EEA Technical report | No 12/2007

Estimating the environmentally compatible bioenergy potential from agriculture

ISSN 1725-2237

European Environment Agency

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Cover design: EEA
Layout: EEA

Luxembourg: Office for Official Publications of the European Communities, 2007

ISBN 978-92-9167-969-0
ISSN 1725-2237
DOI 10.2800/13734

European Environment Agency
Kongens Nytorv 6
1050 Copenhagen K
Denmark
Tel.: +45 33 36 71 00
Fax: +45 33 36 71 99
Web: eea.europa.eu
Enquiries: eea.europa.eu/enquiries

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Acknowledgements

This report was prepared by Jan-Erik Petersen (EEA) with the help of Berien Elbersen (Alterra), Tobias Wiesenthal and Jane Feehan (both EEA), and Ulrike Eppler (Fachhochschule Eberswalde).

It builds on the findings of a background paper being prepared for the EEA on the *environmentally-compatible* bioenergy potential from agriculture by Uwe Fritsche, Kirsten Wiegmann (Öko-Institut, partner of the EEA's European Topic on Air and Climate Change) and Berien Elbersen (Alterra).

Dr Peter Witzke (EuroCare, Bonn) provided helpful guidance in using the CAPSIM model.

The final editing of the report benefited from comments by Ayla Uslu, Anca-Diana Barbu (both EEA), Philippe Pointereau (SOLAGRO) and Hans-Peter Piorr (Fachhochschule Eberswalde). EEA acknowledges advice provided at various stages during the project and the preparation of the report by other colleagues and experts outside the EEA.

Executive summary

Increasing the use of bioenergy offers significant opportunities for Europe to reduce greenhouse gas emissions and improve the security of its energy supply. However, the substantial rise in the use of biomass from agriculture and other sectors for producing transport fuels and energy can put significant environmental pressures on farmland or forest biodiversity as well as on soil and water resources. Consequently, it may counteract current and potential future environmental policies and objectives, such as improving the quality of ground and surface waters or biodiversity protection. These issues are addressed in the EEA Report No 7/2006 on 'How much bioenergy can Europe produce without harming the environment?'.

This report underpins the 2006 document by providing technical details on the scenario assumptions and models for deriving the agricultural bioenergy potential. It supplements the technical explanations of the modelling assumptions and calculations with three different aspects:

- background information on environmental pressures from agriculture that explain the environmental assumptions made;
- examples and information on environmentally compatible modelling approaches; and
- a discussion of policy measures that are important for achieving the environmentally compatible future on which the modelling assumptions are built.

The scenario analysis presented here pinpoints the environmental aspects that should be looked at when increasing bioenergy production on farmland. The model also gives an indication of how much agricultural biomass is potentially available without harming the environment and without counteracting current and potential future EU environmental policies and objectives. As the 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 require further analysis and complementary assessments on a more regional and local scale. Further analysis is also needed for exploring the potential impacts of climate change on the cultivation and yield of energy crops as this aspect was beyond the scope of this study. In addition, this study does not consider the potential environmental effects of biomass production outside Europe as this option falls outside the modelling framework adopted.

Box 1 Key scenario assumptions for estimating the environmentally compatible bioenergy production potential on farmland

a) Assumptions for the maintenance or further development of an ***'environmentally orientated farming'*** in the EU: the present share of 'environmentally orientated' farming would need to increase to about 30 % of the Utilised Agricultural Area in most Member States by 2030; at least 3 % of present intensively used farmland should be set-aside by 2030 for nature conservation purposes; no conversion of permananent grassland, dehesas and olive groves through ploughing for targeted biomass crops.

b) Further technological development and research would allow a ***diversification of energy crops and conversion pathways*** for different types of biomass (2nd generation conversion pathways, biogas, efficient bioenergy combinations).

c) The ***selection of energy crops and their management*** at farm level would follow environmental guidance (adaptation to bio-physical constraints and ecological values of a region, appropriate crop mixes and rotations, low use of inputs, double cropping practices etc.).

The scenario for agriculture builds on a set of general assumptions derived from the EEA's work on environmental outlooks. These were supplemented with specific environmental assumptions to minimise pressures on natural resources and biodiversity (see Box 1). The area assumed to be available for biomass production comprises both the areas that are released from food and fodder production (as a consequence of a further reform of the Common Agricultural Policy and yield increases) and set-aside areas. In addition, as the energy price of bioenergy crops is assumed to reach or exceed food commodity prices in the period to 2030, some land that is projected to be used for producing export surplus might become available for bioenergy production (1).

The 2006 report showed that biomass from agriculture provides the largest bioenergy potential in the long-term. This development would 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 could reach up to 142 MtOE by 2030, compared to 47 MtOE in 2010. Approximately 85 % of the potential will come from 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 energy crop production in each Member State, the competition with food and export markets, the impact of environmental constraints and the yield of the assumed bioenergy crops. Box 2 shows the main modelling and scenario steps taken for estimating the final agricultural bioenergy potential in this study.

In this study, a key factor for avoiding increased environmental pressure from agriculture (due to increased biomass demand for food and energy purposes) was the scenario assumption that a large share of environmentally-oriented farming with lower crop yields will exist. While increasing bioenergy production might provide incentives for transforming extensively used grassland into arable land, ploughing up these permanent grasslands would lead to the loss of their high biodiversity value and a substantial release of soil carbon. Thus, approximately 6 million ha of released permanent grass land (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 would rise by 50 % over the time period to reach 19 million ha by 2030.

Crops dedicated to bioenergy production differ from conventional food and fodder crops as they

Box 2 Main modelling and scenario steps for estimating the final agricultural bioenergy potential

1. Adaptation of the reference scenario study developed in the EEA agricultural outlook study of CAPSIM (EuroCARE, 2004) to an 'environmentally compatible scenario'. The results from this scenario were used to calculate the future land availability for biomass per EU-25 Member State.
2. Creation of an additional scenario calculation for France and Germany with the HEKTOR model in order to show the effect of the introduction of incentive measures such as CO_2 allowance prices on land availability.
3. Environmental assessment and ranking of different potential bioenergy crops based on environmental risk matrices for each environmental zone.
4. Calculating the bioenergy potential per environmental zone in the EU-25 by combining final crop mixes per country with the respective land potential (based on both CAPSIM and additional HEKTOR model applications).
5. Translating the future land potential for biomass crop production into energy values for the optimal crop mix assumptions under step 4, taking into account specific assumptions on e.g. economic efficiency, technological development, today's crop mixes and a smooth (gradual) transition.
6. Carrying out a sensitivity analysis for key parameters determining the land and bioenergy potential in this study. It also compares the study results with other study outcomes, assessing the bioenergy potential from agriculture in Europe.

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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 to combine a high export surplus for cereals with a large agricultural land area. Competition between the production of bioenergy and food for domestic use was disregarded.

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 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 should generally benefit the environment, as perennial bioenergy crops and short rotation forestry normally have less impact on: soil erosion and compaction, nutrient inputs into ground and surface water, pesticide pollution, and water abstraction.

New research (that was not available at the time of this study) indicates that some perennial energy grasses and short rotation coppice plantations have very high water requirements. Consequently, in particular this aspect of energy cropping needs to be reviewed in further detail in future studies.

Work on exploring the available bioenery options has highlighted some potential 'win-win' solutions from energy cropping. With adequate support it could be possible, for example, to use grassland biomass from semi-natural grasslands for the production of bioenergy, thus contributing both to the management of species-rich grasslands and renewable energy production. The introduction of certain perennial energy crops as well as minimum tillage or double cropping systems for the production of biomass for energy purposes could also bring substantial benefits to maintaining agricultural soils.

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, electricity and transport fuels, and which fossil fuels are replaced. The avoided life-cycle emissions compared to fossil fuels can be significant, but some emissions occur during the production of biomass through e.g. the production of fertilisers. A detailed analysis of the avoided greenhouse gas emissions would be useful in completing the environmental assessment of different bioenergy production options and is currently being developed by the EEA.

The study concludes that European agriculture can increase its production of biomass to meet renewable energy targets in an environmentally compatible manner. However, unless appropriate policy measures 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 is likely to lead to increased environmental pressures from farming.

The report presents and discusses a range of policy options for supporting environmentally-friendly farming in general and the environmentally-compatible production of energy crops in particular. Many of these build on existing policy instruments in EU agri-environment and rural development policy. Environmental certification schemes for bioenergy production currently receive considerable political interest, in particularly with regard to the sustainability aspects of biomass and biofuel imports. Their successful introduction will require an effective cooperation between producers, consumers and policy-makers. The development of an environmentally-compatible bioenergy production in agriculture also needs close links between three different policy areas: energy, agriculture and environment. From an environmental perspective, this is a crucial aspect for the further development of EU energy production from agricultural biomass.

1 Introduction

1.1 The purpose of this report

Increasing the share of renewable energy in total EU energy consumption is a key policy objective in the European Union (e.g. EC, 2007). Biomass from agriculture can make a substantial contribution to reaching this objective. However, current agricultural production in the EU is often quite intensive and exerts significant environmental pressures (EEA, 2004; EEA, 2005b). The production of biomass on farmland for energy purposes therefore also carries significant environmental risks. Consequently, a thorough evaluation is necessary for reviewing how agricultural bioenergy production could become compatible with environmental targets in the agriculture sector (EEA, 2006a; EC, 2007; SRU, 2007).

In 2005/2006 the EEA carried out a modelling exercise to estimate the bioenergy potential in the agriculture, forest and waste sectors that could be considered 'environmentally compatible' (EEA, 2006b). This report underpins the 2006 document by providing technical details on the calculation of the agricultural bioenergy potential. It supplements the technical explanations of the modelling assumptions and calculations with three different aspects:

- background information on environmental pressures from agriculture that explain the environmental assumptions made;
- examples and information on environmentally compatible modelling approaches; and
- discussion of policy measures that are important for achieving the environmentally compatible future on which the modelling assumptions are built.

The analysis presented here indicates key environmental aspects that should be looked at when increasing bioenergy production on farmland. It also gives an indication of how much agricultural biomass is potentially available without harming the environment and without counteracting current and potential future EU environmental policies and objectives. As the 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 require further analysis and complementary assessments on a more regional and local scale. In addition, this study does not consider the potential environmental effects of biomass production outside Europe as this option falls outside the modelling framework adopted.

The report discusses in a limited way 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 agricultural 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.

Given the importance of the agriculture sector for the environment and renewable energy production in the EU we felt it necessary to present this work. We hope that it will inspire further analysis and lead to in-depth studies on how to make agricultural biomass production for energy purposes as environmentally friendly as possible.

1.2 Agri-environmental and energy policy background

Agriculture is the dominant land use for approximately 50 % of the land area in the EU-27. As such it is a key influence on the environment in Europe, including soil and water resources, biodiversity and landscape as well as greenhouse gas emissions (e.g. EEA, 2005b). It is also an important economic sector in many rural areas of Europe, and one that is diversifying beyond food production. The production of renewable energy and biomaterials is beginning to be a significant source of income for farmers in Europe. Due to changes in the production and consumption of food in Europe, agriculture has the potential to be a major contributor to bioenergy production in the EU-27. Thus, it can support the efforts to significantly increase the share of renewable energy sources in total energy production in the EU.

At the same time the shape and intensity of the agricultural sector determine the likely success in reaching environmental objectives of the European Union. This relates to the management of the Natura 2000 network of protected sites for biodiversity, the water quality targets included the Water Framework and Nitrate Directives as well as the ammonia reduction targets of the National Emissions Ceilings (NEC) Directive, to name just a few (EEA, 2006a). Can the aim of substantially increasing bioenergy production from farmland be achieved without compromising other environmental objectives at EU level? What conditions need to be met for additional biomass production on farmland to remain environmentally compatible?

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).

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).

In December 2005, the European Commission published a Biomass Action Plan (EC, 2005b) with the aim of increasing 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 increasing the supply of and demand for biomass, overcoming technical barriers, and developing research.

In addition, the Commission presented a comprehensive package of proposed policies and measures to establish a new Energy Policy for Europe to combat climate change and boost the EU's energy security and competitiveness on 10 January 2007 (⁴). This package was discussed at the European Council meeting on 8-9 March 2007 and the Commission's proposals were to a large extent adopted (⁵). For example, a binding target to cut 20 % of the EU's greenhouse gas emissions by 2020 (from 1990), a binding overall goal of 20 % for renewable energy sources by 2020, and a binding minimum target of 10 % for the share of biofuels in overall transport petrol and diesel consumption by 2020 were agreed.

The 20 % share of renewable energy could require around 230 MtOE from primary biomass potential, where 63 Mtoe (⁶) would have to come from agricultural crops (if all biofuels had to come from first generation biofuels) in 2020.

1.3 General approach and structure of the report

The estimation of the environmentally compatible biomass potential from agriculture in this study integrates agro-economic modelling, scientific knowledge on the environmental impact of different

Biomass includes a wide range of products and by-products from agriculture and forestry as well as municipal and industrial waste streams. It thus includes: arable crops, perennial crops and short rotation forestry, trees, agricultural and forest residues, effluents, sewage sludge, manure, industrial by-products and the organic fraction of municipal solid waste. After the conversion process, 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).

(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 in 2003 (EC, 2005b).

(³) 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) European Commission, energy and climate change documents (10 January 2007), http://europa.eu/press_room/presspacks/energy/index_en.htm.

(⁵) EU Council conclusions 8/9 March 2007, http://www.consilium.europa.eu/ueDocs/cms_Data/docs/pressData/en/ec/93135.pdf.

(⁶) Figures taken from the impact assessment paper for the Energy Roadmap — SEC(2006)1719; the 20 % target assumes that second generation biofuels technology will be commercially available by 2020.

agricultural land use types and cropping practices as well as projections and expert assessments of future bioenergy production pathways. These components are all combined in a scenario approach that builds on a number of agro-environmental and policy assumptions for the time horizon to 2030:

a. Environmentally orientated farming practices will be maintained and extended in all EU Member States. Additional agri-environmental policy measures are taken to retain or introduce specific environmental set-aside in intensive farming areas and to have environmentally favourable bioenergy crop mixes and practices.
b. There will be a gradual increase in energy prices and the price level will be higher than the price level we have experienced during the 1990s. This price increase will make the option to develop and implement competitive bioenergy conversion applications more feasible.
c. An almost full liberalisation of agricultural markets will become reality. For this specific study the main scenario assumes a complete liberalisation of all animal sectors (cattle, dairy, pigs and poultry) by 2025, including the abolishment of the milk quota system. For the arable sectors, most arable product prices will approach world market levels from 2020 onwards.

Finally, soil and climatic circumstances as well as the present land use and farming practices are considered to be influential factors. In order to involve these factors systematically and taking their regional variation into account, the general assessment is structured nationally and biomass crop mixes are assessed according to an environmental zonation of Europe.

The environmentally compatible bioenergy potential from agriculture was estimated using the following steps:

1. Formulation of a number of biodiversity protection and soil and water conservation considerations to be incorporated in the storyline assumptions for assessing the biomass potential (see Chapter 2).
2. Adaptation of the reference scenario study developed in the EEA agricultural outlook study of CAPSIM (EuroCARE, 2004) to an 'environmentally compatible storyline', using these adapted storyline results to calculate the future land availability for biomass for each EU-25 Member State (see Chapter 3).
3. Creation of an additional scenario calculation for France and Germany with the HEKTOR model in order to show the effect of the introduction of incentive measures, such as CO_2 allowance prices, on land availability (see Chapter 3).
4. Environmental assessment and ranking of different potential bioenergy crops based on environmental risk matrices for each environmental zone (see Chapter 4).
5. Calculating the bioenergy potential per environmental zone in the EU-25 by combining final crop mixes for each country with the respective land potential (based on both CAPSIM and additional HEKTOR model applications — see Chapter 5).
6. Translation of the future land potential for biomass crop production into energy values for the optimal crop mix assumptions under step 5, taking into account specific assumptions on, e.g. economic efficiency, technological development, today's crop mixes and a smooth (gradual) transition (see Chapter 6).
7. Carrying out a sensitivity analysis for all key parameters determining the land and bioenergy potential in this study. It also compares the study results with other study outcomes assessing the bioenergy potential from agriculture in Europe (see Chapter 7).
8. Discussion of the key environmental considerations which should be realised for achieving the environmentally compatible biomass potential; and providing examples of synergetic biomass cropping options and innovative farming practices for biomass production (see Chapter 8).
9. A review of policy options for supporting environmentally compatible bioenergy production on farmland and outlook on issues and research questions that require further attention (see Chapter 9).

Economic input assumptions matter strongly for the outcome of a modeling exercise such as the one presented in this report. Both food and fossil fuel prices have risen considerably since the time of the study. In addition, the US dollar has declined strongly in favour of the euro. While the price rises for agricultural and energy commodities are likely to cancel each other out to a significant degree, other recent economic developments would have a significant bearing on the results presented. Nevertheless, the approach of the study as a scenario exercise in key factors that determine or influence the environmentally compatible bioenergy potential in Europe is still considered useful in the current policy debate.

2 Environmental pressures on farmland: implications for defining an environmentally compatible future

2.1 Overview of agro-environmental trends in the EU-25

To develop criteria for environmentally compatible biomass production on farmland it is necessary to understand the current relationship between agriculture and environmental objectives within the EU. This has to be seen in the context of current and likely future bioenergy production trends, so as to identify the environmental risks and/or benefits that could be associated with energy crops on farmland. Based on such background information quantitative criteria can be proposed that support environmentally compatible agricultural bioenergy production in Europe.

It should be noted that the criteria developed in this report are based on the best-available data and thorough analysis, but may nevertheless not cover all environmental issues associated with large-scale biomass production on farmland. Possible diffuse nutrient losses from energy cropping, for example, are mainly addressed by an assumed increase in organic farming and the estimated choice of energy crops per environmental zone. These are indirect measures that probably need to be complemented by specific nutrient management guidelines or other measures to minimise the use of external inputs. In addition, the water requirements of some perennial energy grasses and short rotation coppice plantations appear to be higher than assumed for the study (e.g. Dworak *et al.*, 2007). Further research is required in this area.

In spite of regional variations, most agricultural land use in the EU is already intensive. Therefore, increased agricultural biomass production for energy purposes could cause additional pressures on agricultural biodiversity as well as on soil, water and air resources. A number of other studies on agricultural bioenergy production in the EU or individual Member States has indicated this potential issue (e.g. Arblaster *et al.*, 2007; Reijnders, 2005; Elbersen *et al.*, 2005; Fritsche *et al.*, 2004; Feehan and Petersen, 2003; Foster, 1997).

Recent analysis in Germany (where agricultural bioenergy production is already well-developed) shows that potential and actual impacts on water quality and biodiversity have become real environmental concerns. This relates to the conversion of grassland or set-aside land to arable biomass crops, potential inappropriate application of biogas digestate on farmland, higher grassland intensity for biogas production as well as indirect environmental effects via land use intensification on arable and grassland (DVL/NABU, 2007; Osterburg and Nitsch , 2007).

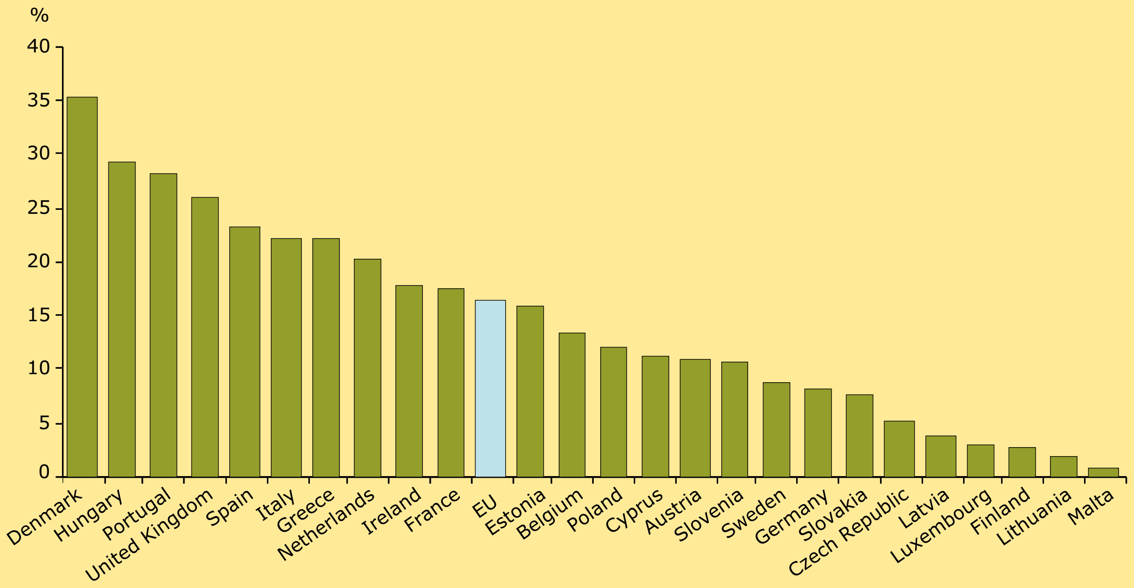
Two EEA reports on agri-environmental issues in the EU-15 Member States (EEA, 2005b) and the new EU Member States (EEA, 2004) point to the most important impacts of current agricultural land use on the environment:

a. Soil erosion remains a significant concern in the EU-15 and appears to be concentrated in the Mediterranean region. It is also an important environmental issue in the new EU Member States.
b. Due to decreased livestock numbers and mineral fertiliser consumption, greenhouse gas and ammonia emissions from agriculture in the EU-15 have declined by about 9 % since 1990. According to current projections (which discount the 2003 CAP reform) a continuation of these trends will not be enough to meet 2010 ammonia emission reduction targets for the EU-15 Member States.
c. The irrigable area in EU-15 increased by 12 % from 1990 to 2000. The majority of this increase occurred in Mediterranean countries where water abstraction rates for agriculture are already highest. Irrigation is also a key factor for agricultural production in the new EU Member States and has placed significant environmental pressure on aquatic ecosystems and water tables (EEA, 2004).
d. Diffuse pollution from agriculture is a major concern for the quality status of ground and surface waters in the EU-25. Gross nutrient balance data and nitrate concentrations in rivers show that this is a particular problem for most north-western Member States. Diffuse pollution

Box 2.1 Importance of permanent grasslands for nature conservation

One third of all permanent grassland habitats listed in Annex I of the EU Habitats Directive are considered to be threatened by an intensification of farming activities (pasture, grass-cutting and haymaking, animal husbandry and harvesting crops). At the same time, abandonment of these activities might put the preservation of 16 Annex I grassland habitats in danger (Ostermann, 1998). It is estimated that approximately 16 % of the habitats in Natura 2000 areas depend on a continuation of extensive farming (Figure 2.1).

Figure 2.1 **Share of Natura 2000 sites covered by 52 targeted agricultural habitats of Annex I that depend on a continuation of extensive farming practices**



Source: Reporting of Member States in the framework of the Habitats Directive (92/42/EEC); status of July 2006.

The continuation of the extensive grassland management is very important for the maintenance of associated biodiversity value (e.g. Anger *et al.*, 2002; Bignal and McCracken, 1996; de Miguel & de Miguel, 1999; Nagy, 2002). For grassland this is especially applicable to practices such as grazing and cutting. As long as these practices only cause low to medium disturbance levels, they determine the relative abundance of plant species in a habitat, and thus influence the competitive abilities of plant species relative to each other, preventing one species from becoming dominant over the rest. The range of species present and structures in the vegetation is therefore maintained at a higher level (see e.g. Palmer and Hester, 2000; Harris and Jones, 1998; Mitchell & Hartley, 2001; Alonso *et al.*, 2001; Stevenson and Thompson, 1993). For farmland birds, the diversity at landscape level is very important. This is strongly influenced by grassland management practices.

from agriculture remains a risk for water quality in the new Member States (EEA, 2005a).

e. Changes in agriculture are a key factor in the decline of biodiversity. This is both due to intensification as well as abandonment or reduction of traditional land uses and farm practices. Current farm trends do not appear to favour the maintenance of high nature value farmland and of agricultural habitats in Natura 2000 areas in the EU-15. Abandonment of grassland management is a particular concern in the new Member States (EEA, 2004; and IEEP, 2007).

