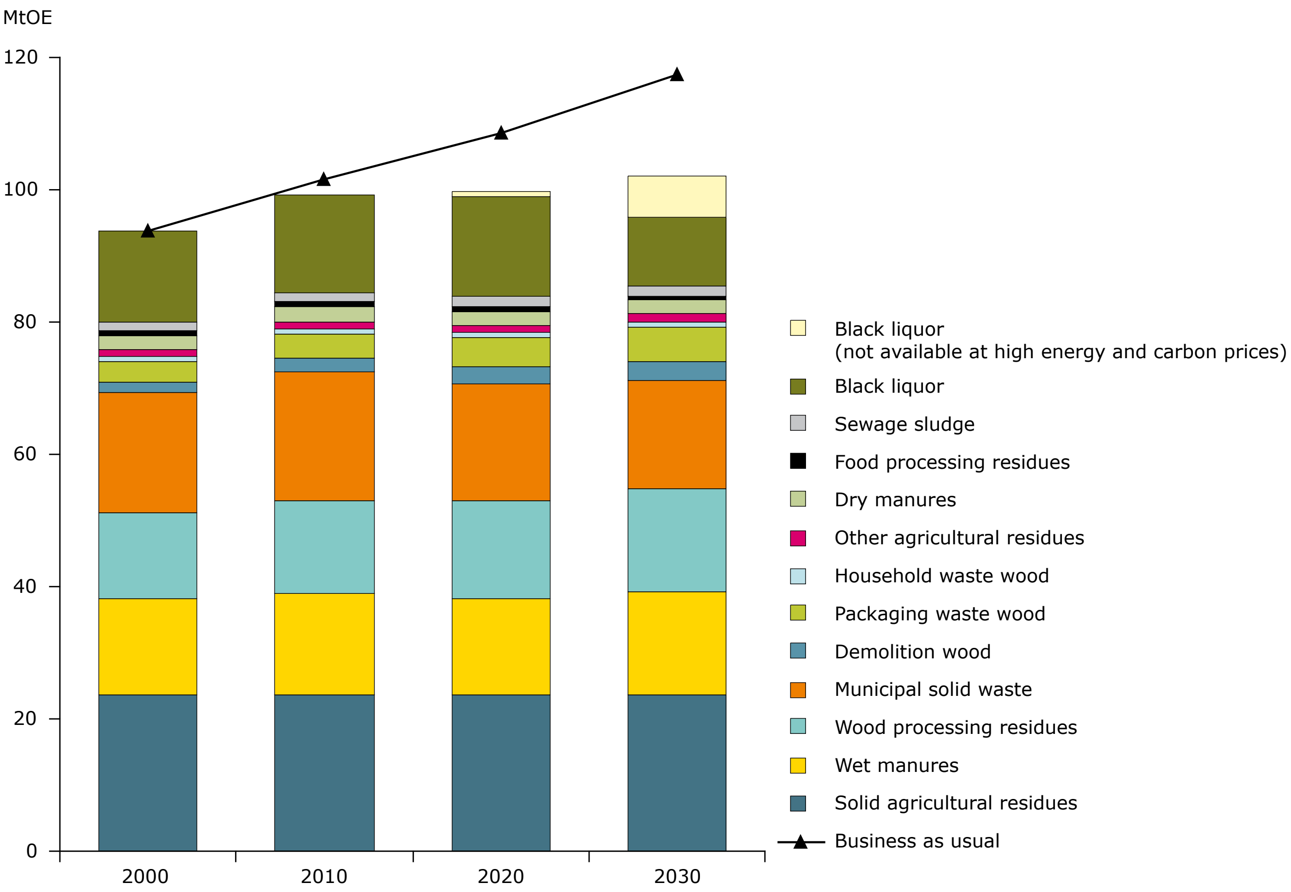
As discussed above utilising biowaste for energy recovery rather than disposal via landfilling or incineration without energy recovery, moves management of that waste up the waste hierarchy. It contributes to reductions of greenhouse-gas emissions and liquid effluents.

5.4.3 Robustness of approach

The greatest uncertainties in the resource estimates are the:

- Historical waste statistics used to estimate wood processing residues and packaging, household, and construction and demolition waste.
- Assumed prevention potential of households waste generation. The assumptions are in line with the policy-objectives to reduce waste generation. The quantification of such

Figure 5.2 *Environmentally-compatible* biowaste energy potential in EU-25



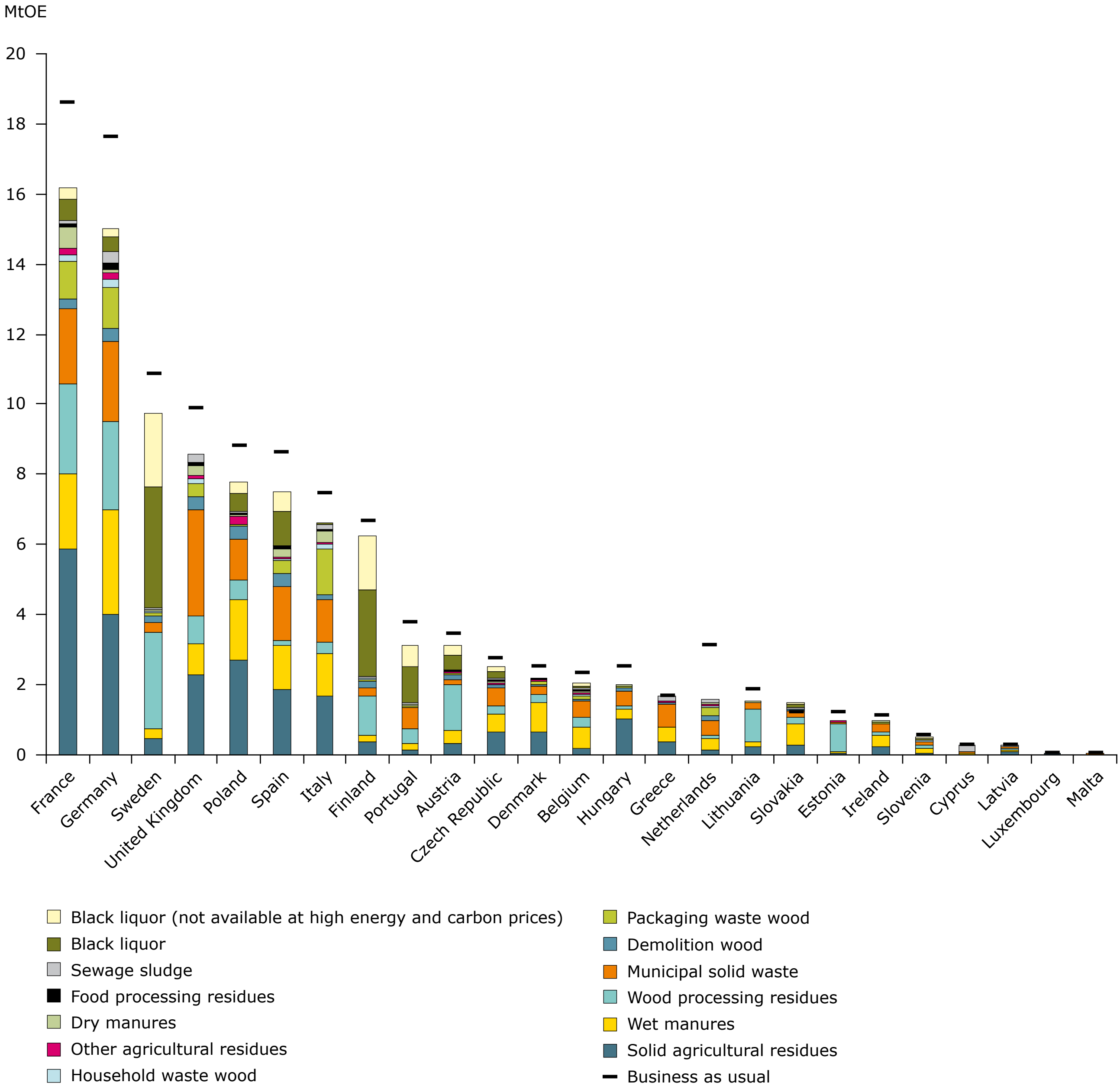
Note: The 'black liquor potential not available at high energy and carbon prices' indicates the reduction in the potential for the case that wood is redirected from pulp and paper to energy production (see Figure 4.3). This was assumed to happen at high energy and carbon permit prices that increase the 'energy value' of wood chips to exceed the commodity price.

assumptions is, however, based on a few case studies only, due to lack of more complete analysis.