This brief review of the impact of current agricultural production on the environment in the EU-25 explains the overall starting point of this study: future biomass production on agricultural land should not impose any additional pressure on farmland biodiversity and environmental resources than is currently the case. In fact, as far as possible, environmental pressures from farming need to be reduced to achieve current EU environmental objectives in the water, air quality or biodiversity areas.

2.2 Current bioenergy production patterns

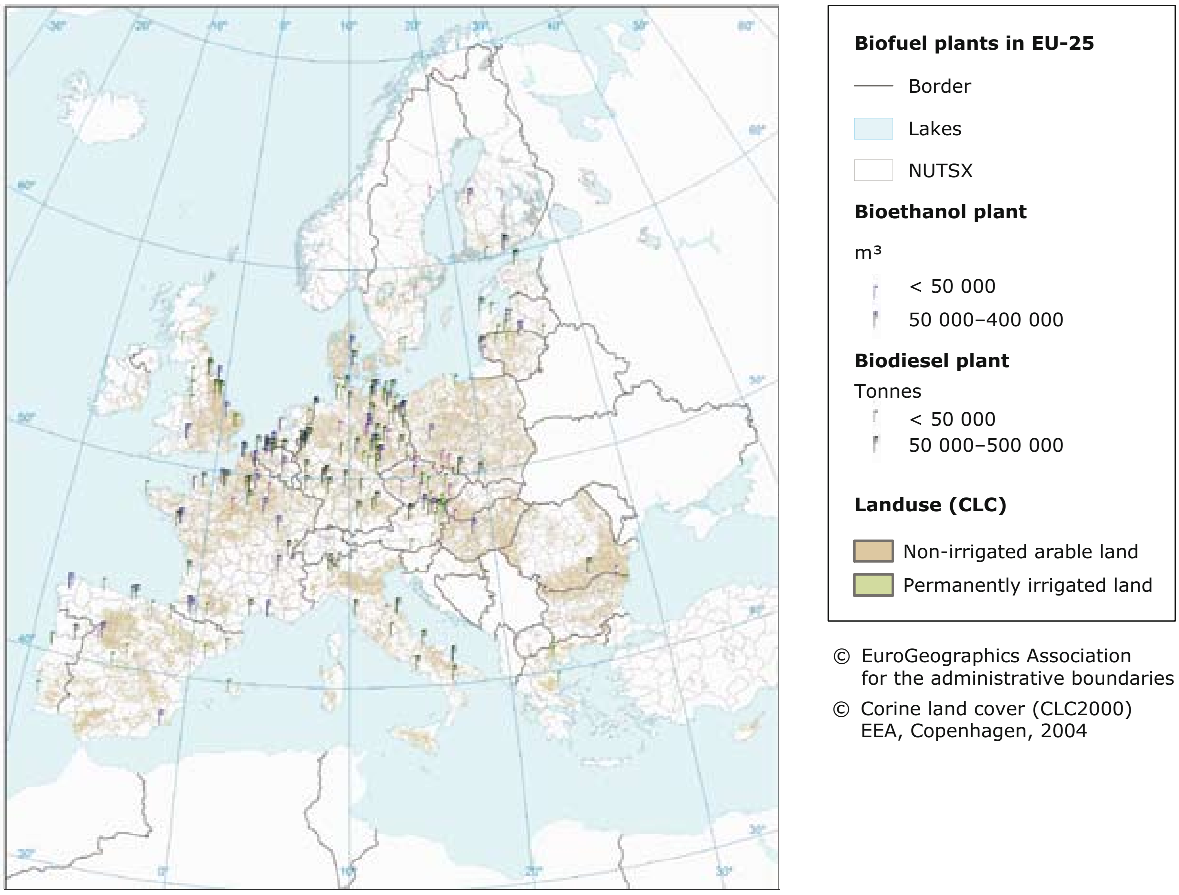
Information on current biomass production patterns in EU-27 agriculture was collected from a number of sources (7) to give contextual information for the analysis presented in the rest of the study. The compilation of data that was completed in mid December 2006 is probably already out-of-date as the development of bioenergy production in the EU is undergoing rapid change.

In 2005, an estimated 3.6 million hectare of agricultural land in the EU-25 was directly devoted to biomass production for energy use. The majority of this land (83 %) was used for oil crops (used for biodiesel), and the remainder devoted to ethanol crops (11 %), biogas production (4 %) and short rotation forestry (2 %).

The production of biodiesel from oilseed crops has increased more than twentifold in the period 1994–2005, resulting in primary energy production of 3 000 ktoe per year, or 3.1 % of total renewable energy production in 2005.

Figure 2.2 provides an EU wide overview of sites of biofuel plants (biodiesel and bioethanol) and their current or planned capacities. A total of 144 biodiesel plants is recorded in 21 countries with a total (planned) capacity (implemented at the latest in 2008) of 12 243 700 tonnes per year. From this

Figure 2.2 Biodiesel and Bioethanol plants in operation or under construction in the EU-27 (production capacities in tonnes (for biodiesel) and m³ (for bioethanol) per year)



© EuroGeographics Association for the administrative boundaries

© Corine land cover (CLC2000) EEA, Copenhagen, 2004

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

Source: Eppler & Piorr 2006.

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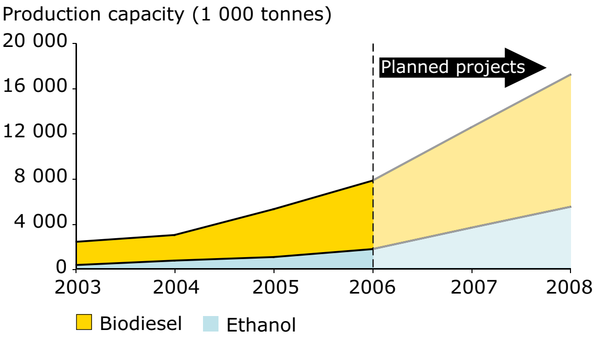
(7) The sources used include Member State reports on progress under Directive 2003/30/EC, press releases and internet sites of relevant industry associations (European Biodiesel Board, European Bioethanol Fuel Association and several national associations), an e-mail inquiry in the Baltic States and information available on the web pages of large biodiesel or bioethanol production companies.

total, 19 biodiesel plants are operating, planned or under construction in the new Member States. The average size of the processing plants for the EU is 85 000 tonnes per year. The largest processing units can be found in Germany, France and United Kingdom with capacities of 500 000 tonnes (one in each country). Relatively large processing units are also found in Belgium (265 000 tonnes) and Italy (250 000 tonnes). In the new Member States relatively large plants can be found in Latvia, Poland and Romania with capacities of 100 000 tonnes. The highest number of plants by far are found in Germany with 51 operating plants, followed by France (12 plants), Italy (10 plants) and Austria (10 plants).

The average production capacity of 51 bioethanol plants in the EU-15 is about 115 000 m³ per year, whereas the 16 plants in the new Member States (8) have an average capacity of 58 000 m³ per year. The largest units are located in the United Kingdom (400 000 m³), Belgium and France (300 000 m³) as well as Austria, Germany and Lithuania (200 000–300 000 m³).

Future processing plants are getting bigger, for example a new plant to be built in Lithuania is projected to convert 300 000 tonnes of crop (380 000 m³ bioethanol). Such large plants need a high biomass input either from imports or from the region surrounding the site in order to keep logistical costs low. If one assumes a cereal yield of 5 tonnes per ha, the new plant in Lithuania would require the output from 60 000 ha of cereal fields. As arable land is only a part of total land use, e.g. 50 % in many regions of Europe, and cereals should only be part of a wider crop rotation, for example 60 %, the regional demand of such a new plant stretches far beyond its immediate surroundings. In this hypothetical case, and assuming no imports, the area required for the ethanol production of the new plant would cover a area of approximately 40 by 50 km around or adjacent to the plant.

Figure 2.3 Expected production increase for biodiesel and bioethanol to 2008



Source: Wiesenthal *et al.*, 2007.

The 5.75 % biofuels target for 2010 set in the Biomass Action Plan has led to a high number of newly established or expanded biofuel plants across the EU-27 and further significant development is foreseeable due to the 10 % binding biofuel target for 2020. These figures show that there will be a dramatic increase in the demand for energy crops within the next few years. The rapid growth of biofuel processing capacities can also be illustrated by comparing the present biofuel production capacity in December 2006 with the planned production capacity up to mid-2008 (see Figure 2.3). Total EU-27 biodiesel processing capacity by end 2006 was 7 055 700 tonnes, whereas an additional 5 727 000 tonnes processing capacity will be added by mid-2008 alone. The corresponding figures for bioethanol are even higher: 4 729 380 tonnes of existing capacity and 7 433 520 tonnes of additional capacity by mid 2008.

The strong growth in biofuel production will already begin to reach agronomic limits, if the 5.75 % target is to be achieved with domestically grown crops for biodiesel in particular. EU-25 oilseed rape production in 2005 stood at a record 15.5 million tonnes, i.e. 28 % more than the average for the preceding five years and further growth to 16.2 million tonnes in 2006 was expected (Ollier, 2006b). In 2005, the area under oilseed rape in EU-25 was 4.8 million hectares, 80 % of which is concentrated in five countries: Germany (1.35 mio. ha), France (1.21 mio. ha), the United Kingdom (0.6 mio. ha), Poland (0.55 mio. ha) and the Czech Republic (0.27 mio. ha).

In Figure 2.4 a comparison is made between the potential production of oilseed rape (2005 hectarage times the average rapeseed yield (2000–2006) per country) and the potential demand from biodiesel processing plants, given their production capacities.

This comparison shows that in several EU-15 member States the demand from biodiesel plants cannot be satisfied by domestically grown oilseed rape. For the EU-10, especially in the Czech Republic and Poland, the cropped area still exceeds the potential demand from processing plants, leaving the possibility to export a large share of production. However, it is doubtful whether the European rape seed

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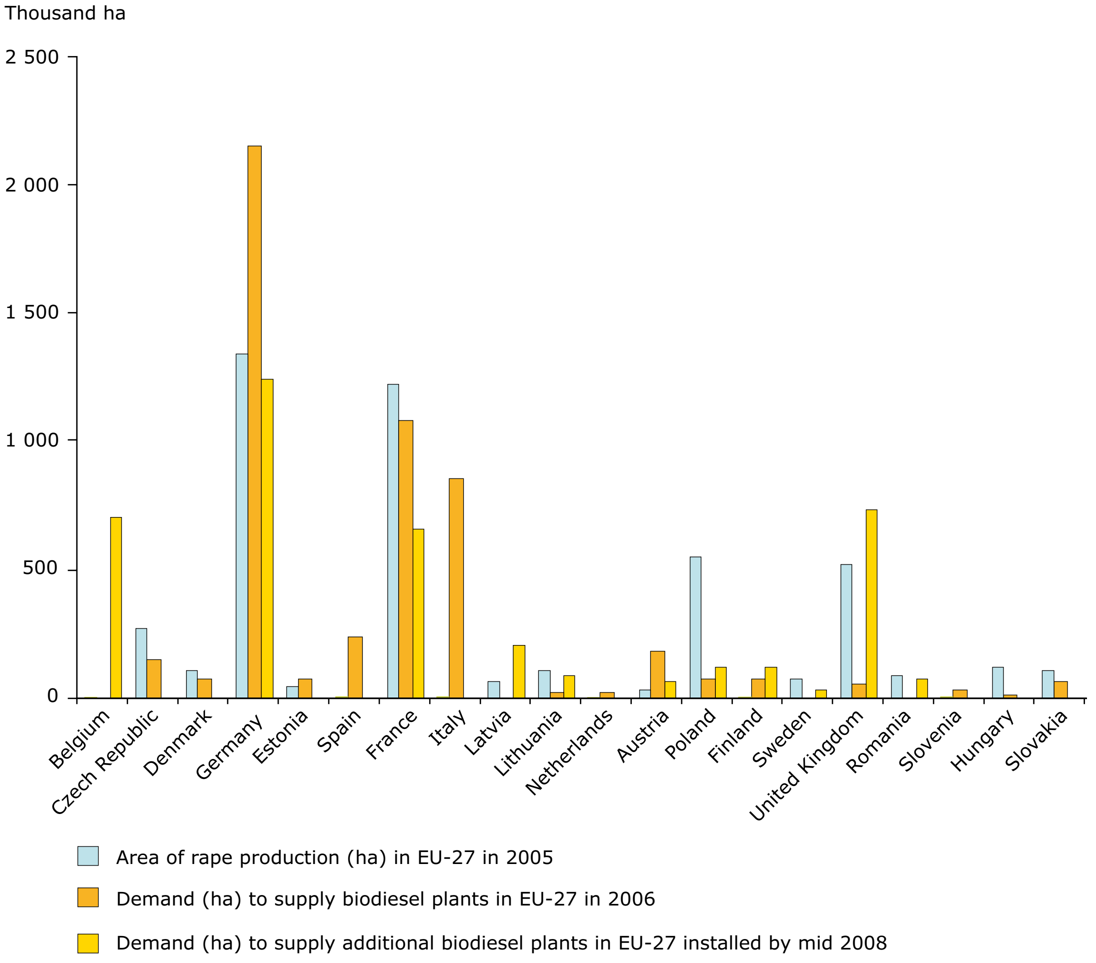
(8) Including Romania and Bulgaria.

Figure 2.4 Comparison of the area (ha) of oilseed rape production 2005 per Member State and area demand for supplying biodiesel plants in Member States in 2006 and in 2008



Source: Eppler & Piorr 2006, Eurostat NewCronos 2005.

production will be sufficient for supplying EU biodiesel capacities in the coming years, given existing targets.

Apart from land area constraints there are also agronomic limits to the cultivation of most bioenergy crops, e.g. in terms of crop rotation needs. For example, an appropriate crop rotation for oilseed rape would require a break of at least three years between rape crops in order to minimise disease pressures. Some crops, such as maize, are self-compatible but lead to significant environmental pressures when grown in a monoculture. The biogas boom in Germany is already leading to local maize monocultures with associated negative consequences for biodiversity and nutrient leaching risks (Schöne, 2007).

Any large biofuel processing plant will exert a significant influence on the crop mix in its regional sphere of supply. This can increase the agri-environmental pressures in the region concerned and may lead to biomass bottlenecks during years of low harvest. Many biofuel operators try to diversify supply options by building plants in large seaports, on the coast or close to navigable waterways (Note: currently approximately 20 % of all biofuel processing units tend to favour these sites). Overall, whether bioenergy feedstocks are imported or not, there are clear environmental risks associated with industrial scale installations. Hence, it is important to develop criteria that support an environmentally sustainable approach to energy production from agricultural (and other) biomass.

2.3 How to define an environmentally compatible future?

Section 2.1 has summarised key environmental impacts of current farming practices on the environment. A key assumption for this study was that future biomass production on agricultural land should not impose any additional pressure on farmland biodiversity and environmental resources than is currently the case and that specific EU environmental objectives should not be compromised (e.g. 'no further loss of biodiversity by 2010', 'good ecological status' of water bodies by 2015 under the Water Framework Directive).

The environmental constraints developed for this study were formulated at an EEA expert meeting in March 2005 (EEA internal note, 2005) and build on agri-environmental knowledge from EEA studies, such as the IRENA report, and a range of scientific papers. Their aim is to preserve existing natural resources as well as landscape and biodiversity values and give scope for a reversal of current trends, e.g. in the biodiversity area. The application of these criteria does not necessarily provide a guarantee for no further loss of natural resources e.g. further work is required in the water area. Nevertheless, they should be helpful in determining an agricultural biomass production potential that may be considered 'environmentally compatible'. The following key environmental constraints are part of the modelling framework in this study:

1. The present share of 'environmentally orientated' farming would need to increase to about 30 % of the Utilised Agricultural Area (UAA) in most Member States, except for densely populated countries such as Belgium, Netherlands, Luxembourg and Malta where the agricultural land per head ratio is very small. In these countries, the necessary share was set at 20 % of UAA by 2030.
2. At least 3 % of currently intensively used farmland should be made available by 2030 for nature conservation purposes in order to re-create ecological 'stepping stones' to increase the survival and/or re-establishment of farmland species in these areas.
3. If in future extensive land use categories such as permanent grassland, olive groves and dehesas/montados are released from agriculture, and therefore become potentially available for biomass production, these should not be ploughed for targeted biomass crops. Instead they should be maintained under their current land cover and ecological structure, while biomass from grass cutting or tree pruning could be harvested for bioenergy production.
4. Biomass crops chosen for future bioenergy production should be selected carefully with respect to both their environmental pressures and their potential to positively influence the landscape and biodiversity quality of an area. The criteria for prioritising these crops on the basis of their environmental performance should involve effects on water, soil and farmland biodiversity.

The sections below describe the rationale for the four environmental constraints set out above.

1) *Determining the share of environmentally orientated farming*

The preservation or introduction of environmentally orientated farming (EOF, which is composed of high nature value farmland and organic farming) was considered essential both for easing environmental pressures from farming and for preserving extensive land use categories that are important for farmland biodiversity and landscapes. Setting a 30 % (or 20 %) target for the share per Member State covers a significant land area, causing a noticeable environmental effect. On the other hand, it also comes close to the current share of extensive farmland categories in many EU countries (see Section 3.2.2). According to estimates available at the time of the study, most of the countries in the Mediterranean, but also Austria, Ireland, the United Kingdom, Estonia, Latvia, Romania, Slovakia and Slovenia already have shares of environmentally orientated farming categories well above 20 % and even 30 %.

Concerns about the likely negative effects of large-scale biomass production on environmentally orientated farming were raised in a study conducted for the EEA by Elbersen *et al*. (2005). In this study several arguments are given why shifts from existing food and feed production to biomass production will most likely take place on land which is sub-optimal for arable cropping, particularly if this concerns ligno-cellulose biomass cropping. This means that the largest pressures to shift to (ligno-cellulose) biomass crops will not be in the highly productive arable areas, but rather in sub-optimal farmlands which coincide most strongly with extensive farmland categories. If the present environmental state of these extensive farmland categories and the related biodiversity values is to be maintained, it should be ensured that biomass production does not lead to a further intensification of these lands. Setting a limit of 30 % for the amount of EOF in all Member States by 2030 would be a measure to ensure this.

2) *Ecological compensation areas in intensively used farmland*

In intensive farmland categories the need for re-creation of ecological stepping stones to enable the linkage between two important habitats may be crucial for the survival of certain species. This is supported by Vickery *et al.* (2004) in a study which showed that farmland bird populations in the United Kingdom continue to decline due to the insufficient quantity and quality of habitats available, especially in intensive agricultural landscapes. Vickery shows that the creation of non-cropped habitats and field margins as well as so-called 'arable pockets' in grassland regions and 'grassland pockets' in arable regions could be effective measures to support bird biodiversity. This hypothesis is supported by the theories of meta-population survival and island theories on which the creation of an ecological network (e.g. the Natura 2000 network) is based (Bouwman *et al.*, 2002).

The importance of landscape measures, such as amount and quality of a habitat, but also their distribution in the countryside for the survival of many species is confirmed by studies such as Vos *et al*. (2001); Opdam *et al*. (2003); Foppen (2000) and Bruinderink *et al*. (2003). These authors show that measures in the wider landscape, including intensive farmland areas, should be carefully considered when setting up an ecological network for targeted species. Re-creating stepping stones in these intensive farmlands will support connections between habitats and establish migration corridors for species that are currently found mainly in protected sites or high nature value farmland. Secondly, such measures are important for increasing the survival rates of species that have adapted to arable farming systems, such as the hare or the great partridge (e.g. Boatman *et al.*, 1999). This study therefore specifies the setting aside of 3 % of intensively used farmland for 'ecological' stepping stones, as the second framework condition in an environmentally compatible bioenergy future.

3) *Maintaining extensive land use categories in their current land cover*

The third assumption for the environmentally compatible future specifies that no permanent grassland should be ploughed up for dedicated biomass crops. A first important reason for this is the potentially enormous release of soil carbon when ploughing up grasslands. This could fully off-set the potential mitigation effect of using renewable energy from biomass as compared to non-renewable energy (see e.g. JEC, 2006; Vellinga, *et al*., 2005; Freibauer *et al*., 2004 & and Vleeshouwer & Verhagen, 2002). A second important reason is that permanent grasslands, especially the extensive semi-natural grasslands, are important habitats for the large number of species of different biota that rely on these habitats (see e.g. Evans, 2000; Anger *et al*., 2002; Bokdam, 2002; Nagy, 2002; Heath, *et al*., 2000; Bignal & McCracken, 1996 & 2000; Osterman, 1998; Tucker and Evans, 1997). The importance of permanent grasslands is also clearly acknowledged in European policy. In the mid-term review of the CAP a standard was introduced to avoid conversion of permanent grassland with a maximum flexibility of 10 % grassland loss per Member State (EC Regulation 1782/2003). Natural and semi-natural grassland formations are an important group of habitats listed in the Annex I of the Habitat Directive. At the same time it is known that most of these permanent grasslands are threatened by either intensification of agricultural activities or by abandonment (see e.g. EEA, 1998 and 2005; Ostermann, 1998).

For these reasons, it is clear that ploughing grassland for biomass production is undesirable from a biodiversity perspective. However, at the same time one finds a process of ongoing abandonment and/or underutilisation of grasslands which is also undesirable. As the removal of biomass through grazing or haymaking is an essential element in maintaining the natural richness of the systems, mechanical removal of biomass may replace animal grazing and hay cutting. In this way the structural diversity of the habitat could be maintained while biomass is removed for energy production (see also Section 8.3).

4) *Choosing an environmentally compatible crop mix*

Under the current policy framework and technological development, bioenergy production until at least 2010 is expected to focus on bioethanol and biodiesel. Up to 2010, it will be produced from rotational crops (Note: farming practices and the potential effects on environment and biodiversity are no different from food and feed crops commonly grown on arable farms). These crops are starch crops (e.g. wheat, potatoes, grain maize, barley and rye), sugar crops (e.g. sugar beet, sweet sorghum) and oil crops (e.g. rape, sunflower, soybeans). After 2010 it is generally expected that conversion techniques will have been developed so that ligno-cellulosic crops (e.g. short rotation crops like coppice of willow, poplar or miscanthus, switchgrass and reed canary grass, or annual crops like hemp and whole-plant cereals) will also become suited for more efficient conversion into biofuels. Furthermore, these crops are also expected to become important as feedstock for conversion into electricity and heat production. The production of these crops is expected to increase considerably over the next 20 years.

The choice of biomass crops and their management at farm level strongly affects the overall environmental impact of energy cropping systems. Environmentally detrimental land use changes (associated with a change from grassland or permanent crops to arable crops) are largely excluded via the first three environmental constraints. Nevertheless, all potential energy crops have different impacts on the environment depending on their suitability to local conditions, their place in a crop rotation and the specific management practices they require. The choice of crops also influences the efficiency of different bioenergy pathways, and the choice of pathway also determines the range of crops that are suitable as biomass feedstock. These issues are briefly discussed above and further explained in Chapter 5.

The environmental impact of different energy crops can be assessed via a number of pressure indicators that are ideally assessed for each environmental zone. The pressure indicators which were used to determine the likely environmental impact of bioenergy crops are listed below:

1. erosion;
2. soil compaction;
3. nutrient leaching to groundwater and surface water;
4. pesticide pollution of soils and water;
5. water abstraction;
6. fire risk;
7 farmland biodiversity;
8. diversity of crop types.

These criteria were applied in a matrix approach to rank the considered energy crops by likely overall environmental impact per zone. This analysis shows that novel perennial energy crops, such as miscanthus, switchgrass or short rotation coppice, generally fare better in environmental terms. However, their impact on water resources needs to be further explored (Dworak *et al.*, 2007). This analysis and the implications for the final proposed crop mix in an environmental perspective are further explained in Chapter 4.

3 Approach to estimating the environmentally compatible potential

3.1 Introduction

This chapter outlines the approach that was used to determine the future potential land availability in Europe taking into account a number of biodiversity protection and soil and water conservation considerations discussed in Chapter 2. Firstly, it sets out how environmental considerations have been translated into correction factors for the baseline agro-economic model (the CAPSIM Animlib scenario). In the next step this new so-called 'environmentally compatible scenario' is used to determine the land availability for biomass production. The creation of this scenario is described in Section 3.2. The application of this scenario to calculate land availability and the results are explained in Section 3.3. The resulting land use potential calculated through the application of this scenario can be called conservative, because a key assumption is that biomass crops will only be grown on land that is 'left-over', i.e. not needed for feed and food production. In Section 3.4 some additional less conservative approaches to calculating land availability are also presented in order to involve additional scenario assumptions on increased energy prices and a coupling between food, feed and biomass markets. An alternative model is introduced and applied to Germany and France to get an understanding of the effect of this scenario storyline (energy and CO_2 allowance prices) on land availability. The results of this additional assessment are then compared to, and integrated with, the calculations based on the CAPSIM Animlib scenario. Finally, the effect of using official land use statistics as a basis for the calculations is discussed in Section 3.5.

3.2 Creation of the 'environmentally compatible' scenario for predicting future biomass land availability

For the estimation of the land availability, the existing CAPSIM (EuroCare, 2005) 'Animlib' scenario is taken as the baseline situation and adapted to an 'environmentally compatible' scenario. The CAPSIM Animlib scenario assumes that no renewable energy targets are set in future EU policy and therefore only involves changes in agricultural markets resulting from the reform of the Common Agricultural Policy (CAP), as described in Section 1.3. The Animlib scenario assumes a complete liberalisation of all animal sectors (cattle, dairy, pigs and poultry), including the abolishment of the milk quota system, and a price level for most arable commodities near to world level. For more information on the CAPSIM model and the Animlib scenario, see Box 3.1.

The CAPSIM-Animlib scenario is taken as the baseline situation from which the share of the UAA that can become available for biomass crop production is estimated. However, before the CAPSIM Animlib scenario could be used as the baseline, two adjustments had to be made:

1) Animlib results from 2025 to 2030 were extrapolated, because 2030 is the time frame the study should cover.
2) Biodiversity protection and soil and water conservation considerations were incorporated, as formulated in Chapter 2, in the Animlib scenario. Prior to this study specific environmental framework conditions had not been incorporated in the Animlib scenario of CAPSIM because it was based on a projection of the present mix of farming systems.

The adapted Animlib scenario results form the basis for estimating the available land for biomass crop production in 2010, 2020 and 2030.

3.2.1 *Extrapolation of CAPSIM Animlib from 2025 to 2030*

Biomass potential is determined by both the yield increase and the changes in land use (area). For the extrapolation a linear regression method is used as there is no hint that yields would reach the genetic maximum (EuroCare, 2004). The regression is applied to the original CAPSIM yields for the years 2001, 2011, 2015, 2025 from which the extrapolation factors for all agricultural products for 2030 result. These 2030 yields are used as input for the next step; namely, the application of a correction factor to the 2030 Animlib yield results in order to incorporate

Box 3.1 CAPSIM Animlib scenario

The CAPSIM model provides results for all agricultural commodities expressed in production size, yields and land requirements by 2010, 2020 and 2025 (⁹). It covers 23 Member States of the European Union; Cyprus and Malta are not included due to limited data availability. The study builds on results from existing projection studies, namely the DG Agriculture 'Prospects for agricultural markets' (July 2004), FAPRI, the USDA/ERS baseline model, IMPACT and FAO projections, integrating these into the CAPSIM model. In this way expert judgments from different projection studies are combined and an average projection is derived. In order to make the projections, the CAPSIM model uses a partial equilibrium modelling approach. CAPSIM contains a broad range of social, economic, technological and policy orientated assumptions. Principally, exogenous assumptions were split into demand and supply side factors:

Demand side:

- Population growth and household expenditure is taken from the set of key assumptions compiled by the PRIMES modelling team, given in 10-year steps from 1990 to 2030. Because the ex post data differ from Eurostat population data which provide the bulk of the CAPSIM database, the projections have been expressed in index form (relative to 2000).
- Consumption is driven by price movements and other shifters (lifestyle, habits) interpreted as preference shifts over time. Price changes are partly endogenous, partly exogenous. For the market clearing exogenous international market prices are taken, where net trade is endogenous. For exogenous net trade prices are taken which are determined endogenously.
- Assumptions on international prices and on EU net trade are derived from the projections of international agencies. Demand and supply side interact on markets. For tradable products international prices (border prices) are linked to EU prices using a price transmission equation based on the law of one price. Without border measures, these international prices would directly apply to EU markets. Price policy instruments are tariffs or, until tariffication is complete, administered prices with associated flexible levies or export subsidies. For non-tradable products (fodder, calves) market clearing occurs on the level of Member States.
- The non agricultural (general) price index is an important special case which was specified in line with assumptions on the EUR/USD exchange rate. The exchange rate used in the baseline projection was fixed at 1.1 USD/EUR from 2001 onwards, in line with European Commission assumptions when the report was prepared (DG Agriculture, 2003).

Supply side:

- The key assumptions operating on the supply side are technology shifts in a wide interpretation, yield developments and price variables. Depending on the trade regime the latter are determined from the interaction with the demand side.
- CAPSIM distinguishes activity levels and yields such that crop yields, for example, are an explicit modelling input. Other changes, such as long run shifts in manure and housing systems, can only be incorporated in the form of parameter shifts of the nutrient balance description and cannot be analysed as a separate activity.
- Regarding the structural change of the farm size distribution, part time farming and labour force changes, explicit analysis goes beyond the scope of CAPSIM. However, structural change may be considered as a special type of technological change when viewed from an aggregate perspective. Considerable efforts have been made to capture the bottom line of these shifts of behavioural functions on the supply and demand side with a sophisticated set of trend projections. These trend projections incorporate a significant number of technological constraints (nutrient balances, land balance) as well as identities (production = area * yield) to compensate for detailed modelling of the individual contributions to overall technological change such as genetic improvements, capital accumulation, input quality and structural change.
- Policy strongly modifies the incentives on the supply side. Gross revenues of activities stem from market revenues and different types of CAP payments.

(⁹) Extrapolated to 2030 for the purpose of this study; see Section 3.2.1.

- Obligatory set aside is specified according to the July 2004 DG Agriculture projections. Non-food production is treated in the same manner.

For the behavioural functions in the CAPSIM model, which include functions for activity levels, input demand, consumer demand and processing, the parameters may shift over time. Such parameter shifts usually reflect linear or nonlinear impacts of technological or structural change.

In the Animlib scenario, the quota regime for milk ends in the year 2025. This is preceded by a gradual drop in the administrative prices for butter and skimmed milk powder, and tariffs for dairy products, starting after 2011. Similarly, market interventions for beef are eliminated, and tariffs for the different meats and eggs are removed. Consequently, EU market prices are assumed to be identical to border (world market) prices in the year 2025. The reduction in milk prices will also decrease quota rents. Once those reach zero, dairy cow herds (– 10 %) adjust until marginal production costs are equal to the reduced milk price (– 33 %). Additionally, the lower price of beef (– 30 %) compared to the reference run will reduce beef production (– 4 %). At the same time, market prices for pork (– 13 %) and poultry (– 28 %) will line up with world markets, and herds adjust (– 5 % for pigs and – 11 % for poultry). The reduced herd sizes also lower the demand for fodder and allow a reduction of the fodder area (– 2 %), which in turn leads to an expansion of other crops (cereals: + 1 %).

The remaining coupled payments are for protein crops and for paddy rice (compensation for strong price cut). The only relevant intervention price is for sugar which has been decreased according to the 2004 Commission proposal (to 421 euro from 632 euro) (10). Intervention prices for cereals remain in place but become irrelevant as world prices are assumed to increase (in nominal terms) and to become equivalent or even higher than EU prices from 2020 onwards.

Recent global cereal price developments have already clearly overtaken the above assumption as a number of bad harvests combined with increased bioenergy demand has led to strong price increases for agricultural commodities globally (OECD/FAO, 2007). This also shows the interaction of European food, feed and bioenergy markets with global markets. This aspect could, however, not be analysed in the current report due to the system limits adopted for this study.

the environmental constraints formulated in this study and create a new environmentally compatible future baseline situation. In Annex I an overview is given of the yield increases used in the original CAPSIM Animlib scenario including the extrapolated yields for 2030.

For the area, no extrapolation is carried out for 2030 as this factor depends on policy. Any extrapolation of this factor that does not involve concrete policy knowledge would deliver results with a very high uncertainty level. Consequently, total production and the product of area and yield are not extrapolated either. In this study the extrapolation to 2030 therefore only involved increased yield levels; agricultural area requirements remained the same as in the 2025 Animlib scenario.

3.2.2 *Incorporation of the environmental considerations*

To develop the 'environmentally compatible' future for this study the Animlib scenario was modified according to the assumption that a part of future agricultural land use (the part used by the environmentally orientated farming) will be more extensive. This correction for extensification implies a higher share of environmentally orientated farming (EOF) by 2010, 2020 and 2030 than is currently projected in the CAPSIM Animlib scenario. By 2030 the share of EOF should be at least 30 % in all EU Member States (apart from Belgium, Luxembourg, Netherlands and Malta).

'Environmentally orientated' farming (EOF) includes both agricultural area under organic farming and High Nature Value (HNV) farming. High Nature Value farmland can be defined as *farmland that comprises those areas in Europe where agriculture is a major (usually the dominant) land use and where agriculture supports or is associated with either a high species and habitat diversity or the presence of species of European conservation concern or both* (Andersen *et al.*, 2003; and EEA/UNEP, 2004).

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(10) This does not incorporate the sugar reform agreement from December 2005. Overall the assumptions used in CAPSIM do not diverge very strongly from the present agreement however.

Table 3.1 Estimated present and future Environmentally Oriented Farming (EOF), combined share of organic and HNV farmland in classes

	Classes			
Year	**2000**	**2010**	**2020**	**2030**
Austria	6	6	6	6
Belgium*	1	2	3	6
Bulgaria	2	4	2	6
Cyprus*	..	..	..	..
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
Romania	5	5	6	6
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 (2003). The HNV farmland shares for the EU-10 and Romania and Bulgaria were estimated using a combination of selected Corine land cover 2000 data and semi-natural grassland estimates (Veen *et al.*, in Brouwer *et al.*, 2001). Countries marked with a * are only given a target of 20 % EOF due to their low agricultural land area per head of population.

In order to reach the 30 % target two main assumptions are made. If the target is currently reached than the share of HNV farmland and of organic farming remain stable until 2030. If the 30 % target is currently not reached the share of organic farmland is assumed to increase while the share of HNV farmland is held constant. In Table 3.1 the current share of combined organic farming and HNV farmland is given in 6 classes, and estimated developments between 2000 and 2030 are displayed.

CAPSIM Animlib does not explicitly differentiate between conventional, HNV and organic farming systems. For each crop there is one yield in CAPSIM which determines the land which is needed for a specific agricultural output (see Annex II). However, in an environmentally constrained future it is assumed that yields are lower for the 30 % share of EOF than conventional yields. In order to incorporate an increased share of EOF in future land use, a correction for yield needs to be applied on the estimated share of farmland under EOF in 2010, 2020 and 2030. This is carried out in three steps:

1. Current yield differences between conventional farming, organic and HNV farming in 2000 are determined and future differences estimated (up to 2030).
2. The division between the HNV farmland and the organic farmland over the different arable and grassland categories is determined. This allows a calculation of the

share of the different land use categories that need to be corrected for lower yields in an environmentally compatible future.

3. The correction for the lower yields is applied to the CAPSIM Animlib scenario resulting in a new environmentally compatible baseline scenario which has a higher land requirement than the original Animlib scenario.

The three steps are described in more detail in the following subsections.

1) Determining the yield differences between conventional and EOF farming

For the determination of the organic-conventional yield differential we follow Offermann (2003) who gave an overview of the crop-wise yield reduction factors for different European countries around the year 2000 (see Tables 3.3 and 3.4).

For the future, the productivity increase in organic farming is assumed to be the same as in conventional farming.

To estimate the yield differential on HNV farmland, the organic yield level as given by Offermann (2003) was used. However, for the future we assume that for this part of the EOF these yields remain constant. So, in contrast to the organic share of the EOF, for which a yield increase over time similar to that of conventional farming was assumed, there will not be an increase on HNV farmland. The reason for this assumption is based on the inherent characteristics of this type of farming system. The nature of farming practices on HNV farms is usually constrained by climatic and topographic factors on these farms, which means that the farming practices are more extensive and more synchronised with natural process and natural fluctuations from year to year (see Andersen *et al.*, 2003; EEA/UNEP, 2004).

Table 3.2 Share of EOF total in the year 2030 by Member State

EOF total	Member States
20 %	Belgium, Netherlands, Luxembourg, Malta
30 %	Denmark, Germany, France, Ireland, Italy, Austria, Finland, Sweden, United Kingdom, Czech Republic, Estonia, Hungary, Lithuania, Latvia, Poland, Slovakia
35 %	Slovenia
36 %	Spain
38 %	Portugal
41 %	Greece
-	Cyprus

Table 3.3 Organic farming yields in EU-15 Member States expressed as shares of conventional yields (= 100 %)

	BE	DK	DE	EL	ES	FR	IE	IT	NL	AT	PT	FI	SE	UK
Wheat	63 %	59 %	61 %	70 %	79 %	50 %	60 %	88 %	73 %	65 %	79 %	60 %	62 %	54 %
Durum	63 %	59 %	61 %	70 %	70 %	73 %	66 %	70 %	68 %	64 %	70 %	60 %	60 %	66 %
Rye	66 %	70 %	60 %	70 %	70 %	60 %	68 %	72 %	77 %	75 %	70 %	48 %	74 %	68 %
Barley	65 %	67 %	64 %	70 %	72 %	75 %	60 %	75 %	79 %	64 %	72 %	52 %	66 %	65 %
Oats	64 %	70 %	70 %	70 %	79 %	70 %	62 %	88 %	64 %	66 %	79 %	64 %	76 %	72 %
Grains maize	95 %	73 %	71 %	70 %	72 %	73 %	77 %	74 %	95 %	87 %	72 %	73 %	73 %	77 %
Other cereals	63 %	70 %	71 %	70 %	70 %	55 %	69 %	70 %	77 %	64 %	70 %	73 %	73 %	69 %
Pulses	78 %	74 %	74 %	70 %	78 %	83 %	70 %	87 %	78 %	84 %	78 %	74 %	74 %	70 %
Potatoes	50 %	71 %	60 %	67 %	67 %	74 %	74 %	81 %	71 %	47 %	67 %	10 %	85 %	60 %
Sugar beets	71 %	86 %	91 %	70 %	70 %	91 %	57 %	70 %	71 %	85 %	49 %	86 %	86 %	86 %
Rape	63 %	63 %	63 %	49 %	49 %	63 %	74 %	49 %	49 %	83 %	49 %	63 %	63 %	63 %
Sunflower seed	63 %	63 %	63 %	49 %	49 %	63 %	74 %	49 %	49 %	83 %	49 %	64 %	64 %	80 %
Grass	80 %	83 %	80 %	70 %	70 %	70 %	80 %	80 %	80 %	90 %	80 %	50 %	79 %	80 %
Other fodder	80 %	83 %	80 %	70 %	70 %	70 %	80 %	80 %	80 %	80 %	80 %	50 %	79 %	80 %

Note: Figures in yellow cells are estimated and not provided by Offermann. These figures are estimated by taking the average yield reduction figures of the neighbouring countries for which data were available from Offermann.

Source: Offermann, 2003.

Table 3.4 Organic farming yields in new Member States expressed as shares of conventional yields (= 100 %)

	CZ	ES	HU	LT	LV	PO	SI	SK
Wheat	66 %	61 %	66 %	61 %	61 %	66 %	66 %	66 %
Durum	66 %	60 %	66 %	60 %	60 %	66 %	66 %	66 %
Rye	68 %	60 %	68 %	60 %	60 %	68 %	68 %	68 %
Barley	68 %	63 %	68 %	63 %	63 %	68 %	68 %	68 %
Oats	71 %	69 %	71 %	69 %	69 %	71 %	71 %	71 %
Grains maize	77 %	72 %	77 %	72 %	72 %	77 %	77 %	77 %
Other cereals	69 %	73 %	69 %	73 %	73 %	69 %	69 %	69 %
Pulses	77 %	73 %	77 %	73 %	73 %	77 %	77 %	77 %
Potatoes	63 %	56 %	63 %	56 %	56 %	63 %	63 %	63 %
Sugar beets	76 %	81 %	76 %	81 %	81 %	76 %	76 %	76 %
Rape	60 %	71 %	60 %	71 %	71 %	60 %	60 %	60 %
Sunflower seed	62 %	64 %	62 %	64 %	64 %	62 %	62 %	62 %
Grass	77 %	64 %	77 %	64 %	64 %	77 %	77 %	77 %
Other fodder	76 %	71 %	76 %	71 %	71 %	76 %	76 %	76 %

Note: Figures in yellow cells are estimated and not given by Offermann. The estimates are derived by taking the average yield reduction figures of the neighbouring countries for which data were available from Offermann.

Source: Offermann, 2003.

Low yields are therefore an inherent characteristic of most HNV systems, and are one of the determinant factors for their biodiversity richness. Therefore, no yield increase for HNV-farming in the calculations was assumed.

In the next step, the yield of each crop was reduced according to the amount of EOF in each country. In order to reach the target of 30 % EOF by 2030, the assumptions were made that the present share of HNV farmland would remain stable until 2030 and the share of organic farming would increase up to a combined share of 30 %. How this works out for the different countries by 2010, 2020 and 2030 is shown in Tables 3.1 and 3.2. It should however be noted that the 30 % share of EOF farmland in 2030 was taken as the target. For the intervening time periods (2010 and 2020), the total 2030 increase was divided into three equal parts for the organic share. No optimisation was applied for the years between 2000 and 2030. This explains why extensification towards a higher share of EOF and the yield increases applied as correction factors to the Animlib scenario in the same time period are not fully correlated for the individual time steps.

2) Estimating types of land use in organic and HNV farmland

To apply the yield reduction correction factors to the right land use classes, the share of arable and grassland in the total UAA of the present EOF farmland (2000) was estimated. This 2000 share was then extrapolated for the future by assuming that on HNV farmland the relative shares would remain the same in 2010, 2020 and 2030. For organic farming, Offermann (2003) was followed. It was assumed that the current organic land use mix is similar to that of conventional farming and that it will also develop in the same way in the future.

For HNV farmland the share of arable and grassland was estimated from the share of the main types of Corine land cover (CLC 2000) classes in which the HNV farmland is assumed to be concentrated in every country (see also Annex IV and Table 3.5).

3) Application of the correction factors and creation of the ecologically constrained future baseline situation

With the information about HNV farmland and organic farming the share of EOF arable land and grassland is calculated as shown in Figure 3.1.

Finally, a correction factor for the yields for each crop by country and year was calculated as shown in the last column of Table 3.6 for a fictitious Member State. When looking at the difference between the original baseline (Animlib) scenario and the adapted 'environmentally compatible' Animlib scenario, land demand rises for the example crop from 100 000 to 107 000 hectares due to extensification (for further explanation see Annex II).

In the original CAPSIM model the UAA decreases from 2001 to 2020 (non-food, set aside and fallow land excluded (11)) due to the market liberalisation

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(11) Non-food production on set aside and fallow land form part of the land potential. Set aside land includes both obligatory and voluntary set-aside.

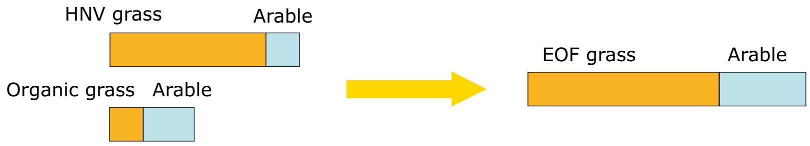
Table 3.5 Share of arable land in HNV farmland and in total UAA in 2000

	Arable HNV	Arable in UAA
Austria	0–20 %	40 %
Belgium	0–20 %	60 %
Cyprus	–	-
Czech Republic	21–40 % *	80 %
Denmark	0–20 %	70 %
Estonia	0–20 %	95 %
Finland	81–100 % **	85 %
France	21–40 %	70 %
Germany	0–20 %	80 %
Greece	21–40 % *	65 %
Hungary	0–20 %	70 %
Ireland	0–20 %	85 %
Italy	41–60 % **	25 %
Latvia	41–60 % **	70 %
Lithuania	61–80 % **	70 %
Luxembourg	0–20 %	-
Malta	41–60 %	75 %
Netherlands	0–20 %	55 %
Poland	0–20 %	80 %
Portugal	41–60 %	65 %
Slovakia	0–20 %	-
Slovenia	61–80 % **	85 %
Spain	0–20 % *	40 %
Sweden	61–80 % **	65 %
United Kingdom	0–20 %	40 %

Note: Recent work by EEA and the EU Joint Research Centre provides different, generally lower, estimates for the share of arable land in total HNV farmland. The stars (*) indicate the divergence from the more recent estimates with ** indicating a strong difference.

Source: Corine land cover 2000 data and HNV farmland study (Andersen *et al*., 2003).

Figure 3.1 Approach to calculating the share of EOF arable and grassland from HNV and organic farming



in the EU. The difference constitutes land that could potentially be used for energy crops. In addition to this difference fallow and set aside land could also potentially be used for energy crops.

For the 'environmentally compatible' scenario with more EOF, CAPSIM is modified. The extensification of agriculture entails a higher land demand to maintain food production with consequent changes to UAA. Thus, the decrease of UAA is less than in the original scenario and less land becomes available for bioenergy cropping.

The other entries for balance are again fallow land, set aside and land for non-food production as in the original CAPSIM data. As these figures do not develop very dynamically the extrapolation of the original data (2025) to the year 2030 does not lead to any changes. For this reason, the original CAPSIM data is used in the scenario with more EOF. In the next section, the results of the application of the 'environmentally compatible' scenario are applied to land use and the results are discussed.

3.3 Conservative results: land availability for biomass crops in an 'environmentally compatible' future

In this part of the study, the future available land for biomass crop production in the 'environmentally compatible' scenario is determined using the corrected CAPSIM Animlib scenario results.