- Use of average 'European' values for calculating the amount of crop residues and animal manures available. These tend to be derived from northern European data and may not be as appropriate for southern European countries.
- Competing uses of some waste streams (e.g. waste wood for chipboard manufacture, food processing residues for animal feeds). With rising fossil energy and CO_2 permit prices an increase in the value of the waste streams as an energy resource may occur. This could lead to waste being diverted away from the competing use, thus increasing the available resource.

The resource availability in 2000 (as calculated in this study) has been compared with two other studies. The first study was carried out for the European Commission to assess bioenergy's role in the EU energy market (Siemons *et al.*, 2004). It considered the total biomass potential to 2020 for the EU-25 plus Bulgaria and Romania. The second one is a study for the German Government (IE, 2004), which covers the EU-25 plus Bulgaria, Romania and Turkey. Overall, the estimates of the current

Figure 5.3 ***Environmentally-compatible* biowaste energy potential in 2030 by Member State**



biowaste resources determined here are similar to these studies. This comparison shows that the biowaste potential calculated here for the year 2000 (including Bulgaria, Romania and Turkey) is 4 % more than the resource estimated in the study by Siemons *et al.* (2004), if similar waste streams are compared. It is also 5 % less than that in the IE study. Differences at the individual waste stream level are greater. The key causes of the differences between the studies include different sources of waste statistics, and assumptions about the amount of waste streams available for energy conversion.

6 Overall results and future challenges

Substantially increasing the production of bioenergy from agriculture, forestry and waste biomass offers significant opportunities for Europe to reduce greenhouse gas emissions and to diversify and secure energy supply. In addition, it might create additional income for farmers and thus help to promote new economic perspectives for rural regions.

On the other hand, greater production of bioenergy could set incentives for a more intense use of agricultural land and forests, and might counteract the objectives of waste reduction policies. An increase in bioenergy production thus bears the risk of additional environmental pressures on biodiversity, and soil and water resources. However, these pressures can be minimised, for example by growing low-impact bioenergy crops and not allowing the ploughing of permanent grasslands or by adapting the intensity of residue extraction to local soil conditions. Applying a number of environmental rules and standards seems therefore necessary when increasing bioenergy production.

This report assessed the amount of biomass that is technically available for energy production without increasing pressures on the environment or counteracting current and potential future EU environmental policies and objectives. As such, the study developed a number of environmental assumptions for bioenergy production as a basis for modelling the available bioenergy potential in a consistent way for the sectors agriculture, forestry and waste.

The following environmental assumptions were used in this study:

- At least 30 % of the agricultural land is dedicated to 'environmentally-oriented farming' in 2030 in every Member State (except for Belgium, Luxembourg, Malta and the Netherlands, where 20 % was assumed).
- Extensively cultivated agricultural areas are maintained: grassland, olive groves and dehesas are not transformed into arable land.
- Approximately 3 % of the intensively cultivated agricultural land is set aside for establishing ecological compensation areas by 2030.
- Bioenergy crops with low environmental pressures are used.
- Current protected forest areas are maintained; residue removal or complementary fellings are excluded in these areas.
- The forest residue removal rate is adapted to local site suitability. Foliage and roots are not removed at all.
- Complementary fellings are restricted by an increased share of protected forest areas and deadwood.
- Ambitious waste minimisation strategies are applied.

The study concludes that a significant amount of biomass can technically be available to support ambitious renewable energy targets even if these strict environmental constraints are applied. The overall *environmentally-compatible* biomass potential increases from 190 MtOE in 2010 to around 295 MtOE in 2030. This compares to a use of 69 MtOE in 2003, of which the *environmentally-compatible* part is included in the overall potential. These figures represent around 16 % of the EU-25 projected primary energy requirements in 2030 under the conditions assumed in this study (35). They also represent 17 % of the current energy consumption, compared with a biomass share of 4 % in 2003.

The potential is sufficient to reach the European renewable energy target in 2010. This requires an estimated 150 MtOE of biomass use according to the Biomass Action Plan, which can avoid some 210 Mt CO_{2eq}. The potential also allows ambitious future renewable energy targets beyond 2010 that may require around 230–250 MtOE of primary biomass.

The regional distribution of the *environmentally-compatible* bioenergy potential (see Table 6.1) — especially for bioenergy crops — and their respective costs could lead to broader economic benefits for some Member States. For instance, the analysis indicates that at least for Poland, exports of bioenergy (products) could be envisioned in the medium-term (36). Similarly, some of the forest and

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(35) In a baseline scenario, this amount of biomass would represent 15 %.

(36) As other research has shown, this is also true for Romania (see IE/BFH/HU/ÖKO, 2006).

agricultural residues may also be subject to trade, either as processed solid biofuels or once converted as liquid or gaseous biofuels.

This study has provided a comprehensive overview of the *environmentally-compatible* bioenergy potential. However, it only represents the *first step* in identifying and *ultimately realising* this potential. The study does *not* analyse policies and measures needed to ensure that environmental criteria are implemented. It cannot be assumed that the correct incentives and necessary safeguards are in place already. Therefore, even a significantly lower exploitation of the biomass resource than the assumed *environmentally-compatible* potential could lead to increased environmental pressures. However, if environmental considerations are sufficiently taken into account, increasing the use of bioenergy will not only avoid greenhouse gas emissions but can in some cases also offer wider benefits to the environment.

The **way ahead** needs to include a refinement and analysis of the assumptions and the approach. This should aim at achieving greater regional resolution of the results that take account of national and possibly also local pressures and solutions. In addition, the following points need to be addressed:

Table 6.1 The *environmentally-compatible* bioenergy potential (in MtOE) by Member State and sector in 2010, 2020, 2030

	2010				2020				2030			
	Agriculture	Forestry	Waste	Total	Agriculture	Forestry	Waste	Total	Agriculture	Forestry	Waste	Total
Austria	0.6	3.3	3.0	**6.9**	1.4	3.3	3.1	**7.8**	2.1	3.5	3.1	**8.7**
Belgium	0.1	0.1	2.1	**2.3**	0.1	0.1	2.1	**2.3**	0.1	0.2	2.0	**2.3**
Germany	5.0	6.3	14.9	**26.2**	13.7	5.3	14.8	**33.8**	23.4	4.8	15.0	**43.2**
Denmark	0.4	0.1	2.3	**2.8**	0.1	0.2	2.2	**2.5**	0.1	0.2	2.2	**2.5**
Spain	7.8	1.7	7.1	**16.5**	12.9	1.8	7.3	**22.0**	16.0	1.5	7.5	**25.1**
Finland	1.9	1.7	6.1	**9.6**	1.8	1.8	6.2	**9.8**	1.3	1.8	6.2	**9.4**
France	2.6	12.7	16.1	**31.4**	7.8	13.2	16.2	**37.2**	17.0	14.2	16.2	**47.4**
Greece	0.0	n.a.	1.6	**1.6**	1.7	n.a.	1.6	**3.4**	2.2	n.a.	1.7	**3.8**
Ireland	0.0	0.1	1.0	**1.1**	0.1	0.1	1.0	**1.2**	0.1	0.1	1.0	**1.3**
Italy	4.1	5.6	6.5	**16.2**	8.9	3.3	6.5	**18.7**	15.2	3.0	6.6	**24.8**
Luxembourg	n.a.	n.a.	0.0	**n.a.**	n.a.	n.a.	0.0	**n.a.**	n.a.	n.a.	0.0	**n.a.**
Netherlands	0.2	0.1	2.4	**2.6**	0.5	0.1	1.6	**2.2**	0.7	0.2	1.6	**2.4**
Portugal	0.7	0.2	2.7	**3.6**	0.8	0.2	2.9	**3.9**	0.8	0.2	3.1	**4.1**
Sweden	0.6	2.2	8.9	**11.7**	1.1	2.4	9.5	**13.0**	1.4	2.4	9.7	**13.5**
United Kingdom	3.4	1.5	8.6	**13.5**	8.8	1.5	8.7	**19.0**	14.7	1.1	8.6	**24.5**
EU-15	27.2	35.7	83.3	**146.2**	59.8	33.2	83.7	**176.6**	95.0	33.3	84.7	**213.0**
Czech Republic	0.8	0.8	2.2	**3.8**	1.3	0.8	2.3	**4.5**	1.6	0.9	2.5	**5.0**
Cyprus	n.a.	n.a.	0.3	**0.3**	n.a.	n.a.	0.3	**0.3**	n.a.	n.a.	0.3	**0.3**
Estonia	0.4	0.2	0.9	**1.5**	1.1	0.2	0.9	**2.2**	1.3	0.2	1.0	**2.6**
Hungary	1.2	0.2	2.1	**3.6**	2.2	0.2	2.1	**4.5**	3.1	0.4	2.0	**5.6**
Lithuania	2.0	0.7	1.4	**4.1**	5.6	0.6	1.4	**7.6**	7.9	0.4	1.6	**9.9**
Latvia	0.4	0.6	0.3	**1.3**	1.0	0.6	0.2	**1.9**	1.5	0.6	0.3	**2.4**
Malta	n.a.	n.a.	0.05	**0.05**	n.a.	n.a.	0.05	**0.05**	n.a.	n.a.	0.04	**0.04**
Poland	14.5	2.0	7.3	**23.8**	24.1	1.5	7.4	**33.0**	30.4	1.2	7.8	**39.3**
Slovenia	0.0	1.3	0.5	**1.8**	0.1	1.1	0.5	**1.7**	0.2	1.0	0.5	**1.8**
Slovakia	0.2	1.0	1.0	**2.2**	0.6	0.9	1.0	**2.4**	1.2	0.9	1.5	**3.6**
New EU-10	**19.5**	**6.8**	**16.0**	**42.4**	**36.0**	**5.9**	**16.2**	**58.1**	**47.3**	**5.7**	**17.5**	**70.5**
EU-25	**46.8**	**42.5**	**99.3**	**188.5**	**95.8**	**39.2**	**99.8**	**234.7**	**142.4**	**39.0**	**102.1**	**283.4**
Net competition effect for forestry						2.1	-0.8	1.3		16.2	-6.3	9.9
EU-25	**46.8**	**42.5**	**99.3**	**188.5**	**95.8**	**41.3**	**99.0**	**236.0**	**142.4**	**55.2**	**95.8**	**293.3**

Note: The agricultural potential comprises dedicated bioenergy crops plus cuttings from grassland. Agricultural residues such as straw and manures are part of the category waste. The forestry potential consists of residues from fellings and complementary fellings. The 'net competition effect for forestry' includes an additional potential due to wood chips redirected from pulp and paper to energy production, which is partly offset by a reduction in the black liquor potential due to the decrease in pulp and paper production. This potential strongly depends on the assumed carbon permit and oil price.

Potential co-benefits between bioenergy production and nature conservation

- Forest management and the removal of residues can contribute to reducing fire risk, especially in forests that are currently unmanaged. The use of such biomass to generate energy could cover some of the cost of fire-prevention measures.
- Similarly, the use of grass cuttings for bioenergy can provide some economic benefit to the management of species-rich grasslands, and thus help to prevent land abandonment and loss of valuable open habitats.
- Bioenergy production can reduce environmental pressure compared to intensive farmland management, if the right crop mix and cropping practice are selected.

- Assessing the overall environmental impact and the benefits of bioenergy production and use requires an **analysis of the whole life-cycle** of bioenergy production. This should include a discussion on how best to use the available biomass potential. Different uses in the competing end-use sectors electricity/heat/transport fuels and different conversion pathways strongly influence the amount of avoided greenhouse gas and air pollutant emissions. Such an assessment was not part of this study, but a rough estimate indicates that the use of the potential calculated saves direct greenhouse gas emissions in the order of 400 to more than 600 Mt CO_2 in 2030 ([37]). The avoided life-cycle emissions will be lower as some emissions occur during the production of biomass through, for example, the production of fertilisers.

  Further research is required to identify potential measures and technologies that minimise life-cycle greenhouse gas emissions while preventing negative trade-offs with air emissions and nature protection. This would best be complemented by an assessment of economics and logistics. For example, biomass conversion plants that use a diverse range of feedstock are less vulnerable to disruptions in the supply flow.

  The choice of the bioenergy conversion pathways also determines the environmental pressures of bioenergy production and its potential, particularly in the agricultural sector. An increased use of large-scale conventional biofuel technologies adjusted to current cropping patterns will be likely to reinforce current trends (e.g. intensification, specialisation, abandonment of marginal grasslands). New technologies and pathways, which allow for a wider range of feedstock, can support crop diversification.

- Most important will be analysis of a **policy framework** that is needed to avoid potential environmental drawbacks and increase potential benefits of bioenergy production. This requires policy action at a range of levels. The EU common agricultural policy already offers a considerable range of tools in support of such action; many of which need to be implemented at Member State or local level. European-level guidance can be an important step in that direction. Annex 6 sets out a range of policy options that can be considered in this context.

  In addition, national and regional administrations as well as producer organisations have a special responsibility in developing and implementing environmental safeguards for bioenergy production. This can be particularly effective as the current biofuels market is to a large degree created as an artificial market by governments. The national Biomass Action Plans (as proposed in EC, 2005b) could be one first step in that direction. Environmental guidelines would then also have to be applied to imported biofuels.

- Finally, the available bioenergy resources and their use in competing end-use sectors depend on **choices** made by the society. This requires a wider involvement of European society, from policy makers to businesses, researchers, NGOs and consumers.

  Depending on the primary aim of increasing biomass utilisation (such as environmental protection, security of supply, rural income), different conversion pathways appear favourable. From an environmental point of view, bio-heat and -electricity production as well as advanced transport fuel conversion technologies allow the use of a broad range of feedstock. This feedstock can include waste and residues and also enables

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([37]) A part of this theoretical emission reduction is already realised by the current use of biomass.

a rapid introduction of high yield, low impact crops. The production of conventional, first generation transport fuels depends on a limited number of crops and uses only the starch or oil parts of those. Thus, they operate on reduced efficiency compared to whole-plant uses. On the other hand, transport biofuels can directly substitute oil in a sector that is highly dependent on oil imports.

Furthermore, it seems likely that there will be increasing competition between food/fodder and bioenergy production on agricultural land. This study assumed such competition to take place only on areas that produce food for export, so as not to decrease European food self sufficiency. However, the extent to which a substitution of food production is desirable needs to be discussed within society.

Overall, increasing the share of bioenergy sources in total energy consumption in Europe is an important goal for reducing greenhouse gas emissions; increasing energy security; and creating alternative activities for rural areas. However, it is important to ensure that increased production of such 'green energy' is *environmentally-compatible*. This study has shown options for making bioenergy production *environmentally-compatible*. To realise this goal and to implement the activities outlined above now requires action at the local, national and European level.

References

Andersen, E. (ed), 2003. *Developing a High Nature Value Farming area indicator.* Report to the European Environment Agency. Copenhagen.

Angelstamm, P., 1992. 'Conservation of communities: the importance of edges, surroundings, and landscape mosaic structure'. In: L. Hansson, (ed.), *Ecological principles of nature conservation*. London, Elsevier, p. 9–70.

Bignal, E.M., D.I. McCracken, 1996. 'Low-intensity farming systems in the conservation of the countryside'. *Journal of Applied Ecology* 33: 413–424.

Bignal, E.M., D.I. McCracken, 2000. 'The nature conservation value of European traditional farming systems'. *Environmental Reviews* 8: 149–171.

Bruinderink, G., v/d Sluis, T., Lammertsma, D.R., Opdam, P., Pouwels, R., 2003. 'Designing a coherent ecological network for large mammals in Northwestern Europe'. *Conservation biology*, Vol 17, No 2.

Council, 2006. Presidency Conclusions European Council 23/24 March 2006. Council Document 7775/06. European Council, 2006.

Crouzet, 2001. *Calculation of nutrient surpluses from agricultural sources*. Technical report No 51. Copenhagen. European Environment Agency. 62 pages.

Donald, P.F., Pisano, G., Rayment, M.D., Pain, D.J., 2002. 'The Common Agricultural Policy, EU enlargement and the conservation of Europe's farmland birds'. *Agriculture, Ecosystems & Environment*.