The following six assumptions are made:

1) Land released from agricultural production in 2010, 2020 and 2030 in the corrected environmentally compatible scenario is used for production of biomass for energy.
2) Projected areas of set aside land ([12]) in 2010, 2020 and 2030 are used for production of bioenergy.
3) Area available for agricultural production under (1) is first reduced by a share ranging from 0.5–2 % for non-agricultural purposes

Table 3.6 Calculation of the adaptation factors for a crop yield for a fictitious Member State with a share of 17 % EOF in 2010

No.	Category		Year 2010	Source and calculation*
(A)	Conventional yield of a crop X	kg/ha	6 000	CAPSIM
(B)	Yield organic farming	%	66.6 %	Offermann. 2003
(C)	Share of organic arable of total UAA	%	2 %	Own assumption
(D)	Organic/extensive yield of X	kg/ha	4 000	(B)*(C)
(E)	HNV yield	kg/ha	3 600	90 % of org. yield
(F)	Share of HNV arable of total UAA	%	15 %	Own assumption
(G)	Corrected yield (overall)	kg/ha	5 600	(G) = (C)*(D) + (E)*(F) + (1–(C+F))*(A)
(H)	Correction factor for area from 2010 on	%	107.1 %	(H) = (A)/(G)
(I)	CAPSIM area	1 000 ha	100	CAPSIM
(J)	Corrected area	1 000 ha	107.1	(J) = (I)*(H)
(K)	Balance corr. — CAPSIM	1 000 ha	7.1	(K) = (J)–(I)

(C)*(D) : organic farming
(E)*(F) : HNV
(1–(C+F))*(A) : conventional

Table 3.7 Estimated future land requirement for non-agricultural uses of released agricultural land

0.5 %	Estonia, Latvia, Lithuania, Bulgaria, Turkey, Romania
1.0 %	Hungary, Slovakia, Poland, Spain, Greece, Cyprus, Slovenia, Portugal, Czech Republic, Finland, Sweden, Ireland, Austria
1.5 %	France, Denmark, Luxembourg, Italy, Malta
2.0 %	Germany, United Kingdom, Belgium, Netherlands

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[12] In a more detailed analysis, a clear distinction between long-term and short-term set aside land would be necessary in order to further specify the environmentally compatible land potential for bioenergy. It can be assumed that exchanging short-term set-aside land for energy production does not necessarily lead to an important loss of valuable habitats (given the 3 % rule for 'stepping stones' in intensive farmland areas). However, this could well be the case where long-term set aside is concerned. Unfortunately, the CAPSIM data used in this study only differentiate between obligatory and voluntary set-aside land.

before being made available for biomass crop production. Non-agricultural purposes include the needs for uses such as urban areas, infrastructure, forestry, recreation, water treatment etc. This future land requirement for non-agricultural uses has been estimated at Member State level by using a combination of information on past trends, population density and Gross Domestic Product. The estimated decrease per 10 years is shown for the different Member States in Table 3.7.

4) Land available for energy production is reduced again by a share of 3 % of the intensive arable land for the creation of environmental 'stepping stones' in intensive farmland areas. For determining the intensive arable land, 2001 was taken as the reference year. It is assumed that between 40–70 % of the arable crops was grown intensively (see Annex II, Table II-3), to which the 3 % share was applied, and that this share is reached by 2010. After that date, the total amount of land used for 'stepping stones' is assumed to remain constant (see Annex II for the share of intensive farmland by Member State).
5) The future land released from agriculture is used for the production of biomass; only when this released land is completely used for energy cropping will the remaining land requirement for biomass be satisfied by future set-aside land. This assumption is logical as land that is still in agricultural use can be converted more efficiently (from an agronomic perspective) to biomass crop production than land that has been out of use for a while.
6) Land that is already in use for biomass crop production in 2000 will remain in biomass crop production in the future and will therefore be part of the future potential.

As a result, we can estimate which part of the released agricultural and set aside land projected in the 'environmentally compatible' scenario will potentially become available for biomass crop production in 2010, 2020 and 2030.

The calculation of the available land for biomass crop production according to the steps specified above is illustrated in Table 3.8 for France and in Table 3.9 for Hungary. The results for France show that most of the land for biomass crops will be released from fodder and grazing land use categories and set-aside land. Land for rotational food crops will increase in the future, reducing the biomass cropping land potential significantly, especially by 2030. If the released cropping and set-aside land is further reduced with land needed

Table 3.8 Estimated future land availability for biomass crop production in France

	2010	2020	2030
(* 1 000 ha)	**France**	**France**	**France**
Total arable land (cereals, oilseeds and pulses, other arable) released	– 1 409.8	– 1 883.8	– 2 306.2
Land released in permanent crops & vegetables	111.4	136.4	151.4
Land released in olives	–1.2	–4.2	–5.2
Land released in fodder	300.2	407.9	496.8
Land released in grazing and grassland	454.8	1 062.5	1 213.2
Total set aside	1 370.0	1 443.0	1 478.0
Total land released and set aside	825.5	1 161.8	1 027.9
Total land already under energy crop production (average 1999–2002)	381.3	381.3	381.3
Total land primarily available including set-aside-non-food in 2000/2001	1 206.8	1 543.1	1 409.2
Non-agricultural land use increase in 10 years (in %)	1.5 %	1.5 %	1.5 %
3 % of intensive farmland	199.2	199.2	199.2
Available as cuttings (former grassland and olive groves)	535.8	262.4	0.0
Available as land for dedicated crop production	453.6	1 058.3	1 208.0
Total net available land	989.4	1 320.7	1 208.0

Source: EEA based on Wiegmann, K., Fritsche, U. & B. Elbersen: 'Environmentally compatible biomass potential from agriculture'. Consultancy report to the EEA, 2005.

for non-agricultural purposes, and 3 % of intensive farmland is taken for 'stepping stones' for nature conservation purposes, the available land will range from 989 400 hectares in 2010 to 1 208 000 hectares in 2030 (see Table 3.8). However, in 2010 a large part of this available land will come from grassland. In the environmentally compatible future of this study, it would be ecologically damaging to plough these lands and use them for arable rotational biomass crops (see Section 2.3 for details). Therefore, these lands are used only for the harvesting of grass cuttings. This implies that in 2010 France still has approximately half a million hectares available for dedicated arable biomass crops (see Table 3.8).

In contrast to France, only a small share of the released land will be available for dedicated crop production in Hungary, especially by 2010 when 470 000 ha will become available for biomass. However, most of it will only be available for grassland cuttings. By 2030 the available land increases to 844 300 ha land and a larger share of this could be used for dedicated biomass crop production (see Table 3.9).

The overall results for all EU-25 Member States are presented in Figure 3.2 and Table 3.10. The specific results per country are given in Figures 3.3 to 3.6 and in Annex III (Tables III-1 and III-2) ([13]). The results show that for the EU-25 the total available land for biomass production will be almost 14 million hectares by 2010, and this will increase to almost 18 million hectares by 2020 and 20 million by 2030 (current non-food production on set-aside included). It also shows that in the next decades the cultivation of energy crops could become more prominent in the new Member States, given the fact that the arable land share (as share of total UAA) is relatively large in these countries and that relatively more land is projected to be released from food and feed production (i.e. they provide almost 50 % of the total arable land potential for biomass by 2020 and 2030). Meanwhile, the total UAA of these eight countries is only one fifth of the total UAA of the EU.

Of the land that becomes available for biomass in 2010 in the whole EU, some 88 % is released in the arable land use category and not in the permanent grassland category. This means that the land can be

Table 3.9 Estimated future land availability for biomass crop production in Hungary

	2011	2020	2030
(* 1 000 ha)	**Hungary**	**Hungary**	**Hungary**
Total arable land (cereals, oilseeds and pulses, other arable) released	– 91.8	– 270.9	– 381.7
Land released in permanent crops and vegetables	58.5	43.5	36.5
Land released in olives	0.0	0.0	0.0
Land released in fodder	0.6	158.9	236.6
Land released in grazing and grassland	56.8	231.2	296.9
Total set aside	497.0	634.0	711.0
Total land released and set aside	521.1	796.7	899.2
Total land already under energy crop production (average 1999–2002)	0	0	0
Total land primarily available including set-aside-non-food in 2000/2001	521.1	796.7	899.2
Non-agricultural land use increase in 10 years (in %)	1 %	1 %	1 %
3 % of intensive farmland	45.9	45.9	45.9
Available but as grass (former grassland)	413.2	511.6	547.4
Available as land for dedicated crop production	56.8	231.2	296.9
Total net available land	470.0	742.8	844.3

Source: EEA based on Wiegmann, K., Fritsche, U. & B. Elbersen: 'Environmentally compatible biomass potential from agriculture'. Consultancy report to the EEA, 2005.

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[13] Please note that the overall potential for the EU-25 is based on the total potential per EU Member State excluding Luxembourg (which is included as part of Belgium) and Malta and Cyprus, for which no data were available. This is why EU-25 results can only be specified for the EU-15 and EU-8 country groups.

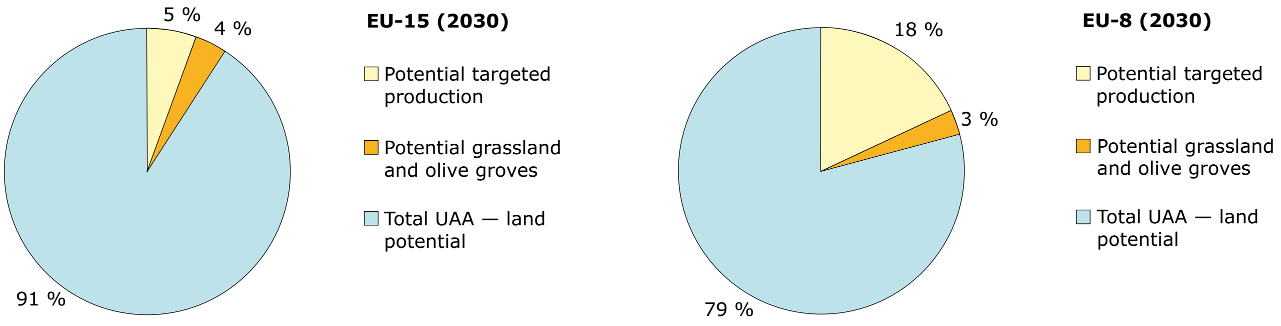
Table 3.10 Land available for biomass crop production in the EU-25

	Land available (*1 000 ha)	**EU-15**	**EU-8**	**EU-15 + EU-8**
2010	Available arable land	6 935.8	5 319.9	12 255.7
	Only available as cuttings (former grassland + olive groves)	1 154.0	525.6	1 679.7
	Total	8 089.9	5 845.6	13 935.4
2020	Available arable land	6 948.5	6 484.1	13 432.6
	Only available as cuttings (former grassland + olive groves)	3 611.5	908.4	4 519.9
	Total	10 560.0	7 392.4	17 952.5
2030	Available arable land	7 375.5	6 931.7	14 307.2
	Only available as cuttings (former grassland + olive groves)	4 759.8	1 097.3	5 857.1
	Total	12 135.2	8 029.1	20 164.3

Note: No data were available for Cyprus and Malta.

Source: EEA based on Wiegmann, K., Fritsche, U. & B. Elbersen: 'Environmentally compatible biomass potential from agriculture'. Consultancy report to the EEA, 2005.

Figure 3.2 Grassland available for extensive biomass crop production (grass cuttings) and arable land available for all dedicated biomass crop production for EU-15 and EU-8 in 2030



Note: No data were available for Cyprus and Malta.

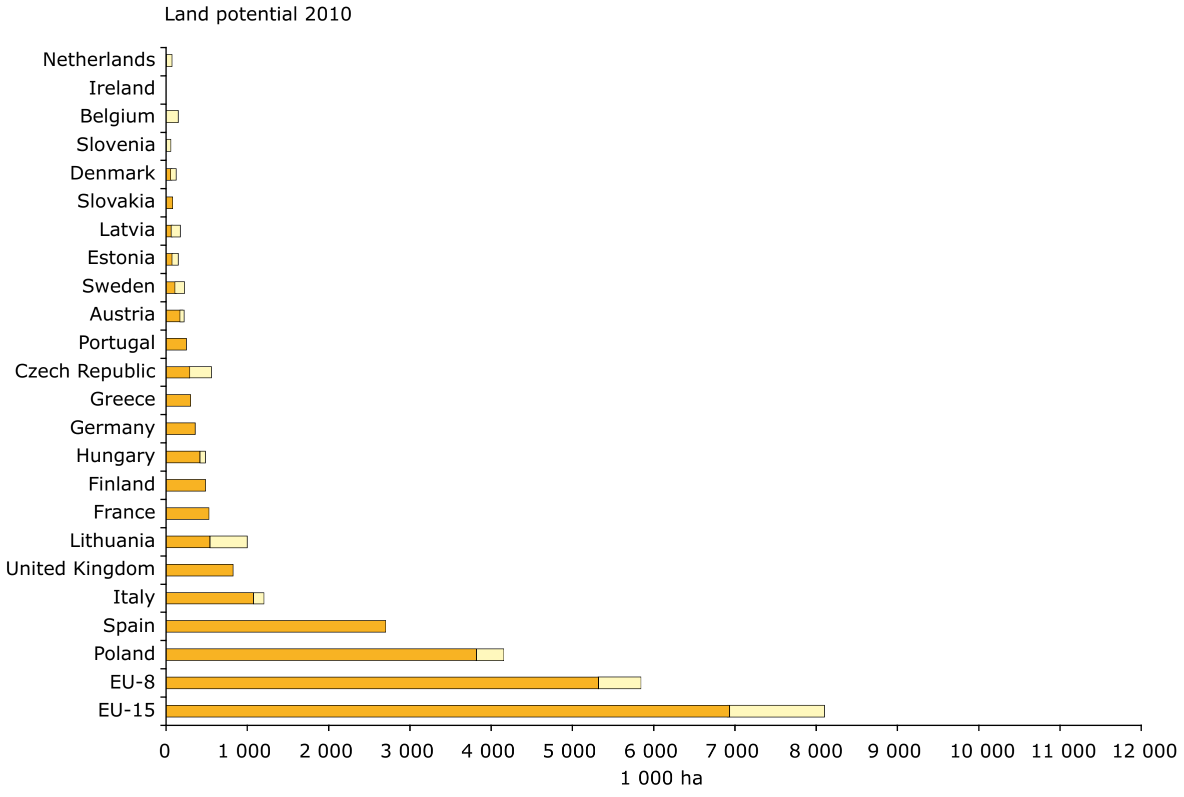
Source: EEA based on Wiegmann, K., Fritsche, U. & B. Elbersen: 'Environmentally compatible biomass potential from agriculture'. Consultancy report to the EEA, 2005.

used for dedicated crop production. It also implies that given the environmentally compatible future that prevents the switching from extensive land use categories to arable, the remaining 12 % of available land can only deliver biomass from grassland cuttings. In 2030 the share of land available in the grassland and olive category increases to almost 30 % of the total potential (see Table 3.10). This category does not include wood cuttings from olive trees.

Under the conditions of an environmentally compatible future, the need for a higher share of extensive biomass crop categories, such as grassland cuttings and perennial crops by 2020 and 2030, would not be difficult to fulfil. Over time more techniques are likely to be developed making the conversion of ligno-cellulosic crop materials into energy more efficient both with regard to net energy output and costs.

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 biomass would be Poland, Spain, Italy, the United

Figure 3.3 Grassland available for extensive biomass crops (grass cuttings) and arable land available for all dedicated biomass crop production for all investigated EU-25 Member States in 2010



Note: No data were available for Cyprus and Malta.

Source: EEA based on Wiegmann, K., Fritsche, U. & B. Elbersen: 'Environmentally compatible biomass potential from agriculture'. Consultancy report to the EEA, 2005.

Kingdom, France Lithuania and Hungary. The new Member States would deliver a substantial share of the available land for biomass, especially when related to their share in the total UAA in the EU (see Figure 3.2).

3.4 Additional approaches for estimating land availability

This study is based on the CAPSIM Animlib scenario which has been modified for an environmentally compatible future by assuming a higher share of production coming from EOF systems and applying a correction factor for yields. However, although the Animlib scenario assumes market liberalisation for all animal sectors, it does not assume full liberalisation for all arable markets (¹⁴). In addition, the Animlib scenario only involves changes in agricultural markets that result from the reform of the CAP and does not include any assumptions about renewable energy targets, higher fossil energy or CO_2 allowance prices. But in reality, rising fossil energy prices and the inclusion of (reduced) greenhouse-gas emissions through emission trading will increase the attractiveness of biomass for energy purposes.

Hence, the results relating to land availability under the environmentally compatible scenario (based on modifications of the CAPSIM Animlib scenario) are a conservative estimate as the classical agricultural food and feed markets are handled with priority. For France and Germany in particular the chosen method shows a noticeably low (arable) land potential which is primarily due to the very high export surplus for cereals in these two countries. Export therefore determines a large part of the land

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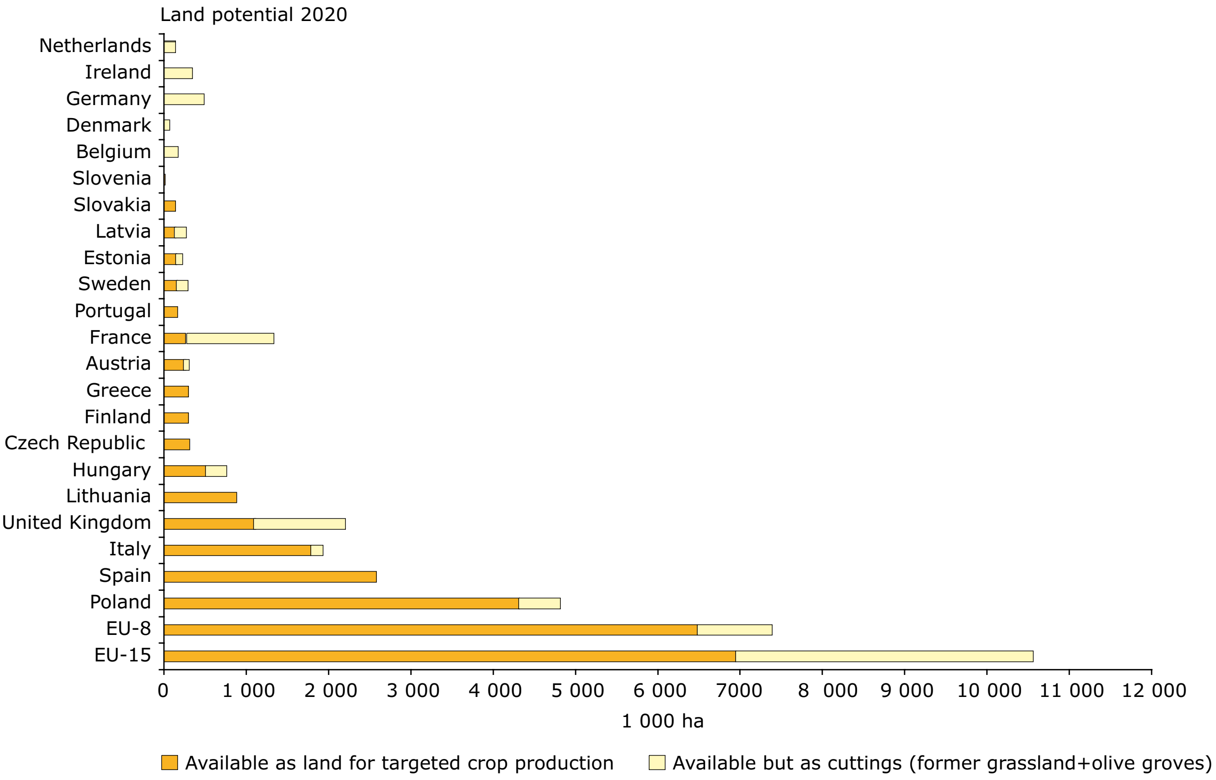
(¹⁴) In this scenario the prices for most cereals are near to world market level prices by 2020. However, premiums are still paid for these commodities. For sugar, no complete liberalisation is assumed. The price hike for cereals in the 2006/2007 marketing year could not be taken into account.

Figure 3.4 Grassland available for extensive biomass crops (grass cuttings) and arable land available for all dedicated biomass crop production for all investigated EU-25 Member States in 2020



Note: No data were available for Cyprus and Malta.

Source: EEA based on Wiegmann, K., Fritsche, U. & B. Elbersen: 'Environmentally compatible biomass potential from agriculture'. Consultancy report to the EEA, 2005.

demand in the modified Animlib scenario. This would mean that in these two Member States even current set-aside land would be brought back into food and feed production. As a result, the crop cultivation for bioenergy would decrease relative to today. However, given European concerns about climate change and expectations of high fossil energy prices, a strong demand for renewable energy sources including bioenergy from biomass can be expected (for a brief review of relevant EU energy policy decisions see Section 1.2). It is therefore necessary to also consider the effect of an increased stimulation of biomass production for bio-energy by higher fossil energy and/or CO_2 allowance prices at the expense of food and feed exports. This additional analysis is carried out using the HEKTOR model (Simon, 2005).

HEKTOR is a model created for assessing the future biomass potential from agriculture in different areas of Europe. HEKTOR is an acronym for HEKtar-KalkulaTOR. It is designed to analyse trends in agricultural land use under different scenarios up to 2030.

The model assumes that all agricultural area not in use for food production is available for biomass production. An overview of the general approach followed in HEKTOR is shown in Figure 3.6. For a more detailed flow chart see also Annex VIII.

In contrast to the CAPSIM approach, the HEKTOR model starts with a bottom-up projection of land needed in order to first fulfil food and feed demands in all Member States. In this approach it is therefore assumed that self-sufficiency rates should be ensured while exports are gradually phased out (15).

HEKTOR also assumes that higher energy prices will disturb CAPSIM's market equilibrium projections, as it will become more attractive from an income perspective to grow energy crops instead of feed

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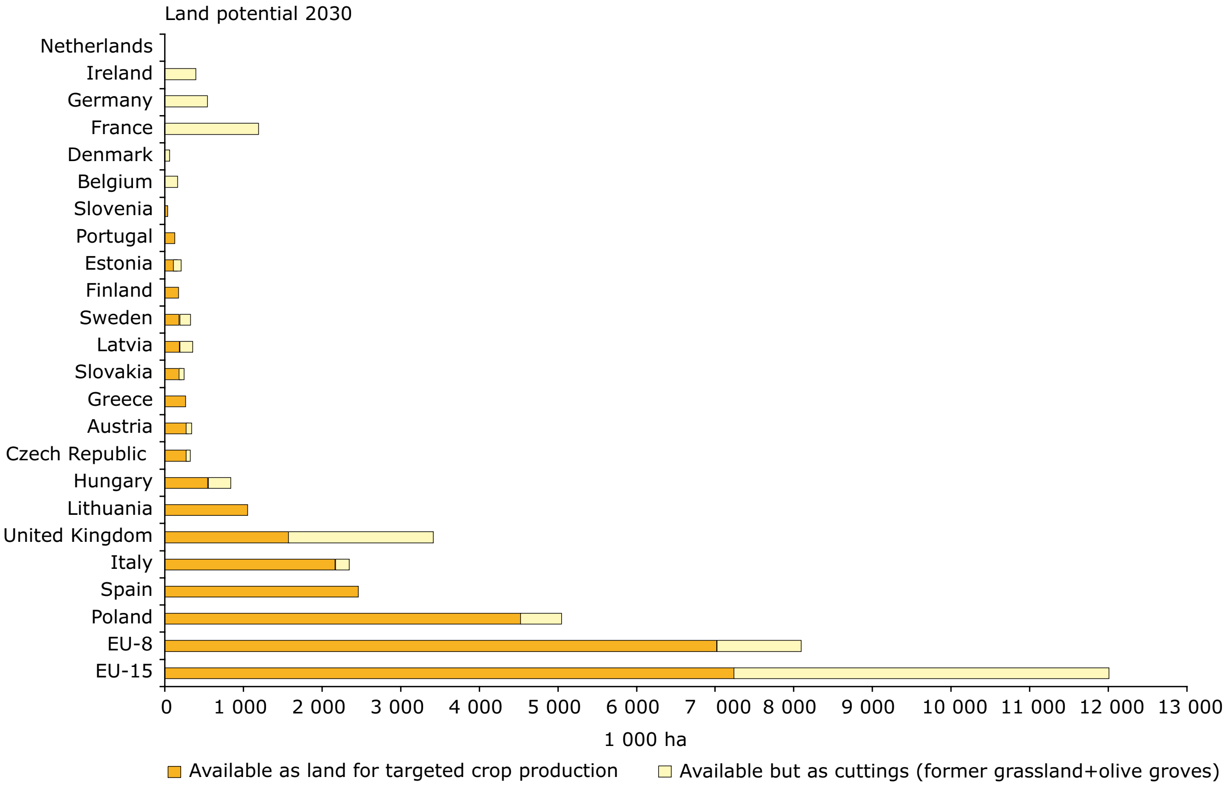
(15) It should be noted that this approach runs counter to most current predictions about the future development of EU (and world) agriculture policies which assume a further liberalisation of world agricultural markets.