EC, 1997. White Paper: Energy for the future — renewable sources of energy, COM(97)599 final. European Commission, 1997.

EC, 1999. Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste, European Commission, 1999.

EC, 2000, Green Paper: Towards a European Strategy for Energy Supply Security, COM(2000)769 final, European Commission, 2000.

EC, 2001. Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market, European Commission, 2001.

EC, 2002a. Council Decision 2002/358/EC: Council Decision of 25 April 2002 concerning the approval, on behalf of the European Community, of the Kyoto Protocol to the United Nations Framework Convention on Climate Change and the joint fulfillment of commitments there under.

EC, 2002b. *Analysis of the Impact on Agricultural Markets and Incomes of EU Enlargement to the CEECs.* European Commission DG AGRI, 2002.

EC, 2003a. Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport, European Commission, 2003.

EC, 2003b. Council Regulation (EC) No 1782/2003 of 29 September 2003 establishing common rules for direct support schemes under the common agricultural policy and establishing certain support schemes for farmers and amending Regulations (EEC) No 2019/93, (EC) No 1452/2001, (EC) No 1453/2001, (EC) No 1454/2001, (EC) 1868/94, (EC) No 1251/1999, (EC) No 1254/1999, (EC) No 1673/2000, (EEC) No 2358/71 and (EC) No 2529/2001, European Commission, 2003.

EC, 2004. Communication of the European Commission of 26/05/2004 on the share of renewable energy in the EU, COM(2004)366 final. European Commission, 2004.

EC, 2005a. *Report On The Green Paper On Energy — Four years of European initiatives*, European Commission 2005.

EC, 2005b. Communication from the European Commission on the Biomass Action Plan, COM(2005)628 final. European Commission, 2005.

EC, 2005c. *Biomass, Green Energy for Europe*. European Commission, DG Research. Luxembourg: Office for official publications of the European Communities.

EC, 2006. Communication from the European Commission on An EU Strategy for Biofuels, COM(2006)34 final. European Commission, 2006.

EEA, 2004. *Impacts of European's changing climate. An indicator-based assessment.* EEA Report, No 2/2004.

EEA, 2005a. *Climate change and a European low-carbon energy system.* EEA Report, No 1/2005.

EEA, 2005b. *The European Environment — State and Outlook 2005.* Copenhagen.

EEA, 2005c. *Agriculture and environment in EU-15-the IRENA indicator report.* EEA Report, No 6/2005.

EEA, 2005d. *European Environment Outlook.* EEA Report, No 4/2005.

EEA, 2006a. *Progress towards halting the loss of biodiversity by 2010.* EEA Report No 5/2006.

EEA, 2006b (in prep). 'Paper and Cardboard — recovery or disposal? Review of LCAs and CBAs on the recovery and disposal of paper and cardboard'. EEA Technical report, forthcoming.

EEA/JRC, 2006. 'Sustainable Bioenergy cropping systems in the Mediterranean. Proceedings of the workshop 9–10 February 2006', forthcoming.

EEA/UNEP, 2004. *High nature value farmland.* European Environment Agency and UNEP regional office for Europe. EEA report, No 1/2004.

Elbersen. B. *et al*., 2005. 'Large-scale biomass production and agricultural land use — potential effects on farmland habitats and related biodiversity'. Technical report, EEA study contract EEA/EAS/03/004. Wageningen-Copenhagen, forthcoming.

EP, 2005. *Report on the share of renewable energy in the EU and proposals for concrete actions,* (2004/2153(INI)). European Parliament, Rapporteur: Claude Turmes. A6-0227/2005.

EURuralis, 2004. *A scenario study on Europe's Rural Areas to support policy decisions*. Wageningen University and Research Center, RIVM.

EUCAR, Concawe, JRC/IES, 2006. *Well-to-wheel analysis of future automotive fuels and powertrains in the European context.* Well-to-tank report. Version 26, March 2006.

EuroCare, 2004. Outlooks on selected agriculture variables for the 2005 State of the Environment and the Outlook Report. EEA/RNC/03/016.

FAO, 2005. *European Forest Sector Outlook Study: 1960-2000-2020*, Main Report by the Food and Agriculture Organisation (FAO) of the United Nations, Geneva Timber and Forest Study Paper 20, 2005.

Feehan, J., Petersen, J.E., 2003. A framework for evaluating the environmental impact of biofuel use. Paper presented at the OECD workshop on biomass and agriculture. June 2003.

Foppen, R.P.B, Bouwma, I.M., Kalkhoven, J.T.R., Dirksen, J., v. Opstal, J., 2000. *Corridors in the Pan-European Ecological Network.* ECNC Technical Series. ECNC, Tilburg.

Foster, C., 1997, Biodiversity of wildlife in energy crop plantations. p. 87–108 In: Bijl. G. van der and E.E. Biewinga. Environmental impact of biomass for energy. Proceedings of a conference in Noordwijkerhout. The Netherlands 4–5 November 1996.

Fritsche, U.R., Dehoust, G., Jenseit, W., Hünecke, K., Rausch, L., Schüler, D., Wiegmann, K., Heinz, A., Hiebel, M., Ising, M., Kabasci, S., Unger, C., Thrän, D., Fröhlich, N., Scholwin, F., Reinhardt, G., Gärtner, S., Patyk, A., Baur, F., Bemmann, U., Groß, B., Heib, M., Ziegler, C., Flake, M., Schmehl, M., Simon, S., 2004. *Stoffstromanalyse zur nachhaltigen energetischen Nutzung von Biomasse.* Öko-Institut e.V., Institut für angewandte Ökologie, Freiburg, Darmstadt, Berlin.

Gewiese A. *et al*., 1988. *Abfallvermeidung — Ein Modellversuch in Hamburg-Harburg im Jahre 1987*. Berlin: INECTUS 1988 quoted in Abfallwirtschaft — Handbuch fur Praxis und Lehre, by: Bernd Bilitewski, Georg Hardtle, Klaus Marek.

Heyer, C., 1841, *Die Waldertragsregelung*, Giessen.

Hole, D.G., Perkins, A.J., Wilson, J.D., Alexander, I.H., Grice, P.V, Evans, A.D., 2005. 'Does Organic farming benefit biodiversity?' *Biological Conservation* 122 (2005) 113–130.

Hope, A., Johnson, B., 2003. Discussion Paper on Biofuels, Terrestrial Wildlife Team, English Nature.

Humphrey, J.W., Sippola, A.-L., Lempérière, G., Dodelin, B., Alexander, K.N.A., Butler, J.E., 2004. *Dead wood as an indicator for biodiversity in European forests: From theory to operational guidance*. In: Monitoring and Indicators of Forest Biodiversity in Europe —From Ideas to Operationality Ed. M. Marchetti. European Forest Institute, Joensuu, pp. 193–206.

IE, 2004. *2. Zwischenbericht. Nachhaltige Biomassenutzungsstrategien im europäischen Kontext: Analyse im Spannungsfeld nationaler Vorgaben und der Konkurrenz zwischen festen, flüssigen und gasförmigen Bioenergieträgern*, Institute for Energy and Environment, December 2004.

IE/BFH/HU/ÖKO, 2006. *Nachhaltige Biomassenutzungsstrategien im europäischen Kontext — Analyse im Spannungsfeld nationaler Vorgaben und der Konkurrenz zwischen festen, flüssigen und gasförmigen Bioenergieträgern*. Report to the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (in print), Leipzig etc.

Image Team, 2001. *The IMAGE 2.2 implementation of the SRES scenarios: A comprehensive analysis of emissions, climate change and impacts in the 21st century*. Main disc. National Institute for Public Health and the Environment, Bilthoven, the Netherlands.

Ingerslev, M., Mälkönen, E., Nilsen, P., Nohrstedt, H., Óskarsson, H., Raulund-Rasmussen, K., 2001. 'Main Findings and Future Challenges in Forest Nutritional Research and Management in the Nordic Countries'. *Scandinavian Journal of Forest Research*. 16:488–501.

Joanneum Research, European Forest Institute, Joint Research Centre, National University of Ireland, Finnish Forest Research Institute, Institute of Forest Ecosystem Research, Potsdam Institute for Climate Impact Research, Hungarian Forest Research Institute, Ghent University, Federal Forest Research Centre Austria, Swedish University of Agricultural Sciences, University of Hamburg, Centre for Ecological Research and Forestry Applications, Universität Padua, 2005: CarboInvent — Multi-Source Inventory Methods For Quantifying Carbon Stocks And Stock Changes In European Forests. http://www.joanneum.ac.at/carboinvent/index.php

Jongman, R., Bunce, R., Metzger, M., Mucher, C., Howard, D., 2005. 'A statistical Environmental classification of Europe: Objectives and Applications'. *Landscape Ecology*. In press.

Kallio, A.M.I., Moiseyev, A., Solberg, B., 2004. *The global forest sector model EFI-GTM. The model structure*. European Forest Institute, Joensuu, EFI Internal Report. 15.

Karjalainen, T., Pussinen, A., Liski, J., Nabuurs, G.-J., Erhard, M., Eggers, T., Sonntag, M., Mohren, F., 2002. 'An approach towards an estimate of the impact of forest management and climate change on the European forest sector carbon budget: Germany as a case study'. *Forest Ecology and Management*. 162:87–103.

Karjalainen, T., Asikainen, A., Ilavsky, J., Zamboni, R., Hotari, K.-E., Röser, D., 2004. Estimation of Energy Wood Potential in Europe. Finnish Forest Research Institute, Joensuu, Working Papers of the Finnish Forest Research Institute 06.

Kruys, N., Jonsson, B.G., 1999. 'Fine woody debris is important for species richness on logs in managed boreal spruce forests of northern Sweden'. *Can. J. For. Res*. 29:1295–1299.

MCPFE (Ministerial Conference on the Protection of Forests in Europe), 2003a. *State of Europe's forests 2003 .The MCPFE report on sustainable forest management in Europe.* Ministerial Conference on the Protection of Forests in Europe, Liaison Unit Vienna, Vienna.

MCPFE, 2003b. *Improved Pan-European Indicators for Sustainable Forest Management.* Ministerial Conference on the Protection of Forests in Europe, Liason Unit Vienna.

MCPFE, 2006, see MCPFE website http://www.mcpfe.org/.

Metzger, M., Bunce, R., Jongman, R., Mucher, C., Watkins, J., 2005. 'A statistical classification of the environment of Europe', *Journal of Global Ecology and Biogeography*. In press.

Meuleman, B., Kuiper, L., Nabuurs, G.J., 2005. *EFFECT : EU forest for renewable energy to mitigate climate*. ECOFYS, Confidential report by order of the European Commission DG Environment.

Nabuurs, G.J., Päivinen, J., Pussinen, A., Schelhaas, M.J., 2003. *Development of European forests until 2050 — a projection of forests and forest management in thirty countries*. In European Forest Institute Research Report. Brill, Leiden, Boston, Köln.

Nikolaou, A., Remrova, M., Jeliazkov, I., 2003. *Bioenergy's role in the EU Energy Market — Biomass availability in Europe.* Centre for Renewable Energy Sources, BTG Czech Republic s.r.o, ESD Bulgaria Ltd, Report to the European Commission.

Offermann, F., 2003. *Quantitative Analyse der sektoralen Auswirkungen einer Ausdehnung des ökologischen Landbaus in der EU.* Berliner Schriften zur Agrar- und Umweltökonomik. Berlin.

Opdam, P. J., Verboom, J., Pouwels R, 2003. 'Landscape cohesion: an index for the conservation potential of landscapes for biodiversity'. *Landscape Ecology* 18: 113–126.

Osterman, O. P., 1998. 'The need for management of nature conservation sites under Natura 2000'. *Journal of Applied Ecology* 35: 968–973.

Päivinen, R., Nabuurs, G.J., Lioubimow A.V., Kuusela, K., 1999. *The state, utilisation and possible future development of Leningrad region forests*, Joensuu, Finland, EFI Working Paper 18.

Päivinen, R., Lehikoinen, M., Schuck, A., Häme, T.,Väätäinen, S., Kennedy, P., Folving, S., 2001. *Combining Earth Observation Data and Forest Statistics*. Research Report 14. European Forest Institute, Joensuu.

Ragwitz, M., Schleich, J., Huber, C., Resch, G., Faber, T., Voogt, M., Coenraads, R., Cleijne, H., Bodo, P., 2005. *FORRES 2020: Analysis of the renewable energy sources' evolution up to 2020.* Final report. Karlsruhe, 2005. (Data on the related primary potential provided by M. Ragwitz, 2005).

Reijnders, L., 2006. 'Conditions for the sustainability of biomass based fuel use', *Energy policy* 34: pp. 863–876.

Reinhardt, G., Scheurlen, K, 2004. *Naturschutzaspekte bei der Nutzung erneuerbarer Energien.* Annex of report to the German Federal Agency for Nature Conservation. Leipzig.

Richardson, J., Björheden, R., Hakkila, P., Lowe, A.T., Smith, C.T., 2002. *Bioenergy from Sustainable Forestry: Guiding Principles and Practices*. Kluwer Academic, Dordrecht, the Netherlands.

Samuelsson, H., 2002. *Recommendations for the extraction of forest fuel and compensation fertilising.* National Board of Forestry (Skogsstyrelsen), Jönköping, Meddelande. 3 — 2002.

Schröter, D., Cramer, W., Leemans, R., Prentice, C., Araujo, M., Arnell, N., Bondeau, A., Bugmann, H., Carter, T., Gracia, C., de la Vega-Leinert, A., Erhard, M., Ewert, F., Glendining, M., House, J., Kankaanpää, S., Klein, R., Lavorel, S., Lindner, M., Metzger, M., Meyer, J., Mitchell, T., Reginster, I., Rounsevell, M., Sabate, S., Sitch, S., Smith, B., Smith, J., Smith, P., Sykes, M., Thonicke, K., Thuiller, W., Tuck, G., Zaehle, S., Zierl, B., 2005, 'Ecosystem Service Supply and Vulnerability to Global Change in Europe'. *Science Vol* 310 (25), pp. 1333–1337.

Schuck, A., Meyer, P., Menke, N., Lier, M., Lindner, M., 2004. *Forest biodiversity indicator: Dead wood — A proposed approach towards operationalising the MCPFE indicator*. In: Monitoring and 41 Indicators of Forest Biodiversity in Europe —From Ideas to Operationality Ed. M. Marchetti. European Forest Institute, Joensuu, pp. 49–77.

Schuck, A., van Brusselen, J., Päivinen, R., Häme, T., Kennedy, P., Folving, S., 2002. *Compilation of a calibrated European forest map derived from NOAA-AVHRR data*. European Forest Institute, Joensuu, EFI Internal Report. 13.

Siemons, R., Vis, M., v.d. Berg, D., Chesney, I.M., Whiteley, M., Nikolaou, N., 2004. *Bio-Energy's role in the EU Energy Market — A view of developments until 2020.* BTG biomass technology group BV, ESD Ltd, CRES, Report to the European Commission.

Simon, S., 2005, *Nachhaltige Energetische Nutzung von Biomasse — dynamische Ermittlung von Biomassepotenzialen in der Landwirtschaft zur Generierung von Szenarien.* In: Schriften der Gesellschaft für Wirtschafts- und Sozialwissenschaften des Landbaues e.V., Bd. 40/05, p. 351–360

Skovgaard, M., Moll, S., Møller Andersen, F., Larsen. H., 2005. Outlook for waste and material flows: Baseline and alternative scenarios, ETC/RWM working paper 2005/1, EEA.

Smith, K.A., Conan, F., 2004. 'Impacts of land management on fluxes of trace greenhouse gases'. *Soil Use Management*: 20, p. 255–263.

Söderström, B., Pärt, T., 2000. 'Influence of Landscape scale on Farmland birds breeding in semi-natural pastures'. *Conservation Biology* 14: 522-533.

Stolze, M., Piorr, A., Häring, A.M., Dabbert, S., 2000. *The environmental impacts of organic farming in Europe*. Organic Farming in Europe: Economics and Policy Vol. 6. Universität Hohenheim, Stuttgart-Hohenheim.

Sverdrup, H., Rosen, K., 1998. 'Long-term base cation mass balances for Swedish forests and the concept of sustainability'. *Forest Ecology and Management*. 110:221–236.