Figure 3.5 Grassland available for extensive biomass crops (grass cuttings) and arable land available for all dedicated biomass crop production for all investigated EU-25 Member States in 2030



Note: No data were available for Cyprus and Malta.

Source: EEA based on Wiegmann, K., Fritsche, U. & B. Elbersen: 'Environmentally compatible biomass potential from agriculture'. Consultancy report to the EEA, 2005.

Figure 3.6 General flow chart for HEKTOR

and food for exports. An additional driving force is the emission trading system which will lead to rising prices for CO_2 allowances. The combined effect of both fossil energy price-related biomass attractiveness and CO_2 allowance price can be shown by a simple indicative calculation: currently the market price of energy crops is geared to the price of the complementary biofuel (conversion costs included). The assumed CO_2 allowance prices of EUR 20, 40 and 65 until 2030 create an economic value in addition to this 'normal market price' (see Table 3.11).

Table 3.12 lists the economic value of the CO_2 allowances in relation to commodity prices. For biogas and short rotation coppice, it is assumed to be 50 % or more of the value of equivalent biomass output in traditional food and feed markets.

From 2020 onwards, the sum of fossil energy and CO_2 allowance prices leads in all but one case to higher prices for bioenergy than for food and feed products. This reflection is underlined by the development of the European oilseed markets which shows that biofuel demand will be the future driver for rape seed prices (DG Agriculture, 2005). It is likely that higher prices for biomass in the energy markets would also affect commodity prices in food and feed markets (at least where there is direct competition for the same biomass). However, this could not be taken into account in the current modelling approach.

From these calculations it becomes clear that a bottom-up projection of land needed to fulfil the food and feed demand for all Member States would be a good method of determining the land potential. These calculations therefore seem a good reason to further complement the land potential calculations of CAPSIM. This additional calculation will deliver the land potential — given the same environmental constraints as applied to the CAPSIM Animlib scenario — but assumes higher energy prices, the availability of CO_2 allowance prices and agricultural production that is generally not far above self-sufficiency levels. However, due to the limited scope of this study it was not possible to carry out a second thorough analysis in parallel for the whole EU. Instead, the HEKTOR model was applied in two large agricultural produce-exporting countries: France and Germany.

3.4.1 *Application of the HEKTOR Model to France and Germany*

As stated above, the mass balance of food supply and demand is central to HEKTOR. The overall food consumption is assessed for each country via a bottom-up approach that builds on population trends and the per-head-consumption of major foodstuffs (16).

The land use for food production is then calculated, using various production processes for crop and livestock production, which can be adapted for each country. In France and Germany, a conventional and an organic farming process for crop production are utilised. For livestock production an integrated farming process is additionally provided.

In the crop sector, the main information is crop yield, differentiated by production process and year. In the scenario period the yields for all crops are still increasing. For animal husbandry there are fodder plants which represent the total mass of fodder needed for the life of an animal. This is converted into a specific fodder mass by kilogram final product. Fodder crops are treated in a similar way to food crops. For the year 2000, the model is based on statistical data from Eurostat. For this year a validation has been carried out which does not

Table 3.11 Economic value of CO_2 allowances in relation to the commodity prices

	2010	2020	2030
CO_2 'price'	**EUR 20/t**	**EUR 40/t**	**EUR 65 /t**
FAME	8 %	10 %	20 %
ethanol	6 %	8 %	17 %
SRF	27 %	35 %	66 %
ethanol+	10 %	13 %	27 %
biogas 2c	27 %	36 %	71 %

Note: The yellow shade indicates CO_2 allowance prices that are more than 30 % of the commodity price.

Table 3.12 Relative energy and CO_2 'value' versus commodity price

Fuel	2010	2020	2030
FAME	79 %	107 %	129 %
ethanol	61 %	84 %	108 %
SRF	100 %	138 %	168 %
ethanol+	74 %	107 %	136 %
biogas 2c	151 %	210 %	260 %

Note: The yellow shade indicates CO_2 allowance prices that are more than 25 % of the commodity price.

Source: Commodity price projection from FAO.

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(16) Cereals, sugar beet, oilseeds, potatoes, pork, beef, dairy products, chicken meat and eggs.

accept a difference of more than 5 % between the calculated land and the statistical data. In fact in both cases the error level is only approximately 2 %. For the other time steps the calculation is based on extrapolated data.

The potential land availability for energy crop production (potential land) is calculated by subtracting the final future extrapolated land requirements from the land requirements in 2000 and then reducing this by the estimated amount of land that would be needed for urbanisation and other non-agricultural activities, such as nature conservation and recreation. The remaining area is available for the production of energy crops (17).

Following the scenarios of Fritsche *et al*., (2004) a new reference scenario (REF) was calculated with HEKTOR that included the major trends in yield increase and the Common Agricultural Policy. REF is the basis for the second scenario (EXT) which considers a higher rate of up to 30 % of the UAA in extensive farming by 2030. A third scenario (RedEx) examines the effect of reduced exports. In this last scenario the production of the main products (cereals, sugar and pig meat) is reduced by the percentage of surplus production in Europe (the share above self-sufficiency level).

The RedEx scenario was chosen for application in this study as it is comparable with the environmentally compatible scenario based on the Animlib approach under CAPSIM. In the RedEx scenario inland production is reduced by a share equivalent to the share with which the 100 % self-sufficiency level is exceeded in the country in question, but only if the production in the EU-25 is also above 100 % self-sufficiency. On the other hand, production is lowered by the percentage needed to reach 100 % self sufficiency for all major crops in the EU-25 (to compare the CAPSIM assumptions on self-sufficiency see Annex IX, Table IX-9.1). An example of how this is calculated in given in Table 3.13.

3.4.2 HEKTOR results for France and Germany

In this section the HEKTOR model calculations under the different scenarios are presented and compared to the CAPSIM Animlib results. Tables 3.14 and 3.15 present the HEKTOR calculations for Germany and France, respectively.

In Germany in the REF scenario, a total amount of 4.3 million hectare of land is available for biomass production in 2030, with arable land accounting for almost three quarters of the area. If in the EXT scenario a total share of 30 % of the UAA in extensive agriculture is assumed the potential area for biomass production is drastically reduced. This can be partly compensated by a reduction of world exports as the results from the application of the world market (RedEx) scenario show.

The HEKTOR model was also applied to the French (18) situation. However, within this study it could only be carried out using a simplified application of the HEKTOR model (Simon, 2005). The HEKTOR model was used in this approach, but considered only main livestock products (milk, beef and pork), a selection of main crops (cereals and sugar beet, animal feed) and grassland.

Table 3.15 shows that in the REF scenario in France a total amount of 4.4 million hectares is available for biomass crops in 2030, with grassland accounting for almost half of the area. In the EXT scenario, the potential area for biomass is drastically reduced. However, the elimination of exports above self-sufficiency levels in the RedEx scenario strongly increases the arable biomass potential.

Table 3.13 Example of how land availability is influenced by self-sufficiency levels

Example crop	Self-sufficiency level	Reduction in the scenario
France	180 %	– 10 % → 170 %
Germany	120 %	– 10 % → 110 %
EU-25	110 %	–/–

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(17) For a more detailed documentation of HEKTOR see the Annex of Fritsche *et al*., 2004.

(18) We thank Sonja Simon (TU Munich) who designed the simplified HEKTOR model and calculated all related figures for this study.

Table 3.14 Results from HEKTOR for available area for biomass production in Germany until 2030 using different scenarios

	REF		EXT		RedEx	
	Arable land	Grassland	Arable land	Grassland	Arable land	Grassland
	Mio. ha	Mio. ha	Mio. ha	Mio. ha	Mio. ha	Mio. ha
2010	1.4	0.5	0.5	0.1	1.2	0.1
2020	2.4	0.7	1.6	0.3	2.8	0.3
2030	3.2	1.1	2.4	0.6	3.5	0.6

Table 3.15 Results from HEKTOR for available area for bioenergy in France until 2030 using different scenarios

	REF		EXT		RedEx	
	Arable land	Grassland	Arable land	Grassland	Arable land	Grassland
	Mio. ha	Mio. ha	Mio. ha	Mio. ha	Mio. ha	Mio. ha
2010	1.3	0.4	0.8	0	2.4	0
2020	1.7	1.4	0.4	0	2.1	0
2030	2.3	2.1	1.1	0.4	2.7	0.5
2030*					2.0	0.0

Note: * = rounded down.

Source: S. Simon and EEA based on Wiegmann, K., Fritsche, U. & B. Elbersen: 'Environmentally compatible biomass potential from agriculture'. Consultancy report to the EEA, 2005.

3.4.3 Comparison of HEKTOR results with CAPSIM based results

The sensitivity analysis with HEKTOR could only be carried out for arable land. Table 3.16 presents these results in an ascending series, cumulating in the HEKTOR result for the year 2030 for the RedEx scenario. This procedure takes into account the fact that land will become available more rapidly than the implementation of technologies, markets and biomass production (e.g. short rotation coppice).

As expected, the HEKTOR model calculates a higher potential of arable land for France and Germany than the environmentally compatible scenario based on CAPSIM does (see Figure 3.7). For both countries combined the additional land potential is 1.5 million hectares in 2010, 3.0 million hectares in 2020 and 5.0 millions hectare in 2030 (19). It should however be emphasised that the major differences between the HEKTOR and CAPSIM calculations in France and Germany are primarily due to the large share of crop production for export purposes. In HEKTOR calculations, the export component is reduced significantly to create space for the production of biomass crops. If the HEKTOR sensitivity analysis were applied to other EU countries which do not have such large export production, the land potential would not diverge so much from the CAPSIM based scenario results.

From the additional HEKTOR analysis the significant influence of model assumptions becomes clear: the bioenergy potential is to a large extent determined by the prices paid for bioenergy and competing products. The high CO_2 allowance price in combination with a high oil price would add an additional 5.0 million hectares of arable land by 2030 for France and Germany to the total EU land potential. However, a lower CO_2 allowance price or a higher increase in world global food prices could lower the relative attractiveness of bioenergy crops, and would reduce the available land for bioenergy.

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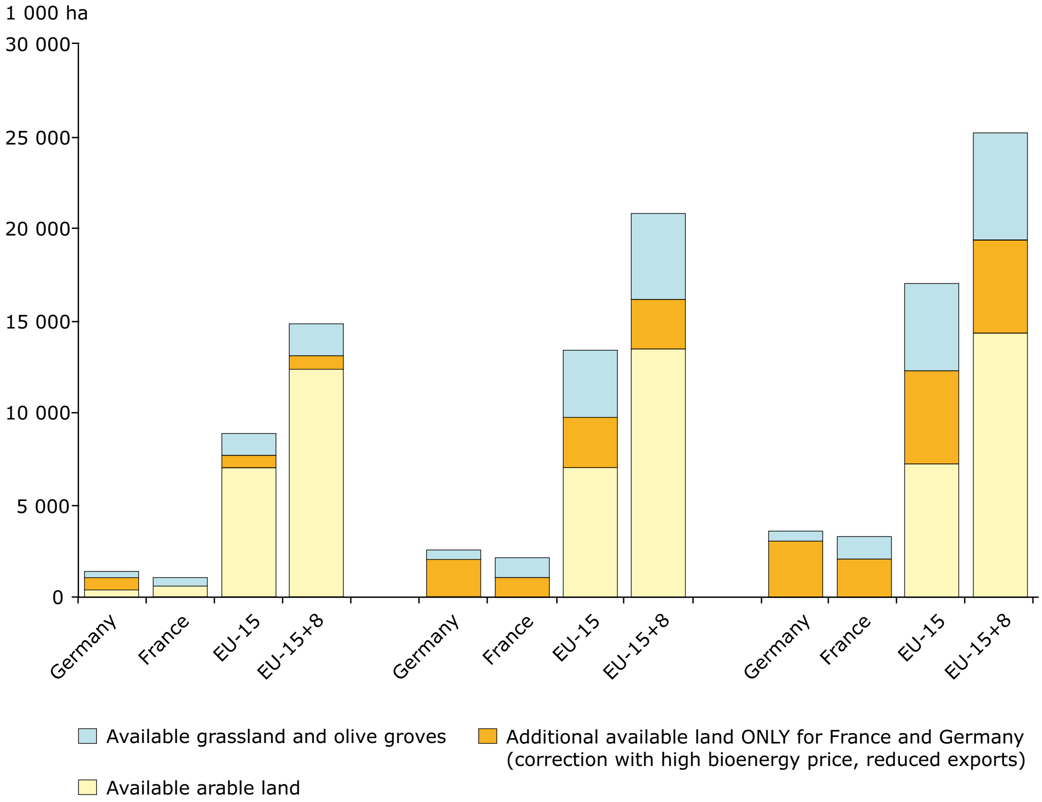
(19) It should be noted that this additional land potential cannot be directly translated into additional bioenergy production as a certain time lag in the switch from export markets to energy markets is to be expected. In addition, the available biomass conversion technology and the relative price differences between food and and energy markets will influence the speed of the transition. These factors were taken into account in estimating the increase of available land and bioenergy production arising from the application of the HEKTOR model (see also Chapter 7).

Table 3.16 Arable land potential for bioenergy production calculated with HEKTOR (based on RedEx-Scenario)

	Germany	France
	Million hectare arable land	
2010	1.0	0.5
2020	2.0	1.0
2030	3.0	2.0

Source: S. Simon and EEA based on Wiegmann, K., Fritsche, U. & B. Elbersen: 'Environmentally compatible biomass potential from agriculture'. Consultancy report to the EEA, 2005.

Figure 3.7 Effect on the availability of land caused by the HEKTOR approach



Note: No data were available for Cyprus and Malta.

Source: EEA based on Wiegmann, K., Fritsche, U. & B. Elbersen: 'Environmentally compatible biomass potential from agriculture'. Consultancy report to the EEA, 2005.

3.4.4 *Land not included in statistics on utilised agricultural area (UAA)*

This study has only calculated the future land potential for biomass crop production from the land that is considered to be part of utilised agricultural area (UAA) in 2000, as registered in Eurostat statistics. However, it is well known that for the new Member States, where a significant share of agricultural lands were abandoned or shifted to fallow or pasture land after the transition from centrally planned to market based economies, the UAA in 2000 is probably smaller than the area of land that can potentially be used for arable agriculture. This implies that the estimates for land availability in this study, based on the UAA 2000 as a starting point, will result in underestimates.

A report by DG Agriculture (2002) on EU enlargement and impacts on agricultural markets and incomes estimates that fodder and pasture lands expanded by 4.5 million hectares between 1987 and 2000. In spite of that, the number of cattle and sheep fell by 49 % during the same period. Hence, arable land used for fodder production decreased and was either converted to grassland land or (long term) fallow land (estimated increase of approximately 2 million hectares). Furthermore, the report also mentions that large areas of land are now used for growing low value-added products, and certain parts of what is now permanent grasslands could well be suitable for arable cropping. Overall, the DG Agriculture study estimates that in the new Member States approximately 6.5 to 7.5 million hectares of additional land should be available for arable biomass crop production compared with the current UAA.

This study only gives a total of 4.5 million hectares of land available for biomass crop production in the new Member States by 2010, which is probably an underestimate if we accept that the DG Agriculture study makes a realistic estimate of the recent land use situation. Furthermore, our approach assumes that permanent grassland is not converted into arable land due to nature conservation considerations and the high release of carbon from ploughed grassland (see Section 2.3). However, in most new Member States land abandonment occurred on a large scale and a high amount of arable land was converted to grassland, or was released from production in the last decade. Therefore, detailed analysis should examine whether the environmental restriction that no grassland should be converted to arable crops could be differentiated for the new Member States.

4 Environmental prioritisation of crops

4.1 Introduction

This chapter describes the initial selection of biomass crop mixes that are most suited to an environmentally compatible future for the different environmental zones in Europe. For this purpose environmental risk matrices are developed, starting from an ecological prioritisation of energy crops for German conditions by a Delphi expert survey (Reinhardt and Scheurlen, 2004). The selection of optimal crop mixes is in principle only the first step towards environmentally compatible biomass production. The farming practices applied in energy cropping are also important but could not be investigated in this study as relevant information is locally-specific and very difficult to obtain.

The risk matrix approach supports the identification of a crop mix per environmental zone in Europe with low relative pressure on the environment and positive effects on local flora and fauna. The assessment of the risks is based on general expert knowledge of average agronomic practices per crop in relation to a number of environmental parameters. The application of specific (extensive) farming practices or crop varieties was not incorporated in the crop choice. Nevertheless, the mixes should support environmentally sound farming practices which are specifically adapted to reducing the environmental problems and risks that are typical to the different environmental zones of Europe.

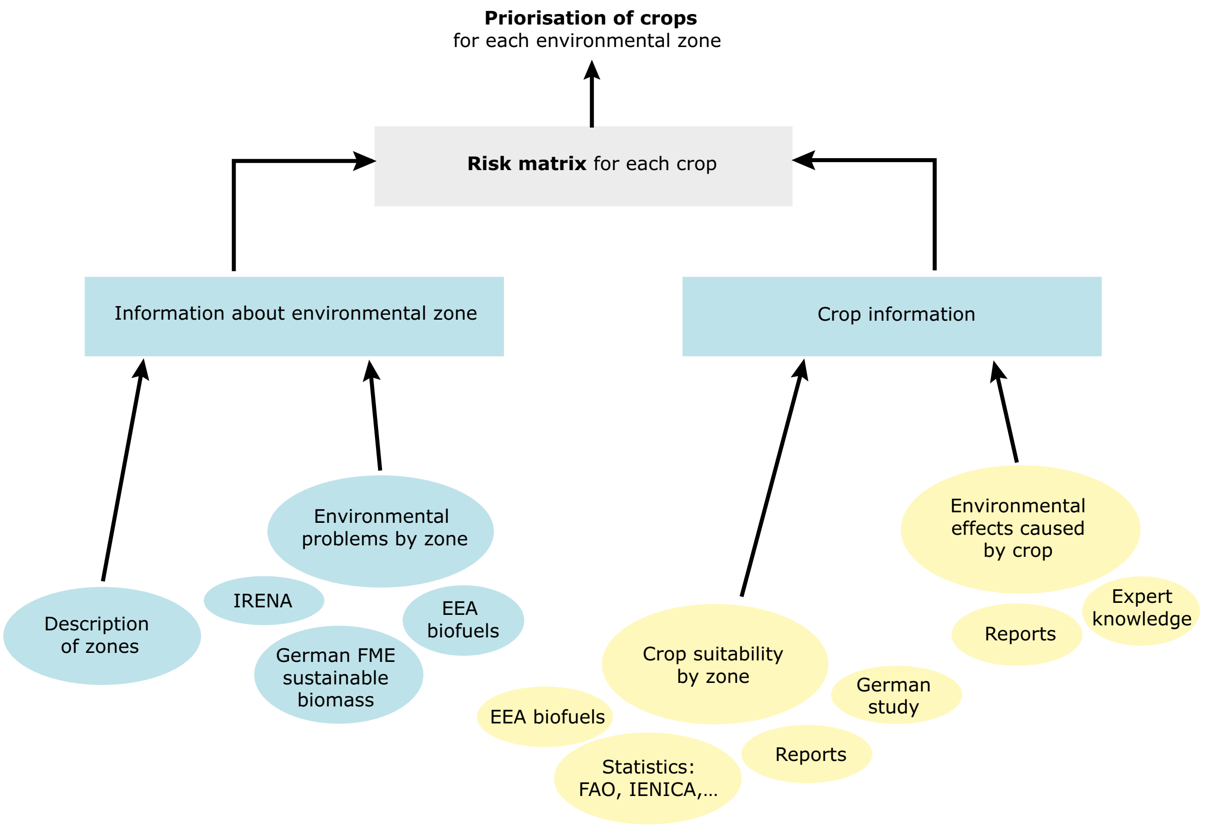
The selection of the optimal biomass crop mixes follows a four step approach (see also Figure 4.1):

1. The main environmental and ecological pressure indicators are selected which drive the prioritisation of the crops in each environmental zone. The selection of the pressure indicators is based on experience from other projects in combination with environmental considerations derived from EU agri-environmental policy objectives (e.g. statutory management requirements and Good Agricultural and Environmental Condition (GAEC) standards linked to cross-compliance in Council Regulation 1782/2003). The prioritisation of crops according to different risk parameters is based on information on agri-environmental pressures per environmental zone described in former projects such as Mirabel I and the IRENA operation (EEA, 2005b) and further reference-based knowledge on the present land use and dominant farming systems in the different environmental zones.
2. The main environmental and farming system characteristics per environmental zone are described as these provide the context within which the optimal biomass crop mixes need to be determined. The characteristics to be incorporated are:

    a. Climatic suitability
    b. Present land use
    c. Present farming systems
    d. Present environmental problems.

3. Thirdly, an initial selection of potential biomass crops per environmental zone is carried out, building on the crops already grown for food, non-food and energy purposes, either in commercial settings or within serious long term experiments.
4. The main biomass crops are prioritised according to their environmental pressures for every environmental zone. This results in the selection of a biomass crop mix per environmental zone which should not impose any additional pressure on environmental resources and farmland biodiversity. The prioritisation is done by specifying matrices in which the different crops are rated, according to the environmental and ecological pressure indicators specified in step 2. However, this prioritisation of crops represents only a rough indication of best crop mixes in terms of environmental effect since differences in environmental pressures imposed by different crops are gradual rather than fixed. Moreover they strongly depend on the farming practices applied. The matrices therefore give only a qualitative orientation and should be interpreted in the context of the specific characteristics of each environmental zone.

Figure 4.1 Overview of the working steps for prioritising biomass crops per environmental zone



4.2 Background on pressure indicators, environmental zones and farming systems

4.2.1 *Selection of pressure indicators*

The selection of the pressure indicators builds on a number of key studies in which the main environmental problems in EU agriculture are discussed (e.g. EEA, 1999; EEA, 2004; EEA, 2005b; Carey, 2005; Petit *et al.*, 2004; Agra CEAS, 2003; Jørgensen and Schelde, 2001; Boatman *et al.*, 1999 etc). In addition to this, the outcomes of a workshop on 'Sustainable Bioenergy cropping systems for the Mediterranean', organised in February 2006 in Madrid by the EEA and JRC (JRC & EEA, 2006) are used to provide a better understanding of the potential environmentally compatible bioenergy crop mixes for the Mediterranean. The selected pressure indicators are:

1. Erosion
2. Soil compaction
3. Nutrient leaching to groundwater and surface water
4. Pesticide pollution of soils and water
5. Water abstraction
6. Fire risk
7. Farmland biodiversity
8. Diversity of crop types

The first five environmental pressure indicators are indirectly linked to farmland biodiversity, which is treated as a separate but dependent indicator.

4.2.2 *Context: Main characteristics of environmental zones*

The environmental stratification of Europe divides the region into zones with a homogeneous, pedo-geo-climatic character. This zonation is based on climate data; data on ocean influence, geographical position (northing) and altitude which have been clustered statistically (see Annex IV). The results are 84 strata which have again been summarised statistically into thirteen major Environmental zones (EnZ) (for map see Annex IV). EnZs have a close relationship to the Biogeographical zones of Europe (Dmeer and Emerald classification). However, they are not completely the same, as the latter have been produced by expert judgment and the EnZ are based on statistical procedures. The EnZs have been ordered according to the mean value of the first principal component which expresses the north-south environmental gradient across Europe ([20]).

Since the thirteen Environmental Zones are relatively homogeneous in terms of climate and altitude factors which are determinant factors for agronomic capacity, they have also been taken as a main regional division for this study. The main characteristics of the twelve zones (the Anatolian Zone is outside the EU-25) are therefore used as contextual information on which the initial biomass crop mixes and their environmental prioritisation can be implemented (see Annex IV, Table IV-.1).

When looking at the main characteristics of the environmental zones (see Annex IV, Table IV-1) it becomes clear that the pedo-climatic characteristics of the environmental zones differ strongly. One notices that the zones with the lowest share of utilised agricultural area are either in the mountainous zones (Alpine and Mediterranean Mountains) or in the most northern latitude zones (Alpine North, Boreal and Nemoral). The zones with the best climatic conditions for agriculture, i.e. those with enough precipitation and/or long enough growing seasons, are Continental, Atlantic, Lusitanian, Pannonian and Mediterranean. The Mediterranean zones have the longest growing season but precipitation is a constraining factor which explains the relatively low share of arable land in total Utilised Agricultural Area (UAA) and a high share in irrigated arable land. In spite of this, both the northern and southern Mediterranean zones are characterised by the largest share of total UAA in overall land area.

The zones with a combination of relatively high share of UAA as well as arable land consist of the Pannonian, Continental and, to a lesser extent, Atlantic Central and Mediterranean North zones. The Member States that are expected to deliver most of the land for biomass crop production (Spain, France, Italy and the United Kingdom) are are also located in these zones, as shown in Chapter 3. These zones and countries have a high potential for delivering large quantities of biomass in the future. The zones with a relatively large UAA, but with a lower share of arable agriculture and thus a higher share of grazing will generally be less suited for biomass production unless it concerns biomass from more extensive and less demanding cultures such as from perennial biomass crops.

4.2.3 Characterisation of farming systems

When looking at the farming types per environmental zones (see Annex IV), one has to be aware that these figures only apply to the EU-15 part of the Environmental zones; data from the EU Farm Accountancy Data Network (FADN) data were not yet available for the new Member States at the time of writing. This implies that the information on farming types in Annex IV for the Continental, Pannonian, Boreal and Nemoral zones only applies to the share of farmland located in the EU-15 Member States. In order to get an understanding of the farming systems in the EU-10 part of these zones, additional information on land use in the new Member States has been added.

Annex V, Table V-1, shows that the most intensive farming systems are found in the Atlantic Central and Continental and Nemoral zones, but only as far as it involves the EU-15. In the Nemoral zone the farming systems presented are very intensive. However, they are only derived from Finnish data and therefore represent only a small part of the total land area. The climatic circumstances in the Nemoral zone create difficult conditions for farming, especially arable agriculture, which also becomes clear from the division over land use types; even more so for the Boreal zone and Alpine North zone. In the Mediterranean and Lusitanian zones the diversity in farm types seems to be greatest, since both cropping and livestock systems are well represented and occur as high and low intensity systems. There is also a very high share of High Nature Value Farmland in these zones. The Continental, Atlantic Central and Mediterranean North contain the highest share of cropping systems which fits well with the overall high share of arable land in these zones.

The zones with the highest share of intensive farming types are the Continental and the Atlantic Central. This is not a surprise as pedo-climatic circumstances are optimal for agriculture, which also makes these zones most suited for the dedicated arable biomass crops. Extensive systems are mostly found in the three Mediterranean zones, the Nemoral, Atlantic North, Alpine South and Lusitanian zones. This is evident from the distribution of IRENA intensity types (only for the EU-15) and the share of HNV farmland (applies to both EU-15 and EU-10 Member States).

([20]) For more information about the environmental zonation see Metzger *et al.*, 2005 and the following website: http://pan.cultland.org/cultbase/?document_id=152&menu_top_level=doc_zone.

4.2.4 *Environmental pressures resulting from pedo-climatic and farming system characteristics*

The types of environmental pressures vary considerably between individual environmental zones due to the combination of specific farming practices and environmental characteristics. For example, erosion is a particular problem where arable farming is practised in mountainous areas or otherwise steep terrain. Wind erosion however, can also be a problem in lowland regions with poor vegetation cover in winter and spring, as is the case in certain parts of the Atlantic and Continental zones. High input use resulting in eutrophication and pesticide pollution is particularly a problem in the Atlantic and Continental zones with high shares of high input agriculture. Soil compaction is also related to intensive farming using heavy machinery, especially in zones with heavy clay soils, such as in the arable farming regions of the Atlantic zone.

Water abstraction problems are typical for the zones with low precipitation, especially the Mediterranean zones, but also in the Pannonian. The same applies for fire risk which is highest in the Mediterranean and medium in the Lusitanian, Alpine and Pannonian zones. Habitat fragmentation problems are particularly severe in zones with more intensive agriculture but also with high urbanisation pressure, such as the EU-15 part of the Continental zone and in the Central Atlantic zone.

Land abandonment is particularly a problem in areas where pedo-climatic circumstances are more limiting to agriculture, such as in mountainous areas in the Alpine and Mediterranean Mountains zones, in drier/arid areas in the Mediterranean zones, but also in the new Member States in the Continental and the Pannonian zones. These are also the zones with a high share of HNV farmland because these low intensity systems are most concentrated in areas where farming has not reached high production levels, either because of natural handicaps or because of the lack of resources to optimise farming.

In environmental zones with extensive land use there is a higher risk that intensification through biomass crop production occurs which could be prevented by choosing biomass crop mixes carefully. On the other hand, land abandonment in these zones is a greater problem, which could be countered by using grass cuttings (especially on semi-natural grasslands) or extensive biomass cropping systems, linked to perennial crops for example. In the next section environmental pressures per zones are discussed in relation to choosing ecologically sound biomass crop mixes. After all, this study assumes that an increase in biomass crop production is only acceptable if it does not lead to additional pressure on the environment. Secondly, it should also lead to further improvement of farmland biodiversity in intensive farmland where certain biomass crops may help to increase landscape diversity (see assessment of crops in Annex VI).

4.2.5 *Conclusions on environmental zones in relation to energy crop mixes*

In terms of the availability of arable land as well as climatic and soil suitability the Continental and Atlantic central zones are best suited for a variety of biomass crops; both for arable crop types that fit in a conventional rotational arable system as well as perennial biomass grasses and short rotation coppice. However, these zones also pose the greatest environmental problems related to intensive farming. The main reasons for this are high use of nutrient and pesticide inputs, a high level of mechanisation, and high specialisation related to low crop and landscape diversity. The introduction of biomass crops in the agricultural systems of these zones will generally not impose any additional pressures on the environment, as this pressure is already high. However, the introduction of the bioenergy crops should aim at lowering the environmental pressure caused by agriculture in these zones. The biomass crop mixes most suited for an environmentally compatible scenario should help to lower the input of nutrients in conventional farming systems, enhance crop diversity and landscape diversity, lower the use of heavy machinery and water, and lead to year-round ground coverage where possible.

The Lusitanian and the three Mediterranean zones as well as parts of the Pannonian and Continental zones situated in the new Member States are still characterised by a high share of medium to low intensive farming systems, often HNV farmland. In these zones one often finds a combination of intensive farming and extensive farming as well as land abandonment. An increase of biomass crop production in these areas could therefore be an additional threat to farmland biodiversity. However, it could also be an opportunity, if produced in an environmentally sound way, to reduce certain pressures from agriculture. The choice of the biomass crop mixes (and practices) is therefore very important. With regard to abandoned land, where this concerns grassland, using the cuttings for energy purposes might present an opportunity to conserve these areas from natural succession.

In the case of the dry Mediterranean and Pannonian zones it is particularly important that increased biomass crop production does not lead to an increased use of water (through irrigation) and agro-chemicals. For the choice of the right crop mixes it is important to realise that landscape diversity should be maintained or increased and specific biomass crop types need to be chosen that do not increase the risk of fires. The potential advantage of new biomass crops in these zones is that they may help to counter land abandonment and erosion risks, if introduced carefully.

Across the environmental zones in the new Member States, the introduction of biomass crops should also be carried out taking current extensive practices into account and should not lead to a loss of field boundaries or the monotonisation of the landscape. As in the Mediterranean zones, biomass crop production can provide an opportunity to bring abandoned lands into use again, as long as intensive practices are not applied and semi-natural grassland areas are preserved.

4.3 Prioritisation of energy crops per environmental zone

Bioenergy crops can be roughly categorised in three groups. These comprise two types of rotational arable crops:

1) Sugar/starch crops: e.g. sugar beet and potatoes;
2) Oil-starch crops: e.g. sunflower, oilseed rape, cereals, maize, sorghum.

The third group consists of ligno-cellulose crops:

3) Short Rotation Coppice (e.g. willow and birch) and perennial biomass grasses (e.g. *Miscanthus, Switchgrass, Reed Canary grass and Giant Reed*).

The energy crops in the sugar, starch and oil category are all rotational arable crops that are commonly grown as food and feed crops. From an energy perspective, they are best suited to the production of biofuels (first generation) and biogas. The production of these crops for biomass and their potential impacts on environment and farmland biodiversity will not be very different from when they are used for feed and food production. However, publications based on research and field trials have shown that new farming practices and varieties can be introduced when growing rotational arable crops for biomass purposes. This opportunity arises because the main aim is to produce high quantities of dry biomass per hectare while the biomass source of the end product is not so important. For example, the varieties of maize and sorghum best suited to conversion into bio-energy are not the same as those for food and feed production, whereas the other arable biomass crops mentioned are generally not different from the varieties used for feed and food production. It is therefore likely that requirements in relation to soil quality and input use (e.g. pesticides) are generally lower for the crops used for biomass production than for feed and food products. This implies that the use of inputs, especially crop protection and herbicides could be lower, the introduction of no-till practices might be an option and harvest periods as well as harvesting techniques could also be different.

The ligno-cellulose crops are all perennial crops that become attractive with the introduction of second generation technology. The technology for an efficient conversion of these crops will not be available in the next five years and hence the introduction of these crops on a larger scale will only happen after 2010. Table 4.1 provides an overview of the main characteristics of four perennial bioenergy crops based on a literature survey. This shows that the production of both SRC and perennial biomass grasses is fundamentally different from arable crops. As they can be regarded as permanent crops with a rotation time of at least 15 years, the harvest of the biomass would only start after two to five years. Furthermore, input use, and machinery requirements are much more limited than with arable crops. From an erosion risk perspective, these crops provide good soil protection (at least after the establishment phase), as some of the varieties of these crops were even developed for this purpose (e.g. Switchgrass). The effects of these crops on landscape structure can be great, as they tend to grow to between 2–5 meters. Therefore, the impact is exacerbated if they are grown over large areas. However, when grown as strips they may have a positive function on landscape diversity and can create valuable (shelter) habitats for certain mammals and bird species.

For the initial selection of the suitability of biomass crops to be assessed in this study we relied on four sources:

- Present crop mixes and crop yields per zone information derived from statistics (Eurostat, 2005 and FAOSTAT, 2005)
- Present crops already grown for biomass (IENICA, 2004)
- Experiments with biomass crops in different zones (literature research)
- Information on field trials with novel biomass crops presented at the workshop 'Sustainable bioenergy cropping systems for the Mediterranean', in February 2006, Madrid (JRC-EEA, 2006).

Table 4.1 Characteristics of perennial energy crops

Attribute	**Miscanthus**	**Switchgrass**	**Reed canary grass**	**Giant Reed**
Latin Name	*Miscanthus* spp.	*Panicum virgatum L.*	*Phalaris arundinacea L.*	*Arundo donax L.*
Available genetic resources	Many varieties available; Clone M. gigantheus is mainly used	Many varieties used, depends on latitude	Many varieties available	Wide genetic base available
Native range	South East Asia, Japan	North America	Europe	Mediterranean region and other
Yields in tonnes dry matter per year	Up to 10 t in Northern regions, and up to 30 tonnes in southern regions	Up to 10 t in Northern regions, and up to 30 tonnes DM in southern regions	Up to 15 tonnes	Up to more than 30
Photosynthesis system	C_4	C_4	C_3	C_3
Height	Up to 4 m	Up to 2,5 m	Up to 2 m	Up to 5 m
Rotation time	15 years	15 years	10/15 years	15 years
Propagation method	Vegetative (rhizomes), seed under development	Seed	Seed	Vegetative, (rhizomes)
Adaptation	Moderate winters, sufficient/low moisture	Moderate winters, sufficient/low moisture	Colder regions, moist conditions	Warm regions, moist conditions
Adaptation range in Europe	Cool and warm region of Europe (Denmark to Greece)	Cool and warm region of Europe (Denmark to Greece)	Cold and wet regions of north-western Europe (Finland, Sweden, United Kingdom, the Netherlands, Eastern Europe)	Southern Europe, Southern France, Italy, Greece, Spain
Establishment	Rhizomes or plantlets	Seed	Seed	Rhizomes
Harvest time	Autumn to early spring	Autumn to early spring	Autumn to early spring	Autumn to early spring
Required machinery	Normal and special farm equipment	Normal farm equipment	Normal farm equipment	Special farm equipment
Harvest requirement	Normal baling (heavy) of chips	Normal baling	Normal baling	Baling is not an option. Stalks or chips
Fertiliser input	In northern EU up to 50 kg N. In the south 50 to 100 kg N	In northern EU up to 50 kg N. In the south 50 to 100 kg N	Higher than for C_4 grasses	Higher than for C_4 grasses
Pesticide input	Low, possibly in first year	Low, possibly in first year	Low, possibly in first year	Low, possibly in first year
Runoff potential	Low	Low	Low	Low
Water use	Low	Low	Medium	Medium
Field pass frequency	1 x per year after establishment	1 x per year at harvest	1 x per year at harvest	1 x per year at harvest
Erosion control	Good/very good	Very good	Very good	Good/Very good
Risk of it becoming a weed?	No	No	Yes, it is a weed	Depends on region. In southern areas it is a weed
Slope requirements	Only limit is equipment — no round bales	Only limit is quipment — no round bales	Only limit is equipment	Only limit is equipment — no round bales
Shelter for animals?	Yes, much better than annual crop	Yes, much better than annual crop	Yes, much better than annual crop	Yes, much better than annual crop
Food for animals, insects?	Less if no seed production	Yes, seeds are food	Yes	?
Room for other plants in the field?	Limited, not if well established	Not if well established	Not if well established	Limited, not if well established
Risk of fires	High	High	High	High

Note: More recent research shows that the water requirements of perennial energy crops can be substantial, see background paper for a JRC/EEA workshop in October 2007: http://re.jrc.ec.europa.eu/biof/.

Source: This table was compiled by W. Elbersen and R. Bakker based on own research and literature review (21).

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(21) This table was produced under the EEA study contract EEA/EAS/03/004. The fnal report of this study should be referenced as follows: Elbersen. B.; Andersen. E.; R. Bakker;. Bunce. R.;.Carey P.; Elbersen. W.; Eupen. M. Van; Guldemond. A. Kool. B. Meuleman. G.J. Noij & J. Roos Klein-Lankhorst (2005). Large-scale biomass production and agricultural land use – potential effects on farmland habitats and related biodiversity. EEA study contract EEA/EAS/03/004.

In Annex V, Table V-1, the initial crop mixes for biomass production per environmental zone are listed. The largest number of suitable crops is found in the Continental, Pannonian, Atlantic Central, Alpine South and Lusitanian zones. For the Mediterranean zones, some additional potential biomass crops were suggested at a recent EEA/JRC workshop which are considered to have a strong potential in terms of production of biomass and are well adapted to the Mediterranean climate. However, the crops included are only those for which field trials have already delivered positive results in the Mediterranean situation. Extra crops reviewed after the workshop include (see also Fernandez, 2006):

- Oil crops Carinata (*Brassica carinata*) and Castor bean for the production of biodiesel. The former is a relative of oilseed rape and the latter is already used for biodiesel production in Brazil.
- Sugarcane and prickly pear for production of bio-ethanol. The first is the main bio-ethanol crop of Brazil and the latter is a type of cactus.
- Ligno-cellulosic crop Cynara (*Cynara cardunculus*) which is a type of thistle. The fruits of this plant contain oil (for biodiesel) and the rest of the plant could be ligno-cellulosic feedstock.

Besides crop mix, one further factor is important in the prioritisation approach used: the 'double cropping' practice. This is a cropping system that has been specifically designed for environmentally friendly biomass production and that has given good initial results in Germany. The expectation is that in the future this approach could fit well in an environmentally friendly biomass production system in more environmental zones. A further explanation of the double cropping approach is given in Box 8.3.

4.4 Environmental prioritisation of bioenergy crops per environmental issue

This section describes the approach taken for the environmental evaluation of potential biomass crops. It builds on an initial prioritisation based on a relative assessment which aims to rank them according to pressures between crops. The comparison relies to a large degree on imperfect data which leads to uncertainty in the final results. This should be taken as a relative assessment only. In addition, the final environmental impact of the different crops will be very much influenced by the actual farming practices applied. However, farming practices are not covered in this report and need to be analysed in follow-up work.

The environmental pressure indicators are combined with the potential biomass crops in order to come to an initial crop-by-crop description of potential environmental risks (see Annex VI). Detailed matrices are only elaborated for the cultivation of arable biomass crops, which allows a comparative assessment of environmental impacts and benefits between these crops.

Risk matrices were also developed for perennial crops but field-based experience and published references are much more limited for these often novel crops. The assessment presented is therefore of a more qualitative nature. Nevertheless, it shows that there are significant differences between arable and perennial crops.

4.4.1 Soil erosion

Soil erosion risks are particularly high 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, 2005b). As a result of dry summers in these areas, soil cover is also limited in summer which increases the risk of erosion in autumn when rainfall starts. In northern parts of Europe erosion by water is not such a problem as rainfall is spread out more evenly over the year and there are fewer regions with steep slopes and shallow soils. Nevertheless, the simplification of crop rotations and increase of maize acreage in the last decades mean that soil erosion is the number two factor for soil damage; soil compaction is ranked as number one. Severe erosion incidents were observed, e.g. in Northeast Germany, with soil losses of more than 40 T/ha/yr (Frielinghaus & Winnige, 2002).

Wind erosion is a problem in more open, flat or undulating terrain with sandy soils where soil cover is limited over the year and there are no wind-breaking landscape elements. The flatter, more intensive agricultural zones of Europe experience this to the greatest extent. Soil erosion and degradation also affect large areas in central and eastern Europe due to a range of physical and farm management factors (EEA, 2004).

The effectiveness of any crop, management system or protective cover depends on the level of protection available at various periods during the year, relative to the amount of erosive rainfall that falls during these periods. In this respect, crops which provide a protective cover for a major portion of the year (e.g. alfalfa or winter cover crops) can reduce erosion much more than crops, which leave the soil bare for a longer period of time (e.g. row crops such as sugar beet or maize), especially during periods of high erosive rainfall (spring and summer). However, most of the erosion on annual row crop land can be reduced by leaving residual cover greater than 30 % after harvest and over the winter months, or by inter-seeding a forage crop (e.g. red clover).

Soil erosion risk is also affected by tillage operations, such as the depth, direction and timing of plowing, the type of tillage equipment and the number of passes. Generally, the less the disturbance of vegetation or residue cover at or near the surface, the more effective the tillage practice in reducing erosion (Boardman & Poesen 2006; Montanarella 2006).

Overall, it can be concluded that crops with whole year coverage, such as pasture, are very good in countering soil erosion. Energy crops, such as perennial biomass grasses with dense soil coverage, perform as well as pasture in this respect, especially after the initial 1–2 year establishment period. This is also why they score well with regard to soil erosion in the matrix of environmental pressures per crop in Annex VII.

4.4.2 Soil compaction

The risk of soil compaction depends on the use of heavy machinery, soil texture, soil particle size and characteristics of plant rooting. Compaction can reduce water infiltration capacity and increase erosion risk by accelerating run-off. In addition, it has adverse effects on the soil biodiversity and soil structure and may lead to problems such disturbed root growth.

Soil compaction is a result of the use of heavy machinery for land cultivation, e.g. ploughing and harvesting. Greater axle loads and wet soil conditions increase the depth of compaction in the soil profile. For example, the late harvesting of sugar beet and maize in harvest after the first autumn rainfall or spring planting is often carried out before the soil is dry enough to support the heavy harvesting or planting equipment (Horn *et al*. 2000; Akker & Schjønning 2004). Compaction caused by heavy axle loads (i.e. greater than 10 tonnes per axle) on wet soils can extend to depths of two feet or more. Such deep compaction is more likely to persist than the shallow compaction associated with other farm or harvesting practices, which can be largely removed by tillage (Horn *et al*. 2000; van den Akker & Schjønning 2004).

Cropping approaches or cultivation practices that include reduced tillage or long periods without ploughing, e.g. by using clover grass in the crop rotation or planting perennial crops, have less soil-associated compaction problems. Double cropping systems for biomass production can also provide good results if they are combined with limited ploughing requirements. However, perennial biomass crops score particularly well. Detailed information on crop ranking with regard to soil compaction is provided in Annex VI.

4.4.3 Nutrient inputs in ground and surface water

Diffuse losses from agriculture continue to be an important source of nitrate and phosphate pollution in European waters (EEA, 2005a). For instance, about 40 % of the total nitrogen load in the Danube River and 50 % in the Baltic Sea come from farming (Behrend/EuroCat, 2004; EEA, 2005a). Diffuse pollution from agriculture remains a risk for water quality in the new Member States (EEA, 2004).

Nitrate concentrations in waters in most central and southern EU regions are still high (ranging between 40 to 20 mg/l NO_3) and cause large problems with eutrophication and the recreational use of lakes and estuaries. Consequently, they threaten human health and the diversity of indigenous fish, plant, and animal populations (EEA, 2003).

Taking the above into account, it is important to review nutrient leaching risks from different crops. Only a complete nutrient cycle balance (preferably including the whole conversion process of biomass to energy) in combination with specific factors, such as length of soil coverage by crop, growing and harvesting periods and rooting depth and precipitation surplus, would deliver the full picture on nutrient leaching risk per crop. However, for the prioritisation of crops the assessment was limited to relative nutrient inputs, harvested nitrogen per crop, average soil coverage and precipitation surplus. These input figures are generally available for the conventional rotational arable crops, and can be regarded as good proxy indicators for nutrient leaching pressures when jointly assessed per crop within a specified environmental zone. For novel bioenergy crops these figures are much more difficult to derive, however, since very limited practical experience is available. Moreover, experimental field trials have also been limited or have not delivered information on the aspect of nutrient efficiency. Thus, for these novel crops only an expert estimate could be made. However, this is specified per crop in the risk matrices in Annexes VI and VII.

Average nitrogen inputs per crop are derived from the European Fertiliser Manufacturers Association (EFMA) which provides national fertiliser application rates per crop (see Table 4.2). Table 4.3 presents additional data for the specific situation in France as well as other relevant factors, such as mineral and organic nitrogen applications and the periods that crops do not provide field cover.

Both the EFMA and French figures show that nutrient inputs are highest on wheat, maize, potatoes and oilseed rape, but also that these vary strongly between countries. The French figures also show that mineral fertilisers are clearly not the only source of nitrogen, especially for silage maize.