Tucker, G.M., Evans, M.I., 1997. *Habitats for Birds in Europe: a conservation strategy for the wider environment.* BirdLife Conservation Series No 6. Cambridge, Great Britain, BirdLife International.

Vellinga, V, van den Pol-van Dasselaar, A., Kuikman, P.J., 2005. 'The impact of grassland ploughing on CO_2 and N_2O emissions in the Netherlands'. *Nutrient Cycling in Agroecosystems* 70: 33–45.

Vickery, J., Bradbury, R., Henderson, I., Eaton, M., Grice, P., 2004. 'The role of agri-environment schemes and farm management practices in reversing the decline of farmland birds in England'. *Biological conservation* 119, p. 19–39.

Vos, C.C., Verboom, J., Opdam, P., Ter Braak, P., 2001. 'Toward ecologically scaled landscape indices'. *The American Naturalist*, Vol: 183, No 1.

Wadsworth, R.A., Carey, P.D., Heard, M.S., Hill, M.O., Hinsley, S.A., Meek, W.R., Pannell, D.J., Ponder, V., Renwick, A.W., James, K.L., 2003. *A review of Research into the environmental and socio-economic impacts of comtemporary and alternative cropping systems.* Report to Defra.

Annex 1: General scenario assumptions

Table A1 Main characteristics of the LCEP scenario with expanded renewables

	1990	2000	2010	2020	2030
Gross inland energy consumption (ktoe)	**1 554 333**	**1 650 700**	**1 761 899**	**1 816 685**	**1 826 931**
Solid fuels	430 600	303 200	206 326	120 821	76 653
Liquid fuels	596 184	635 600	612 963	606 535	556 740
Natural gas	259 191	376 000	488 644	581 831	595 089
Nuclear	196 944	237 700	245 307	210 248	203 595
Electricity	2 180	2 100	2 091	2 057	2 363
Renewable energy sources	69 234	96 100	206 567	295 194	392 491
Electricity generation (GWh$_e$)	**2 455 642**	**2 897 900**	**3 397 131**	**3 849 729**	**4 129 689**
Nuclear	780 025	921 200	952 609	822 467	841 517
Hydro — renewables	272 737	359 500	552 169	765 127	987 556
Thermal (incl. biomass)	1 402 880	1 617 200	1 892 352	2 262 134	2 300 616
Final energy demand (ktoe)	**1 009 710**	**1 074 400**	**1 186 945**	**1 263 169**	**1 290 128**
Industry	327 201	309 100	333 635	353 867	366 828
Tertiary	140 665	279 100	167 344	182 718	194 877
Households	268 112	154 200	303 361	315 269	311 552
Transports	273 732	332 000	382 606	411 316	416 871
CO$_2$ emissions (Mt CO$_2$)	**3 769.5**	**3 664.9**	**3 441.4**	**3 279.6**	**2 984.1**
CO$_2$ emissions (index; 1990 = 100)	**100**	**97.2**	**91.3**	**87**	**79.2**
Energy prices					
Crude oil (EUR$_{2\,000}$/GJ)	4.03	5.30	3.78	4.60	5.32
Hard coal (EUR$_{2\,000}$/GJ)	1.89	1.39	1.36	1.32	1.28
Natural gas (EUR$_{2\,000}$/GJ)	2.25	2.93	3.21	3.94	4.44
Renewable premium (EUR-cent/kWh)	0	0	1.2	2.4	4.5
Permit price (EUR /tCO$_2$)	0	0	12	30	65
Indicators					
Population (1 000)	441 127	453 400	461 227	462 113	458 161
GDP (1 000 MEUR$_{2000}$)	7 315	8 939	11 433	14 462	18 020
Gross inland consumption/GDP (toe/MEUR$_{2000}$)	212.5	184.7	154.1	125.6	101.4
Gross inland consumption/Capita (kgoe/capita) Use toe to be consistent	3524	3641	3820	3931	3988
CO$_2$ emissions/Capita (t of CO$_2$/capita)	8.5	8.1	7.5	7.1	6.5
CO$_2$ per unit of GDP (t of CO$_2$/MEUR$_{2000}$)	515.3	410.0	301.0	226.8	165.6
Carbon intensity (t of CO$_2$/toe)	2.4	2.22	2.0	1.8	1.6
Import dependency (percent)	44.8	47.2	50.0	56.1	55.5

Source: EEA, 2005a.

Annex 2: Share of environmentally-oriented farming

Table A2 **Estimated present and future share of environmentally-oriented farming in UAA, expressed in classes**

Year:	**Classes**			
	2000	**2010**	**2020**	**2030**
Austria	6	6	6	6
Belgium	1	2	3	6
Cyprus	n.a.	n.a.	n.a.	n.a.
Czech Republic	3	4	6	6
Denmark	2	3	5	5
Estonia	5	6	6	6
Finland	3	4	5	6
France	4	5	6	6
Germany	2	3	5	6
Greece	7	7	7	7
Hungary	4	5	6	6
Ireland	5	6	6	6
Italy	6	6	6	6
Latvia	5	6	6	6
Lithuania	5	6	6	6
Luxembourg	1	2	3	5
Malta	4	4	5	5
Netherlands	1	2	3	5
Poland	3	4	5	6
Portugal	7	7	7	7
Slovakia	6	6	6	6
Slovenia	7	7	7	7
Spain	7	7	7	7
Sweden	5	5	6	6
United Kingdom	6	6	6	6

Classes:	
0–4.9 %	1
5–9.9 %	2
10–14.9 %	3
15–19.9 %	4
20–24.9 %	5
25–30 %	6
> 30 %	7

Note: Organic farmland shares are based on Offermann (2003). The HNV farmland shares for EU-15 are based on EEA/UNEP, 2004. The HNV farmland shares for the New Member States were estimated using a combination of selected Corine land cover 2000 data and Semi-natural grassland estimates. No data was available for Cyprus.

Annex 3: Indicative comparison of crop prices for bioenergy compared to commodity prices

The costs of the bioenergy crops were determined from the 'shadow price' of their feed/food equivalent from world market development (based on DG AGRI and FAO projections), and the relative costs of farming and harvesting. Furthermore, the relative 'attractiveness'of their energy value compared to oil and the avoided CO_2 emissions, expressed in CO_2 equivalent savings when compared to oil, were both considered. Assumptions on oil and CO_2 permit prices were taken from a recent EEA scenario (EEA, 2005a). The same calculations were also carried out with a higher oil price than that used in the EEA (2005a). This sensitivity was carried out in order to reflect recent price developments.

The assessment concludes that for a variety of energy conversion technologies (e.g. heating, co-firing, second generation biofuels), the monetary energy value of (some) bioenergy crops (i.e. their market value) is higher than the commodity price.

Table A3.1 Relative energy and CO_2-'value' versus commodity price at EUR 35 per barrel oil in 2030

Fuel	2010	2020	2030
– FAME	53 %	65 %	81 %
– ethanol	51 %	67 %	87 %
– SRF	71 %	98 %	132 %
– ligno-cellulosic ethanol	57 %	75 %	99 %
– biogas (double cropping)	111 %	147 %	194 %

Note: 100 % is the commodity price paid. Commodity prices are global prices (excluding subsidies) taken from FAO.

The price paid for energetic use of crops is based on assumptions on the developments of fuel prices and the carbon permit price (energy crop premium payments are not included). Oil prices are assumed to be EUR 35 per barrel in 2030, and the CO_2 permit price is assumed to rise to 65 EUR/tCO_2.

Table A3.2 Relative energy and CO_2-'value' versus commodity price at EUR 50 per barrel oil in 2030

Fuel	2010	2020	2030
– FAME	79 %	107 %	129 %
– ethanol	61 %	84 %	108 %
– SRF	100 %	138 %	168 %
– ligno-cellulosic ethanol	74 %	107 %	136 %
– biogas (double cropping)	151 %	210 %	260 %

Notes: The same assumptions are made as in Table A.3, except for oil price. It was assumed that the oil price would rise to EUR 50 per barrel in 2030, in addition to the CO_2 permit price.