If nitrogen inputs are high and nitrogen removal by crop at harvest is large, the nitrogen surplus will still be small or even negative. Reasons for a high nitrogen uptake are usually the result of good nitrogen fixation and/or high yields per crop and per hectare. In Annex VIII an estimate

Table 4.2 Nutrient inputs per crop in 1999/2000

kg N/ha 1999/2000	**BE/LU**	**DK**	**DE**	**EL**	**ES**	**FR**	**IE**	**IT**	**NL**	**AT**	**PT**	**FI**	**SE**	**UK**	**EU-15**
Wheat	155	148	165	70	98	164	160	80	190	105	80	85	125	188	139
Barley	100	78	150	75	93	118	110	70	85	95	60	72	78	127	107
Rye, oats, rice	90	80	120	85	82	105	96	95	85	63	60	70	68	107	96
Grain maize. incl. corn cob maize	70	-	150	190	231	170	-	200	44	107	160	-	-	-	179
Potato	160	120	140	200	142	150	120	110	168	105	100	70	83	158	142
Sugar beet	125	100	145	140	178	130	180	90	110	88	150	120	100	104	126
Oilseed rape	150	100	170	-	109	145	150	80	180	125	100	80	110	190	153
Sunflower, soy, linseed	20	70	50	50	14	45	0	40	0	45	-	-	60	52	33
Pulses (peas, beans)	20	-	25	40	9	0	0	30	20	2	5	40	-	4	8
Silage maize	80	30	85	80	80	45	105	150	35	105	80	-	-	58	70

Source: EFMA.

Table 4.3 Nutrient inputs and practices per crop in France 2001

	Area (ha)	**Yield tonnes/ha**	**Mineral nitrogen in kg/ha**	**Organic nitrogen in kg/ha**	**Estimated N surplus (kg/ha)**	**Days without coverage**
Wheat	4 460 192	6.8	172	4	46	50
Durum wheat	306 370	4.4	168	4	64	100
Barley	1 705 042	5.7	125	8	52	110
Grain maize	1 867 079	8.7	159	40	75	200
Silage maize	1 471 655	12.6	75	163	109	230
Oilseed rape	707 609	2.2	44	8	89	60
Peas	413 716	4.0	0	1	28	225
Sunflower	707 609	2.2	44	2	18	250
Sugar beet	405 351	72.7	127	47	59	..
Potato	155 867	39.9	155	36	73	..

Source: Survey on agricultural practices 2001 — SCEES and NOPOLU-System2 BETURE-CEREC/SOLAGRO (for Nitrogen Surplus).

is made of this surplus, given specific minimum and maximum nitrogen application (only mineral fertilisers) and yield rates per crop and per group of countries. The figures in Annex VIII show for the northern countries of Sweden and Finland that larger surpluses of nitrogen can be expected with barley, sugar beet, oilseed rape and linseed, while wheat, rye and potatoes show negative to neutral surpluses. In the countries of the Atlantic zone, the crop with the lowest nitrogen surplus is potato while crops like barley, sugarbeet, rape and linseed have a higher chance of producing surpluses. In Austria, most crops perform relatively well with low surpluses produced. This is because of the low nitrogen application rates reported for this country in combination with medium to high crops yields. The only two crops with a clearly higher risk for leaching in Austria are barley and oilseed rape. In the central and southern European countries, only sunflower has a low nitrogen surplus risk and rape and pulses have a medium risk. All other crops risk producing high surpluses because of the relatively high artificial fertiliser application rates reported by EFMA in combination with generally low to medium crop yields per hectare. Differences in estimated nitrogen surpluses in tables in Annex VIII and the French figures in Table 4.3 are partly related to the incorporation of manure fertilisers in the French calculation.

For making the final estimate of the risk for nitrogen leaching per crop, as specified in Annex VI, the average soil coverage and precipitation surpluses per environmental zone were taken into account in combination with data on estimated nitrogen surpluses in Annex VIII (where available). Although soil coverage per crop depends strongly on farming practice, a rough grouping of crops according to this factor can be carried out. The situation in France for specific crops in Table 4.3 already provides an idea of the arable crop types. It shows that maize, peas and sunflower perform much worse than cereal crops. For sugar beet and potatoes, no figures are given. Many EU-15 Member States have introduced obligatory green crop cover during winter as part of cross-compliance rules. Although this is meant as an erosion prevention measure, it will also help to reduce leaching in wintertime. However, there will still be differences in soil coverage per crop due to a short growing season and/or long establishment periods that go beyond this minimum period.

Although much less information is available for perennial biomass crops, one can assume that they impose a lower environmental risk from nitrogen leaching and emissions. Nitrogen inputs are much lower for these crops, especially after their establishment, and do not require tillage. They also have dense soil coverage, especially the grass types (e.g. miscanthus, switchgrass), and root deeply. Nutrient efficiency is therefore better for perennial biomass crops than for conventional arable crops used for biomass production.

4.4.4 Pesticide inputs in ground and surface water

IRENA indicator 9 reported that the total estimated amount of pesticides used in agriculture increased by 20 % between 1992 and 1999, and the total quantity of pesticides sold, expressed in active ingredients, grew by 11 % during the same period (EEA, 2005b). The IRENA indicator 30.2 on pesticides in water showed that data are available only for a selection of EU-15 Member States, which shows that there is a recent trend towards reducing pesticide residue in water. Nevertheless, the occurrence of pesticides in water bodies above regulated standards remains a problem, in spite of reported decreases in pesticide concentrations in some Member States. The main negative effects of pesticide pollution are on aquatic, terrestrial flora and fauna, and human health. Therefore, crops with low demand for protection from pests and disease are a preferable choice for production of biomass for energy purposes.

However, a good evaluation of pesticide inputs is not possible due to insufficient availability of information, as many aspects such as dose, effect and persistence are important for an environmental assessment. In order to find a connection between crop and pesticide inputs, pest sensitivity of a crop, as qualitatively described in the literature, was chosen as a proxy indicator. The resulting estimates are listed by crop in Annex VI.

4.4.5 Water abstraction

Agricultural water use is a serious concern, especially in southern parts of Europe, where water is scarce and highly variable from year to year and where agricultural use of total water consumption is 50 % (22) (EEA, 2005b). The irrigable area in EU-12 increased from 12.3 million ha to 13.8 million ha between 1990 and 2000, i.e. by 12 %. In the Mediterranean countries, France, Greece and Spain, the irrigable area increased by 29 % during the same period. Irrigation is also important for arable production in the new, south eastern EU

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(22) Southern Europe in this context includes France, Greece, Italy, Portugal and Spain.

Member States, in particular Bulgaria, Hungary, Romania and Slovakia (EEA, 2004). The impacts of increased water abstraction and irrigation include loss of wetlands and the disappearance of habitats due to the creation of dams and reservoirs, soil salinisation and contamination, salt water intrusion in coastal aquifers, and the destruction of extensive, biodiversity-rich land use systems, such as dehesas, arable pseudo-steppes etc. (EEA, 2004 and 2005).

Using a crop type focus for irrigation, the IRENA indicator fact sheet on water use intensity (EEA, 2005b) shows that in Spain, Greece and France grain maize is the most important crop in terms of share of irrigated crops. In France, 40 % of the irrigated area is used for grain maize cultivation. The increase of the cropping area of this crop was the main reason for the strong increase in irrigated area from 1990 to 2000 in France. Areas of irrigated wheat, sunflowers and potatoes are also quite substantial in the south of Europe. At this moment no figures are available on the share of irrigated crops already used for bioenergy production. However, it is clear that the increased demand for bioenergy crops could lead to further pressure on water resources, especially if this leads to an increase of crops grown with irrigation.

In Annex VI the different potential biomass crops have been relatively ranked in terms of performance in relation to water use efficiency (WUE) and water consumption, based on data from Berndes (2002); Jørgensen and Schelde (2001), and Doorenbos and Kassam (1986). WUE is a measure of the yield, usually expressed as the amount of dry matter (DM) produced, per unit of water, which is expressed as the amount of water evapotranspired from the crop field (i.e. through leaves of the crop, the weeds and from the soil) during the whole growth cycle.

Using FAO data for irrigated crops (Doorenbos and Kassam, 1986), the WUE values for total cropped biomass under relatively good management lie in the range 1 to 9 gram DM per kg evapotranspired (ET) water (see Table 4.4), and typical values for the WUE of energy crops lie in the range from 1 to 4 gram DM per kg ET water (Berndes, 2002). The energy crops referred to by Berndes include biodiesel crops (oilseed rape), bioethanol crops such as cereals, maize, sugarcane and sugarbeet, and ligno-cellulose crops like miscanthus. The maximum water use efficiency (e.g WUE = 4) is obtained under optimum management techniques, so that crop growth is not impeded by nutrient stress, weeds, pests and diseases. In addition, the evaporation from the soil surface is kept as low as possible by promoting early crop canopy closure.

The estimated maximum WUE for C_4 crops is somewhat higher than for C_3 crops (see Table 4.4); this is especially the case for optimum management and sunny climates. C_4 crops need higher temperatures and are therefore confined to warmer regions in Europe, including the Mediterranean, where water scarcity is a problem. Based on crop specific WUE figures (whole plants) derived from FAO data (Doorenbos and Kassam, 1986), the maximum value for WUE per crop increases in the following order: oil crops (rape, sunflower), protein crops (beans, soybeans, groundnuts), alfalfa, C_3 cereals (wheat, barley, rye), root crops (potato, sugar beet), C_4 cereals (sorghum, maize) and C_4 grasses (sugar cane, miscanthus) see also Table 4.4.

A number of factors need to be taken into account for a full assessment of water use efficiency and the related environmental ranking of individual energy crops. Firstly, the WUE goes down if it is related only to the harvestable part of the plant. For example, the grain yield of wheat is about 40 percent of the whole plant biomass. Thus whole plant use would increase the WUE value for wheat substantially.

Secondly, in the case of bioenergy crops, it is also useful to express the WUE in relation to the energetic value of a crop. This information was however not available for this study, but generally it is clear that this may range strongly between crops. Oil crops have higher energetic value than starch and ligno-cellulose crops. But it also depends on the water content of the biomass. The higher the water content of the crop, the lower is the energetic value (although this seems to account for only 2 percent of the total water use per energy unit; see Berndes, 2002).

For the assessment of high water abstraction risk by biomass crops, the WUE expressed as grammes of DM per kg of ET water (under optimal cropping situations) was combined with an estimation of the average water requirement of the crop. Information of WUE in relation to energetic value of the crop could not be used as only limited information was available on this issue. However, the crop selection in Chapter 5 assumes that an increasing share of whole biomass crops will be used for bioenergy generation, which makes it acceptable to use a WUE coefficient related to the full DM produced by the plant and not only the harvested (grain) crop.

4.4.6 *Increased fire risk*

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

Table 4.4 Water use efficiency (WUE) and other crop characteristics

			Growing period		Total water requirement growing period		Growing season	Yield crop		Yield biomass DM		WUE gr. product/kg water		WUE gr. biomass DM/ kg water	
			Short	Long	Short	Long	Europe	Temperate	Mediterranean	Temperate	Mediterranean	Low	High	Low	High
Crop	Crop type	Use	Days	Days	Mm	Mm	Mm	Ton/ha	Ton/ha	Ton/ha	Ton/ha	gr./ kg water	gr./ kg water	gr./ kg water	gr./ kg water
Alfalfa	C_3	Biomass	100	365	800	1 600	summer	10.0	21.8	10.2	25.6	1.5	2.0	1.5	2.0
Maize	C_4	Starch	100	140	500	800	summer	6.0	8.8	13.2	22.0	0.8	1.6	1.8	3.5
Olive	C_3	Oil	210	300	600	800	winter/ spring		7.0		22.6	1.5	2.0	3.4	4.5
Pea, fresh	C_3	Protein	65	100	350	500	summer	3.0	0.5	1.3	1.3	0.5	0.7	0.2	0.3
Pea dry	C_3	Protein	85	120	350	500	summer	0.8	0.7	2.0	2.0	0.2	0.2	0.4	0.5
Potato	C_3	Starch	100	150	500	700	summer	40.0	9.5	18.0	15.8	4.0	7.0	1.8	3.2
Rice	C_3	Starch	90	150	350	700	summer	6.0	5.7	10.9	12.8	0.7	1.1	1.3	2.0
Safflower	C_3	Oil	120	160	600	1 200	summer		3.6		11.7	0.2	0.5	0.6	1.5
Sorghum	C_4	Starch	100	140	450	650	summer	3.0	4.4	7.5	12.4	0.6	1.0	1.5	2.5
Soybean	C_3	Protein	100	130	450	700	summer		3.2		9.2	0.4	0.7	1.1	1.8
Sugarbeet	C_3	Starch	160	200	550	750	summer	55.0	10.2	23.4	25.5	6.0	9.0	2.6	3.8
Sugarcane	C_4	Starch	270	365	1 500	2 500	summer		28.0			5.0	8.0	4.0	6.4
Sunflower	C_3	Oil	90	130	600	1 000	summer	2.5	3.2	9.2	12.9	0.3	0.5	1.1	1.8
Tobacco	C_3	Biomass	90	120	400	600	summer	2.0	2.3	3.3	4.2	0.4	0.6	0.7	1.0
Wheat	C_3	Starch	100	130	450	650	summer/ winter	6.0	5.2	12.9	12.9	0.8	1.0	1.7	2.2

Source: Own adaptation by K. van Diepen ([23]) based on Doorenbos and Kassam (1986) and Berndes (2002).

by bad land management and/or the lack of land management (land abandonment) making the density of dry inflammable biomass high and/or a lack of fire breaks. For biomass crop establishment in areas which have a high fire risk, it is important therefore to choose crops with low fire spreading characteristics. However, the introduction of perennial biomass crops would not necessarily add to the fire risk in the Mediterranean (JRC & EEA, 2006) for two reasons. Firstly, because fire risk in these types of crops is only present for a short period of the year (i.e. just before harvesting), which does not coincide with the period in which there is generally a high fire risk (summer-autumn period). Secondly, if there is a fire in a biomass crop this will generally only lead to a loss of the crop; there is a low risk of the fire spreading to forest and shrub lands. Consequently, the selection of biomass crops for the Mediterranean needs to take account of the susceptibility to burning of a crop and the location of the crop. The risk of fire appears particularly relevant for SRC and perennials crops which are more likely to be placed near forests and shrub lands.

4.4.7 Diversity of crop types

The loss of crop diversity has been caused by the continued specialisation in farming in recent decades. This process occurred simultaneously with a simplification of cropping systems which led to reduced crop diversity, but also a decrease in non-cropped habitats, such as grassland areas, field boundaries and tree lines. This simplification also substantially reduced landscape diversity leading to a loss of diversity in farmland habitats and associated farmland flora and fauna (EEA, 2005b). Piorr *et al.* (2004) analysed crop diversity in Germany from the beginning of agricultural statistics and concluded that the highest crop diversity occurred between 1925 and 1935, after which there was a continuous decline.

Crop and related structural diversity in agricultural ecosystems is an important factor for preserving and developing biodiversity. In general, greater diversity in land cover goes hand in hand with a larger range of ecological niches, creating habitats for a greater number of species. However, this study could only

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(23) Alterra, Wageningen, Centre for Geographic Information.

include field level crop diversity in the risk matrix (based on agricultural statistics). The contribution of biomass crops to the crop diversity of a region is assumed to be positive if the crop does not yet occur widely in one region. Therefore, novel rotational arable crops and ligno-cellulose crops always score better on this aspect than the arable crops which are already widely grown in most regions for food and feed purposes.

The most optimal biomass crop mixes chosen in every location in Europe should help to enhance crop and landscape diversity. In highly specialised farming systems, like in northern and western parts of the EU, crop diversity would already be increased substantially by adding one or more biomass crops to the rotation. However, new biomass crops may not be taken up in such specialised farming systems, as current approaches and crops may already be very productive and economically competitive. Hence, crop diversification due to energy cropping cannot be expected to happen in every region without specific guidance or support. To outline future options this study presents a scenario which is based on the introduction of innovative land use systems. These are currently not part of established bioenergy conversion pathways but highlight future chances.

4.4.8 Link to farmland biodiversity

The IRENA study (EEA, 2005b) concluded that extensive farming systems are important for maintaining the biological and landscape diversity of farmland, including Natura 2000 sites and High Nature Value farmland. It also showed that between 1980 and 2000 the majority of the farmland birds in the EU-15 strongly declined. IRENA data for Prime Butterfly Areas (PBAs) highlight that 80 % of all agricultural PBAs experience negative impacts from intensification, abandonment or both. 43 % of all agricultural sites suffer from intensification, whereas abandonment is a significant problem in 47 % of the sites. Both impacts occur simultaneously in 10 % of all sites.

Among the major land use types, permanent grassland is generally considered the most important from a landscape and nature conservation perspective (Ostermann, 1998; Bignal and McCracken, 2000; and Beaufoy *et al.*, 1994). Extensively managed permanent grassland provides habitats for many specialised plant and animal species (e.g. Brak *et al.*, 2004; and Beaufoy *et al.*, 1996). For example, 92 % of all target butterfly species in Europe depend on extensive grasslands.

Agricultural biodiversity in the new Member States has also been negatively affected by intensification and reclamation measures in the past, even though agriculture is less intensive in the new Member States than in EU-15 Member States (see EEA, 2004). Agricultural land use trends in recent years point to intensification and abandonment of farming as key factors for the habitat quality of farmland. BirdLife International estimated that out of the 571 International Important Bird Areas in these countries, 27 % were negatively affected by abandonment and 33 % by intensification in 2000.

Overall, the viability of fauna and flora in agricultural landscapes depends on four important landscape factors: amount and quality of habitat, spatial configuration of the habitat within the landscape, and landscape permeability. The combination of these four landscape factors influences the capacity of populations:

- to disperse in the landscape;
- to have enough opportunities to feed, roost, find shelter;
- to encounter with other individuals to reproduce themselves;
- to maintain a large and healthy enough population (see e.g. Bouwman *et al.*, 2002; Vos *et al.*, 2001; Opdam *et al.*, 2003; Foppen *et al.*, 2000; and Bruinderink *et al.*, 2003).

Since farmland areas in Europe still provide important habitats for a large number of species, farming activities have a major influence on the four landscape factors. The pressures exerted by biomass production can be categorised into those that exhibit a direct influence on landscape factors by causing, habitat fragmentation, habitat diversification, changes in canopy structure and soil cover. These effects may lead to changes in the amount of habitat, the configuration and also the permeability of the landscape for different species.

On the other hand, biomass production may also have an indirect influence via the environment, such as eutrophication, acidification and water balance which usually is very influential for habitat quality. This implies that the selected environmental pressure indicators for prioritising energy crops are therefore also indirectly linked to farmland biodiversity. Table 4.5 lists some principal relationships between the first five environmental pressure indicators and biodiversity.

From a farmland biodiversity perspective, the introduction of biomass crops should not lead to a further intensification of farming but rather be used as an opportunity to extensify farming as well as create more landscape and crop diversity. In the prioritisation of crops, this will be incorporated as is described in next sections.

4.5 Result: environmental risk matrices per crop

For each potential energy crop (whether currently widely grown or not), a ranking exercise for each environmental pressure indicator was carried out using the available expert knowledge on each environmental issue. A low risk of environmental impact is scored with A, a high risk with C. The following tables provide examples for maize as an annual crop (Table 4.6) and for short rotation coppice (SRC) of willow and poplar as perennial crops (Table 4.7).

The above tables show that maize and SRC score very differently on all environmental issues and that the latter clearly performs better from an environmental perspective. However, Chapter 5 shows that environmental ranking does not lead to a complete shift of all bioenergy crops to SRC

Table 4.5 Environmental pressures and their link to farmland diversity

Environmental pressure	Link to farmland biodiversity
Erosion	Causes a loss of organic soil substances and leads to a loss of habitats. Furthermore, water filtering and buffering functions are reduced with potentially negative effects on biodiversity. Resulting nutrient losses cause eutrophication of surface water affecting wildlife flora and fauna.
Soil compaction	Soil structure and other affected soil parameters (air and water household) may lower abundance/diversity of soil biodiversity and wildlife flora.
Nutrient leaching to groundwater and surface water	Causes eutrophication of surface water and soils affecting wildlife flora and fauna (e.g. shift in species) and may also have direct toxic effects on flora and fauna.
Pesticide pollution of soils and water	Toxic substances affect flora and fauna directly.
Water abstraction	Water abstraction may reduce the ground water level and cause changes in flora and fauna.

Table 4.6 Overview of environmental pressures per crop — maize used for bioethanol production

Aspect	Score	Reason
Erosion	C	Long period of uncovered soil, row crop
Soil compaction	C	Poorly developed root system; late harvesting on wet soils and usually followed by sowing of winter crop
Nutrient inputs into surface and groundwater	B/C	N-application rates are generally high but also good N-utilisation by crop. Especially in Central and southern Europe N-surpluses in maize are reported to be high. Leaching risk is high because of low soil coverage (row crop)
Pesticide pollution of soils and water	B	Poor competitive ability until the crop canopy has closed; subject to many diseases and pests, hence crop protection is quite intensive
Water abstraction	B	Medium water requirement and high water efficiency. In Mediterranean will require irrigation because typical summer crop
Increased fire risk	A	Harvested before dried up
Link to farmland biodiversity	B/C	Generally negative impacts on quality of habitats. Most severe impact in southern regions because of irrigation requirement leading to disturbance of hydrological regimes. Provides some shelter opportunities for fauna in autumn
Diversity of crop types	C	Very common crop in most parts of EU (except Northern Europe)

Table 4.7 Overview of environmental pressures per crop — SRC poplar and willow plantations

Aspect	Score	Reason
Erosion	A	Permanent crop
Soil compaction	A	Deep rooting + permanent crop
Nutrient inputs into surface and groundwater	A	High nitrogen uptake
Pesticide pollution of soils and water	A	Very competitive
Water abstraction	B	Unclear situation regarding requirement of water
Increased fire risk	-	-
Link to farmland biodiversity	A	No or low pesticide and nitrogen applications, so no direct negative impacts on habitat quality; nesting habitat and provides winter shelter
Diversity of crop types	A	Currently not very common

Note: Recent research shows that the water requirements of SRC plantations can be quite high.

Table 4.8 Environmental prioritisation of annual crops for the Nemoral and Boreal Zone

	Arable crops					
Boreal and Nemoral	Linseed (oil)	Other cereals (oats, barley, rye, triticale)	Wheat	Oilseed rape	Sugar beet	Potatoes
Erosion	B	B	B	A	C	C
Soil compaction	A	A	B	A	C	C
Nutrient leaching to ground and surface water	B	B	B	C	C	B/C
Pesticide pollution of soils and water	B	B	B	C	C	B/C
Water abstraction	A	A	B	B	A	A/B
Increased fire risk	-	-	-	-	-	-
Link to farmland biodiversity	B	B	B/C	B/C	B	C
Diversity of crop types	A	B	C	A/B	B	B

or to crops with a similar prioritisation, as yield considerations and greenhouse gas balance also influence the final crop choice.

In the final steps, the crops were prioritised according to the pressures per crop and the contextual information per environmental zone, as described in Section 4.3. The results of the prioritisation per environmental zone are given in Annex VII. Overall, three clusters of zones with similar crop prioritisations can be distinguished:

1. Northern and western Europe: farming systems with generally no risk of water shortage;
2. Southern Europe: risk of water shortage and increased fire risk;
3. Eastern Europe: risk of water shortage.

For the first cluster all risks have similar indicators, only increased fire risk was exempted as it is generally not a problem in this part of Europe. In southern and central Europe water shortage and increased fire risk (due to dry field residues) lead to another ranking of these two risk factors. In eastern Europe, especially in the Pannonian zone, water shortage may be a problem.

As example, the prioritisation of annual arable crops for the Nemoral and Boreal Zone and for the Atlantic Central and Lusitanian zone is shown (Tables 4.8 and 4.9).