A similar conclusion was derived for the forest sector. Here, the costs of collection and chipping were factored in, and compared to oil prices. The assumed carbon permit prices in this study together with the assumed oil price of EUR 35 per barrel in 2030 would correspond to an 'energy value' of wood chips of about EUR 44, EUR 64, and EUR 94 per cubic meter of dry wood chips for 2010, 2020, and 2030, respectively. If a higher oil price of EUR 50 per barrel was assumed, the resulting energy values of wood chips would be EUR 54, EUR 78, and EUR 120 per cubic meter of dry wood in 2010, 2020, 2030, respectively. Thus, a growing share of wood becomes more competitive in the energy market than in the 'materials' market (e.g. pulp/paper, woody products).

Annex 4: Environmental pressures by crop

Table A.4 Environmental pressures by crop

	Permanent grass		Temporary grass		Maize		Double cropping		Mustard seed		Hemp		Linseed (oil)		Clover/Alfalfa		Sugar beet		Oilseed rape	
	Rank	Reason	Rank	Reason	Rank	Reason	Rank	Reason	Rank	Reason	Rank	Reason	Rank	Reason	Rank	Reason	Rank	Reason	Rank	Reason
Erosion	A	Provides whole-year soil cover	A	Provides whole-year soil cover	C	Soil is uncovered over long period, row crop	A	Reduced tillage, long / permanent soil cover	A (B)	Provides winter cover, (grown as row culture if for oil use)	A/B	Summer crop but provides good soil cover	A/B	Can provide winter cover, not always dense crop	A	Provides whole-year soil cover	C	Row crop, sown late, thus bare soil into late spring	B	Row crop, but dense soil cover
Soil compaction	A	Not very frequent machinery use (only for fertilisation and cutting)	A/B	Does not involve heavy machinery	B	Poorly developed root system; average machinery use	A	Reduced tillage, long / permanent soil cover	A	Large taproots, can alleviate the effects of soil compaction	A	Deep and dense root system	A	Winter cover crop, large taproots, can alleviate the effects of soil compaction	A/B	Does not involve heavy machinery; permanent soil cover	C	Heavy machinery and harvested mass lead to soil compaction	A	Deep and dense root system
Nutrient leaching to ground and surface water	A	No/extensive input, good nutrient use; permanent soil cover	B	Possible nutrient losses after ploughing	C	High demand and often highly fertilised	A	Moderate demand, good fertiliser uptake	A/B	Medium demand, good fertiliser uptake	A	Moderate demand, good fertiliser uptake	A	Low-medium demand	B	Possible n-losses after ploughing (leguminous crops)	B/C	High fertiliser demand and soil erosion risks	B/C	High demand, leaching risk depends on use of harvest residues
Pesticide pollution of soils and water	A	Generally no or little pesticide use	A	Generally no or little pesticide use	C	High pesticide use due to poor competitive ability; subject to many diseases	A	Generally no pesticide use	B	Generally few pesticide treatments	A	Generally no pesticide use	B	Generally few pesticide treatments	A	Generally no pesticide use	B	Various pesticide treatments to eliminate weeds	C	Various pesticide treatments to combat pests
Water abstraction	A	Generally not irrigated	A	Generally not irrigated	A/B	High water efficiency (C4) but often irrigated	A/B	Depends on the cultivated crops	B	High water demand	B	Requires deep soils with good water supply	A	Low water demand	A (B)	Requires a certain soil humidity; alfalfa is irrigated in southern europe	A/C	Often irrigated in southern europe		n/a
Fire risk	B	Risk depends on sward management in summer dry regions	B	Risk depends on sward management in summer dry regions	—	n/a	—	n/a	—	n/a	—	n/a	—	n/a	—	n/a	—	n/a	—	n/a
Link to farmland biodiversity	A	Low or no chemical inputs, older grasslands often very species-rich	B/C	Often intensively managed, low species-diversity with several cuts per year	C	High pesticide use, low weed diversity, some shelter in autumn	B	Low input use, can be flower-rich, but may be cut several times a year leading to direct wildlife impact	B	Medium to low input use, nectar source, not too dense structure	B	Low input use, attractive shelter crop	A/B	Low input use, open crop structure with weeds, may provide fodder in autumn	A/B	Low input use, source of nectar, is feed source and can provide shelter	B	Often high pesticide use, but can provide nesting habitat and shelter in autumn	B/C	High pesticide use, some pollen offer but very dense crop
Diversity of crop types	A	Adds diversity in arable regions	A	Adds diversity in arable regions	B/C	Is dominant crop in some regions; self tolerance	A	A new approach and incorporates several crops	A	High, as currently not common	A	High, as currently not common	A	High, as currently not common	A	Adds diversity in arable regions	B	Common in intensive areas but not self tolerant	A/B	Common in some member states

Note: A means low risk, B means medium risk, C means high risk, n/a means not applicable: criterion is not relevant as crop is only grown under certain climatic conditions. Eucalyptus is considered not to be part of an *environmentally-compatible* crop mix.

	Sunflower		**Potatoes**		**Other cereals**		**Wheat**		**Sorghum**		**Giant reed** *Arundo donax*		**Kardoon** *Cynara cardunculus*		**SRF eucalyptus**		**SRF poplar, willow**		**Reed canary grass** *Phalaris arundinacea*		**Switch grass** *Panicum virgatum*	
	Rank	Reason	Rank	Reason	Rank	Reason	Rank	Reason	Rank	Reason	rank	reason	Rank	Reason	Rank	Reason	Rank	Reason	Rank	Reason	Rank	Reason
Erosion	B/C	Row crop, leaves bare soil into late spring	C	Root and row crop, leaves bare soil into late spring	A	Winter cereals provide good soil cover	A	Winter wheat provides good soil cover	A	Good soil cover if suffiicient water available	A	Permanent crop, hence good soil cover	A	Permanent crop, hence good soil cover	A(B)	Permanent crop, but leaves soil rather bare	A	Permanent crop, hence good soil cover	A	Permanent crop, hence good soil cover	A	Permanent crop, hence good soil cover
Soil compaction	A	Deep and dense root system	C	Heavy machinery and harvested mass lead to soil compaction	A	Intensive rooting system, harvest in dry weather	A	Intensive rooting system, harvest in dry winter	A	Deep rooting system	A	Deep rooting, permanent crop	A	Deep rooting, permanent crop	A	Deep rooting, permanent crop	A	Deep rooting, permanent crop	A	Deep rooting, permanent crop	A	Deep rooting, permanent crop
Nutrient leaching to ground and surface water	A/B	Moderate demand, good fertiliser uptake	B/C	Moderate demand, but late growth and soil erosion risks	A	Moderate demand and good uptake	A	Higher fertiliser demand but good uptake	A	Requires only basic fertilisation	A/B	Moderate to medium nutrient demand; permanent soil cover	—	Data insufficient	A	Takes a lot of nutrients	A	Significant nutrient demand but good uptake also; permanent soil cover	A/B	High nutrient demand; permanent soil cover	—	Data insufficient
Pesticide pollution of soils and water	B	Can undergo various pesticide treatments to combat pests	B	Fairly pesticide intensive	A	Moderate number of pesticide treatments	B	Generally high number of pesticide treatments	B/C	Numerous diseases, not very competitive in the beginning	A	Very competitive, hence no or little pesticide applications necessary	A	Very competitive, hence no or little pesticide applications necessary	A	Very competitive	A	Very competitive, hence no or little pesticide applications necessary	A	Very low input necessary	—	Data insufficient
Water abstraction	B	A water efficient crop but often irrigated as better growth	C	Usually on sandy soils/ with high water demand: often irrigated	A	Moderate water demands	B	Highest water demand of all cereals	A/C	Water demand depends on variety used	B/C	Requires a certain soil moisture; suspected of altering hydrological regimes and reducing groundwater availability by transpiring large amounts of water in semi-arid conditions	A	Well-suited to mediterra-nean climate	B	Requires a certain soil moisture; suspected of altering hydrological regimes and reducing groundwater availability by transpiring large amounts of water in semi-arid conditions	B	High water demand, but no irrigation expected	A/B	Needs moist fertile habitats; higher water demand	A	Drought resistant and very efficient water use (c4), but because of deep roots ground water abstraction possible
Fire risk	A	Mostly low risk as harvested in early summer	—	n/a	A	Mostly low risk as harvested in early summer	A	Mostly low risk as harvested in early summer	A	No high fire risk as fully utilized	C	Giant reed is highly flammable throughout most of the year and appears highly adapted to 'extreme' fire events	—	Data insufficient	C	Because of high oil content	—	n/a	—	Data insufficient	—	Data insufficient
Link to farmland biodiversity	A/B	Low input use when not irrigated, pollen offer, weed diversity and potential winter stubble	B/C	Mostly high pesticide use, intensively managed, but can provide autumn shelter	B	Medium use of inputs, can have open structure; nesting habitat when spring crop	B/C	Mostly high input use, dense crop	B	Low input use, can be open crop and source of food (seeds)	B	No/low pesticide use; can be nesting habitat and provides winter shelter	B	No/low pesticide use; can provide winter shelter, probably source of pollen	C	Suppresses nearly all other plants	A/B	No/low pesticide use; nesting habitat and provides winter shelter; but can have negative impacts on open landscape structures	B	No/low pesticide use; can provide winter shelter	B	No/low pesticide use; can provide winter shelter
Diversity of crop types	B	Very common in bulgaria and romania (spain and portugal)	B	Very common in some member states	B	(Very) common	C	Most common cereal	B	Relatively common in dry regions	A	Currently not very common	A	Currently not very common	C	Currently common in the south	A	Currently not very common	A	Currently not very common	A	Currently not very common

Annex 5: Net calorific values

Table A5.1 Lower heating value, dry matter yield and energy yield per hectare by agricultural crop

	LHV GJ/tDM	Yield in tDM/ha	GJ/ha
Double cropping, optimal	15.2	17.5	266.0
Maize whole plant	16.5	13.0	214.5
Maize corn	21.4	9.5	203.3
Triticale whole plant	16.4	12.0	196.8
Double cropping, reduced yield	15.2	12.5	189.4
Wheat whole plant	17.1	10.0	171.0
SRC poplar	18.5	7.5	138.8
SRC willow	18.4	7.5	138.0
Wheat corn	17.0	6.0	102.0
Barley/triticale corn	17.0	5.5	93.5
Rape seeds	26.5	2.5	66.3
Sunflower seeds	26.5	2.5	66.3
Sugar beets	1.9	14.0	26.6

Note: Double cropping systems are expected to deliver relatively high energy yields per hectare because they involve the harvesting of the whole crop. However, it should also be noted that these double cropping systems are only assumed to occur in a limited number of Member States concentrated in the Atlantic, Continental and Alpine zones. These areas have sufficient rainfall for this type of cropping.

Conversion factors used for forestry biomass:

1 Gg biomass (oven-dry) = 18.6 TJ
1 m^3 wood (oven-dry) = 8.714 GJ

Table A5.2 Net calorific values used for different waste streams

Waste stream	NCV (GJ/t at harvest/as received)	Notes
Solid agricultural residues (cereals)	14.6	Assuming 15 % moisture at harvest
Solid agricultural residues (prunings)	8.2	Assuming 50 % moisture at harvest
Chicken litter	9.3	
Demolition wood	13.5	Based on softwood (33 % moisture)
Packaging waste-wood	13.4	Assuming 50:50 split between hard and softwood (33 % moisture)
Household waste-wood	13.0	
Wood processing waste-wood	13.0	

Annex 6: Possible policy measures to influence the environmental effect of bioenergy cropping

Potential policy measures to minimise or improve the environmental impact of bioenergy crops on agricultural land are described in the Table A6. Particular attention is paid to agricultural policy instruments, although a similar approach could also be developed for the forestry sector. The analysis presented below is a first attempt to structure and evaluate possible policy measures relevant to agricultural bioenergy production. Further more detailed work is required for assessing the suitability of different policy instruments at national level.

The first four potential measures are particularly suited for enforcing or supporting general environmental management standards. Measures 5 to 7 have the best potential for facilitating specific cropping systems or conversion technologies, e.g. the use of grasslands for energy production. Measures 8 and 9 are important tools in the planning and improvement of policy at regional to European level. The evaluation of the different policy options could be taken further but that was not feasible at this stage.

Table A6 Possible policy measure influencing the environmental impact of bioenergy cropping

Measure	Advantages	Disadvantages	Implementation questions
1) Environmental certification of bio-energy production	Creates incentives for behavioural change; Promotes an optimal use of resources.	May not be easy to establish; Criteria may be difficult to define.	Voluntary or obligatory? What are the precise environmental baselines and standards? Are these just input and resource saving measures; or could also limit per ha productivity? Who organises and pays for controls?
2) Cross compliance	Uses existing instrument; Could apply widely to farmers; Already has environmental scope.	Only enforces minimum standards; Effectiveness to be proven.	Existing legislation needs to be adapted. Only to cover input use etc, or could also fix a maximum share of certain crops?
3) Area specific standards, e.g. limiting the use of certain crops in specific areas	Potentially a very direct and strong instrument; Protects areas of high environmental interest.	Most likely difficult to push through without compensation; Political resistance to be expected; Not very flexible and 'unfair' to some farmers in the areas affected.	Is a blanket ban on certain crops (in specific areas) appropriate? How to identify crops and delimit the areas? Use for Natura 2000 and/or HNV farmland areas?
4) Environmental farm advice	Increases general awareness and goodwill of farmers; Should improve input management efficiency.	Effect strongly depends on farmer uptake; Implementation of advice not ensured.	Do we know enough on how to manage energy crops from an environmental perspective? How to ensure sufficient advisory capacity and outreach?
5) Favouring certain crop mixes via crop premia	Leaves some flexibility to farmers; Could have a wide-ranging effect.	Difficult to envisage how to favour certain crop mixes, appears rather complex; Effects may only be indirect.	What happens if the target crops become dominant? Use a top-up payment for high levels of crop diversity?
6) Investment support for specific conversion systems	Encourages innovative approaches; May be cost-efficient if limited to start-up phase.	Environmental benefits not guaranteed if not monitored closely; Wider implementation at farm level not automatic.	Could this favour semi-natural grasslands through novel technologies?
7) Rural development measures for local 'crops to energy' networks; including LEADER approaches	Would ensure local sourcing; Should lead to environmentally adapted systems; Increases understanding among a wide range of actors at local level.	Already lots of demands on rural development policy; Can be a complex instrument to use; Impact depends on applications from potential recipients.	What measures would be suitable? Do we need to introduce additional measures in RD programme menus? How to tackle the integrated aspect of such local systems?
8) Regional planning/ SWOT analysis	Should lead to comprehensive approach; Engages (local) stakeholders; Helps to evaluate unintended side-effects, e.g. on the tourism value of certain landscapes.	Medium to long-term approach; Implementation uncertain; Depends on other instruments for implementation.	Which existing processes should cover strategic planning on energy cropping? Is there enough interest/knowledge at local level? How to combine with complementary support measures?
9) Monitoring and evaluation	Increases knowledge about environmental effects of bioenergy crops; Key to better policy (planning).	Potential impact only in longer term; 'knowing' does not equal 'acting'; Reluctance to spend money in this area.	How to design these appropriately? How to finance? How to integrate into policy decisions?

Annex 7: List of abbreviations

BFH	Bundesanstalt für Forst- und Holzforschung, Hamburg
BtL	Biomass-to-liquids (biofuel from Fischer-Tropsch synthesis)
CAP	Common agricultural policy
DM	Dry matter
EEA	European Environment Agency
EFISCEN	European Forest Information Scenario
EnZ	Environmental Zone
EOF	Environmentally oriented farming
ETC	European Topic Centre (of the European Environment Agency)
EU	European Union
FAO	United Nations Food and Agriculture Organisation, Rome
FAME	Fatty Acid Methyl Ether
FSC	Forest Stewardship Council
GHG	Greenhouse Gas
GJ	GigaJoules
GWh	GigaWatthour
ha	Hectare
HEKTOR	HektarKalkulator
HNV	High nature value farming
IE	Institut für Energetik und Umwelt, Leipzig
LCEP	Low Carbon Energy Pathway
LHV	Lower heating value (also net calorific value)
MCPFE	Ministerial Conference on the Protection of Forests in Europe
MJ	MegaJoules
MS	Member States of the European Union
MSW	Municipal Solid Waste
MtOE	Million tonnes of oil equivalent
NCV	Net calorific value (also lower heating value)
NGO	Non government organisation
PJ	PetaJoules
PRIMES	Energy model run by the University of Athens; used by EEA and DG TREN
SRC	Short-rotation coppice
SRF	Short-rotation forestry
UAA	Utilised Agricultural Area

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