In the Nemoral-Boreal zone, the choice of arable biomass crops is much more limited than in the Atlantic-Lusitanian zone. For the latter zone,

Table 4.9 Prioritisation of annual crops for the Atlantic Central and Lusitanian Zones

	Arable crops												
Atlantic central/ Lusitanian	**Hemp**	**Double cropping**	**Mustard seed**	**Clover/ Alfalfa**	**Linseed**	**Sun-flower**	**Sorghum (only in Lusitanian)**	**Other cereals (Barley, rye, oats, triticale)**	**Rape**	**Wheat**	**Potatoes**	**Sugar beet**	**Maize**
Erosion	A	A	A/B	A	B	B/C	B	B	A	B	C	C	C
Soil compaction	A	A	A	A/B	A	A	A	A	A	B	C	C	C
Nutrient leaching to ground and surface water	A	A	A/B	B	B	A	B	B	C	B	B/C	C	C
Pesticide pollution of soils and water	A	B	A	A	B	B	B	B	C	B	C	C	B
Water abstraction	B	B	B	A	A	B	B	A	B	B	B	B	C
Increased fire risk	-	-	-	A/B	-	-		-	-	-	-	-	..
Link to farmland biodiversity	B	B	A	A	B	A	B	B	B/C	B/C	C	B	C
Diversity of crop types	A	A	A	A	A	A	A/C*	B	B	C	B	B	C

* = very common in Romania and Bulgaria.

Note: A = low risk, C = 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.

this enables a wider choice of crops with a relatively better agri-environmental performance, both for arable crops and for perennials (see Annex VII).

Overall, the crops with the best environmental performance in the more temperate Atlantic part of Europe include hemp, mustard seed, clover-alfalfa and linseed and the double cropping system. The worst environmental performance is found for crops that are currently used for biomass which are oilseed rape, wheat, potato, sugarbeet and maize.

In the central parts of Europe characterised by warmer summers (Continental, Pannonian and Lusitanian zones), the best and poorest performing crops are similar to those in the Atlantic zones. However, the choice of crops with a middle ranking, such as sunflower and sorghum, and the choice of perennials is greater.

In the Mediterranean, the best performing crops are clover/alfalfa, sunflower and other cereals, while the poorly performing crops include wheat, sugarcane, potato and maize. The novel crops are assessed to be somewhere in between, but their prioritisation is less reliable as not all environmental parameters for these crops are known.

A wide range of perennial crops is available for the Mediterranean, although for these crops the fire risk is clearly higher than for arable crops. The perennial crop that performs by far the worst is eucalyptus which poses extremely high risks for erosion, fires, biodiversity and most importantly large hydrological problems.

4.6 Conclusions for energy crop mixes by environmental zone

Crop prioritisation by environmental zone gives initial recommendations towards identifying an environmentally compatible crop mix for biomass production in most environmental zones of Europe. Given the time and resources available for this project, the suggested crop mixes are a first demonstration of this approach for determining environmentally compatible bioenergy production systems. In spite of this, the resulting crop mixes should be a good basis for estimating the eventual bioenergy potential calculated in Chapter 5 of this study. However, it should be borne in mind that the environmentally compatible crop mix will not be the only factor determining the eventual crop mix but considerations such as economic efficiency (expressed as energy yield per crop per hectare), current land use as well as available experience and knowledge with different crops and technologies are also involved. Furthermore, the possibility of using a whole crop for bioenergy generation is taken into account as it will increase the energy efficiency of a crop (energy content per ha).

As knowledge about novel crops for the Mediterranean zone, such as Kardoon (Cynara cardunculus), Brassica carinata, Castor bean and prickly pear, is still limited, they were not included in the final crop mix in Chapter 5. This applies both to agri-environmental performance as well as to energy value and technological aspects of the conversion into energy. The only exception is sugarcane; Brazil has gained significant experience in using sugar as the main source for bioethanol. This crop will be included in the initial selection of crops, but because of the high water requirement it is not suited for the final 'environmentally compatible' crop mix for the Mediterranean zone.

Overall, perennial biomass crops generally impose a significantly lower risk on the environment than arable crops, and they may even provide positive benefits to farmland biodiversity in intensive agricultural landscapes under specific farm management practices. In the light of this, it is advisable from an environmental perspective to incorporate perennials as a minimal percentage in the total future biomass production area in each Member State. Further research which takes more local circumstances into account (e.g. farming practices, biodiversity stock, energy requirements, socio-economic situation, opportunities for biomass delivery chains etc.) should provide further analysis on the best crop mixes, locations and practices for growing biomass crops, including perennials.

The data and information about the cultivation of perennials in the different environmental zones is still rather limited. This contrasts strongly with the annual crops for which more assessment material was available. Two conference papers that were recently completed provide new information (Dworak *et al.*, 2007; and Eppler *et al.*, 2007). However, these were not available at the time of preparing this study.

In relation to annual crops, energy crops and approaches that enlarge crop diversity and enable the introduction of extensive cropping system are very attractive, e.g. fodder crops and double cropping systems.

For further work on the environmental prioritisation of energy crops, a clear differentiation between assessments for arable (annual) energy crops and perennial energy crops is advised. The latter have completely different impacts on the environment and the landscape, and should therefore be assessed separately.

As regards optimal crop mixes per environmental zone, most of the perennials in the Atlantic, Lusitanian and Continental zones are attractive, while for arable crops the cereals (excluding wheat), linseed, clover/alfalfa mixes, hemp, and double cropping systems are ranking well. In the more northern Boreal zone this mix would be similar, except for the double cropping system which needs a longer growing season. In the Mediterranean zone, the environmental evaluation favours arable crops with a relatively low water requirement and a high water use efficiency, such as cereals (excluding wheat), clover-alfalfa mixes, and sorghum, and would lend support also to perennials, such as Miscanthus, switchgrass and Giant reed.

Finally, it should be mentioned that more research is needed on the best farming practices and new crop mixes. The double cropping system is just one approach which needs much more practical investigation, including field trials in different locations all over Europe using very different combinations of crops. This applies particularly to suitable biomass crop mixes for southern European regions. So far, there seem to be several potential novel crops for this arid region. However, very little experience has been gained in growing them in field trials in Europe, estimating their agri-environmental performance and converting them into energy products.

5 From land availability to bioenergy potential

5.1 Introduction

This chapter explains the conversion of the land potential to a bioenergy potential. The overall results in terms of bioenergy potential are presented in Chapter 6. The available primary bioenergy potential will be expressed in terms of the lower heating value ([24]). Further specifying the results in terms of different energy products (biofuels, electricity and heat) would have been strongly assumption-based, and therefore was not attempted.

In order to calculate the energy value, the results from the previous working steps are brought together. They include:

1. the land potential;
2. the environmental prioritisation of crops by zone (sustainable crop mixes);
3. the crop yields.

For the inclusion of the crop yield information a conversion factor from kilograms harvested dry matter into joules is added and the average joules per hectare of a specific crop can be calculated. These yields expressed in joules per crop per hectare are a proxy value for the efficiency ([25]) of the biomass crops both in terms of green house gas (GHG) balance, land use efficiency and economic efficiency. This proxy value for efficiency is used together with the environmentally compatible crop mix to determine the final crop mix per country.

Although assessing the efficiency of the whole biomass to energy pathway is not an objective of this study it is clear that this issue cannot be completely ignored when deciding on the final environmentally compatible crop mix. This is why the energy yield in joules per hectare per crop was also taken into consideration when identifying the most appropriate crops.

Yield is a very good proxy value, both to express economic efficiency as well as indicate the GHG balance and land use efficiency. An efficient GHG balance is reached when the biomass energy product delivers a clear net CO_2 emission reduction compared to the fossil reference. The choice of crops and the input of fertilizers are the first factors influencing this efficiency at field level. Low yielding crops may have a low nitrogen leaching risk. However, if their yield is so low that three times as many hectares have to be cropped to reach the same yield in terms of energy as a high yielding crop with a higher fertiliser input use, the GHG balance for the latter crop may still be better. A further argument to take yield into account is land use efficiency. Increased demand for biomass will create an additional pressure on the land. If we only grow low yielding crops, which perform well from an agro-environmental perspective, the pressure for expanding the arable area will be considerably higher than for a situation where higher yielding crops are also used.

Taking both yield and agro-environmental performance into account will help to strike a good balance between different environmental aspects and economic criteria. Moreover, it offers good arguments for deselecting the very low yielding crops which only perform well from an agro-environmental perspective and the high yielding and high input crops with a very bad agro-environmental risk profile.

Figure 5.1 shows a detailed scheme of the individual working steps in the calculation of the energy potential. All calculations are based on input values specific to Member State and/or environmental zone and take 2010, 2020 and 2030 as target years.

For the choice of the eventual crop mix, the environmentally compatible crop mix in Chapter 4 was taken as a basis (see Figure 5.1). An optimisation is then made between the environmental ranking of crops, the efficiency expressed in energy yields per hectare, and the expected development of future technologies (e.g. conversion and energy use). Since it takes some time for future technologies to become commercial and for novel crops and new energy

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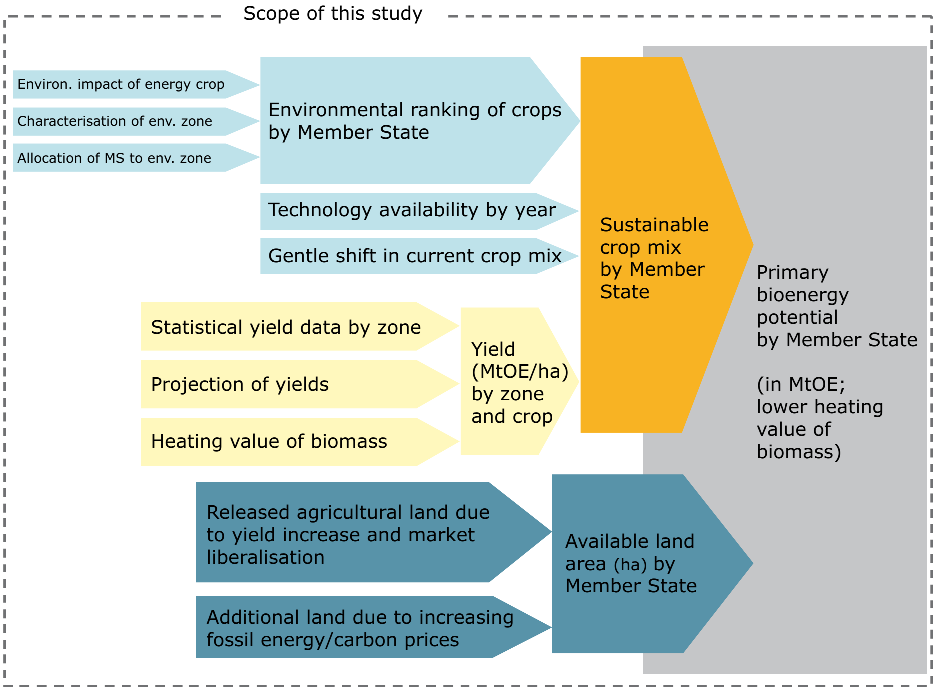
[24] For green biomass the potential is given as the lower heating value of the biogas that could be produced by fermentation.
[25] The specific yields also indicate the optimal use of the land in order to get the highest bioenergy output.

Figure 5.1 Overview of the working steps to calculate the environmentally compatible biomass potential by Member State



cropping and farming practices to be introduced into farming activities, the calculations incorporate a time span within which a gradual shift from the current crop mix to the identified environmentally and economically compatible crop mix takes place. For perennial crops (especially short rotation coppice), the period from establishment to first harvest is also taken into account. As already mentioned in Chapter 4 (Section 4.5) the novel bioenergy crops for the Mediterranean have only been included in the agri-environmental prioritisation, but are not included in the final 'environmentally compatible' crop mix described in this chapter. This choice had to be made because still too little is known about these crops in terms of cropping practices as well as their likely energy yield and the most suitable conversion processes to energy products.

Some general assumptions about the method of the assessment need to be mentioned before discussing each step in the calculation of final energy value:

1. For the ranking of crops per Member State the environmental considerations described in Chapter 4, the energy yields per hectare, the expected technological developments and the gradual shift from today's to future crop mixes were all taken into consideration in a so-called 'heuristic' process (26).
2. As this assessment was only applied to the national level, no local factors could be considered.

The necessary expert element in the choice of final crop mix per Member State introduces some additional uncertainty in the calculation of final potential energy yield. However, this is not considered to matter much in comparison to other uncertainty factors that are an inevitable part of any scenario study. The necessary assumptions about future yield increases, food and energy prices, environmental constraints or the limitations of the modelling tools employed are likely to be even more important factors for the uncertainty range of the final results shown.

5.2 Step 1: allocation of Member States to environmental zones

The crop prioritisation in Chapter 4 is specified per environmental zone (see Annex IV for map and description of environmental zones). Since these zones do not necessarily coincide with national

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(26) As one cannot compute an 'optimum' in a three-dimensional decision space (environment, CO_2 reduction, economy), the ultimate 'rules' to combine the environmental risk matrices, the specific yields, and the starting conditions in the Member States (i.e. year 2000 agricultural crop mixes) were based on expert judgment, not on a quantitative model.

boundaries, this section explains how the crop mix per environmental zone is allocated to each Member State. In order to simplify the model calculation, for every Member State one dominant zone is determined as the most influential in the selection of crops and average yields. This will result in only a relatively small error for most Member States, as only neighbouring zones with similar yields and crops are affected. However, for larger and more diverse Member States covering several environmental zones, like France, Germany, Spain, Sweden and the United Kingdom, more environmental zones were selected to be dominant in the determination of crop mixes and yields. The dominant environmental zones per Member State are given in Table 5.1.

5.3 Step 2: estimated crop yields per environmental zone

For the calculation of the energy potential from the land potential for each crop yield, yield increase and harvested dry matter was specified per environmental zone (see Tables 5.2 to 5.4). Most yield figures are estimated from long term averages in FAO STAT. Where these were not available yields were estimated from published field research quoted in previous bioenergy studies (e.g. for the year 2000 this is done by taking the arithmetic average of crop yields of bigger countries which represent the same environmental zone, see Table 5.5).

Table 5.1 Allocation of Member States in environmental zones

Member State	Main Env. Zone	Land potential for bioenergy crops in 2030, or not?	Additional zones covered by this Member State
Austria	CON-PAN	yes	ALS
Belgium	ATC	no	
Germany	ATC	yes	Half CON
Denmark	ATN	no	
Spain	MDN	yes	MDS, MDM and LUS
Finland	BOR-NEM	yes	
France	ATC	yes	LUS, MDN and MDM
Greece	MDN	yes	MDS
Ireland	ATC	no	
Italy	MDN	yes	MDM and MDS
Netherlands	ATC	no	
Portugal	LUS	yes	MDN and MDS
Sweden	BOR-NEM	yes	CON and ALN
United Kingdom	ATC	yes	ATN
Czech Republic	PAN	yes	CON
Estonia	BOR-NEM	yes	
Hungary	PAN	yes	
Lithuania	BOR-NEM	yes	
Latvia	BOR-NEM	yes	
Poland	CON	yes	
Slovenia	PAN	yes	MDM
Slovakia	PAN	yes	CON

BOR-NEM:Boreal-Nemoral
ALN: Alpine North
ALS: Alpine South
CON: Continental
ATN: Atlantic North
ATC: Atlantic Central
PAN: Pannonian
LUS: Lusitanian
MDM: Mediterranean Mountain
MDM: Mediterranean North
MDS: Mediterranean South

Table 5.2 Yields of arable crops for energy purposes by environmental zone (year 2000, dry matter)

Ton DM per ha	Rape seeds	Sunflower seeds	Sugar beet	Maize corn	Wheat corn	Barley or Triticale corn	Sweet sorghum
BOR-NEM	2.7	-	14.5	-	6.2	-	-
ATN	2.9	2.5	14.3	9.5	7.6	5.4	-
ALS	-	-	-	-	-	-	-
CON	2.7	2.4	14.5	7.3	6.2	5.1	5.0
ATC-LUS	3.	2.3	18.1	8.6	6.9	6.1	8.1
PAN	1.6	1.7	10.1	5.3	3.5	3.0	5.0
MDM/MDN/MDS	1.4	1.5	15.8	9.4	2.8	3.1	12.7

BOR-NEM: Boreal-Nemoral; ALN: Alpine North; ALS: Alpine South; CON: Continental; ATN: Atlantic North; ATC: Atlantic Central; PAN: Pannonian; LUS: Lusitanian; MDM: Mediterranean Mountain; MDN: Mediterranean North; MDS: Mediterranean South.

Source: FAO statistical data and own adaptations.

Table 5.3 Estimated whole crop yields for arable crops for energy purposes by environmental zone (year 2000, dry matter)

Ton DM per ha	Maize whole crop	Tricticale whole crop	Wheat whole crop	Double cropping Optimal yield	Double cropping Reduced yield
BOR-NEM	-	-	12.5	-	-
ATN	0.0	13.0	15.1	19.3	13.8
ALS	-	-	-	-	-
CON	10.9	11.3	12.5	17.5	12.5
ATC-LUS	12.8	13.1	13.9	20.1	14.4
PAN	7.9	6.5	7.1	14.9	10.6
MDM/MDN/MDS	14.2	5.9	5.7	13.1	9.4

BOR-NEM: Boreal-Nemoral; ALN: Alpine North; ALS: Alpine South; CON: Continental; ATN: Atlantic North; ATC: Atlantic Central; PAN: Pannonian; LUS: Lusitanian; MDM: Mediterranean Mountain; MDN: Mediterranean North; MDS: Mediterranean South.

Source: Öko Institut, 2003 and Elbersen *et al.*, 2005.

Table 5.4 Estimated yields of perennials for energy purposes by environmental zone (year 2000, dry matter)

Ton DM per ha	SRC poplar	SRC willow	Miscanthus	Reed canary grass	Giant reed	Switchgrass
BOR-NEM	6.7	7.5	-	7.7	-	-
ATN	6.7	7.5	8.8	7.7	16.6	7.7
ALS	-	-	-	-	-	-
CON	6.7	7.5	12.5	9	11.0	9.0
ATC-LUS	7.5	7.5	9.5	6.2	9.0	8.0
PAN	7.5	7.5	9	9	9.0	9.0
MDM/MDN/MDS	6.5	7.5	16.5	16.6	9.0	9.0

BOR-NEM: Boreal-Nemoral; ALN: Alpine North; ALS: Alpine South; CON: Continental; ATN: Atlantic North; ATC: Atlantic Central; PAN: Pannonian; LUS: Lusitanian; MDM: Mediterranean Mountain; MDN: Mediterranean North; MDS: Mediterranean South.

Source: Elbersen *et al.*, 2005.

Table 5.5 Member States whose average yields were applied to the whole environmental zone

Zone	Representative Member State
Boreal-Nemoral	Finland
Atlantic North	Average United Kingdom and Denmark
Alpine South	No potential
Continental	Average Germany and Poland
Atlantic Central	France
Pannonian	Hungary
Mediterranean North, South and Mountain	Average Italy and Spain

Table 5.6 Yield increase rates by crop and year

	Oilseeds	Cereals	Whole plants, perennial energy grasses, SRC
2000–2010	1 %	1.5 %	1.0 %
2010–2020	1 %	1.5 %	1.5 %
2020–2030	1 %	1.5 %	2.5 %

The assumptions concerning future yield increases are differentiated by oil crops, cereals (maize only) and other energy crops (like whole-plant use of common arable crops, short rotation coppice and perennial energy grasses). For dedicated energy crops, the yield increase is expected to be higher than for traditional agricultural crops, especially as the breeding potential of the crops for non-food purposes has only recently been exploited. In contrast, yield increase rates for common arable crops already started to slow in the 1980s in Europe. This is why the increase in yields for these crops is assumed to be limited (OECD/FAO, 2005; Fritsche *et al.*, 2004).

5.4 Step 3: Ttranslation of harvest mass to energy by crop

The conversion from the biomass potential to an energy potential is carried out via the lower heating value of the harvested mass (dry matter). The data in Table 5.7 exclude conversion losses, i.e. gross yields after harvest from the field. Only in the case of green biomass for fermentation (e.g. double cropping systems or whole maize plant) does the lower heating value refer directly to biogas. Table 5.7 shows that the 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 mentioned that these double cropping systems only occur in a limited number of Member States concentrated in the Atlantic and Continental zones, where sufficient water is generally available.

Using a combination of the lower heating value data with the data on crop yields per hectare, the energy yields per hectare per crop per Member State were calculated (27). Since yields increase over time, the model incorporates single tables of yields for each time step (see Annex X for all Member States and Table 5.8 for Poland as example).

For Poland, Table 5.8 shows that for arable rotational crops the highest yields in energy per hectare are reached for all whole plant applications, especially in a double cropping practice. If only the fruit (seeds, beets or grain) is used as feedstock, the bioenergy potential is much lower. However, maize still delivers a relatively high yield, followed by wheat, sugarbeet and barley-triticale grain. When looking at the perennial biomass crops the highest yields come from the energy grasses, especially miscanthus, while the SRC plants (short rotation coppice) are expected to deliver lower yields.

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(27) Average crop yields can be deceptive in this context as energy crops may not be grown on the same land as standard food crops. However, since this study generally excludes extensive, less productive areas from biomass production this effect should not be a major source of error for the calculations presented here.

Table 5.7 Lower heating value (LHV), dry matter yield and energy yield per hectare by crop

	LHV GJ/t_{DM}	yield in t_{DM}/ha	GJ/ha
Double cropping, optimal	15.2	17.5	266.0
Maize, whole plant	16.5	13.0	214.5
Sorghum, whole plant		12.0	
Maize corn	21.4	9.5	203.3
Triticale, whole plant	16.4	12.0	196.8
Double cropping, reduced	15.2	12.5	189.4
Wheat whole plant	17.1	10.0	171.0
Miscanthus,	18.0	9.0	162.0
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, Rye, Oats, triticale corn	17.0	5.5	93.5
Rape seeds	26.5	2.5	66.3
Sunflower seeds	26.5	2.5	66.3
Mustard seed/linseed	26.5	2.5	66.3
Potatoe		18	
Sugar beets	1.9	14.0	26.6
Grass cuttings, Clover, Alfalfa	calculated as biogas potential:		
	21.6 MJ/m³		0.67 m³ biogas per kg_{DM}

Note: The lower heating value quoted relates to the dry matter content of the biomass.

Source: EEA based on Wiegmann, K., Fritsche, U. & B. Elbersen: 'Environmentally compatible biomass potential from agriculture'. Consultancy report to the EEA, 2005.

5.5 Step 4: sustainable crop mix by Member State

In this step optimisation is achieved between the environmental ranking of crops, the yields per hectare and the development of future technologies (conversion and energy use). These aspects are first worked out separately and then integrated.

5.5.1 Yield and environmental prioritisation

Now that the lower heating value per crop per hectare per Member State is calculated, this information needs to be aggregated to the whole Member State level. This requires the further incorporation of environmental ranking per crop per Member State as described in Chapter 4 and the crop yields, including the assumed yield increases over time. The environmental constraints are taken into account via the incorporation of the environmentally compatible crop mixes resulting from Chapter 4. Efficiency considerations in terms of GHG balance, land use and economy are indirectly involved through prioritising crops according to their energy value expressed in joules per hectare.

Table 5.9 provides an overview of the ranking of crops based on environmental and efficiency considerations.

Table 5.9 shows that crops that are scoring well regarding energy yield ('*') and agri-environment ('**') get the highest priority ('***'). In the Atlantic Central zone, for example, double cropping systems score high on yield and agro-environmental performance. In the Mediterranean, the best options seem to be sorghum and other cereals. Overall, it is clear that in some zones the crops that perform well for both environment and yield are very scarce. This is especially the case for the Boreal-Nemoral zone and the Mediterranean where we start from yields derived with no or limited irrigation. For these zones more sub-optimal choices had to be made where crops were selected that at least perform relatively well in terms of agro-environment and give medium energy yields.

Table 5.8 Energy yields for Poland by crops and time step in GJ per ha

Poland — yields traditional arade [GJ/ha]

Year	Rape seeds	Sunflower seeds	Sugar beet	Maize corn	Wheat corn	Barley and triticale corn
2000	55	66	108	203	129	92
2010	66	70	122	181	123	101
2020	73	77	134	210	143	117
2030	81	85	148	244	166	135

Poland — yields whole plants for fermentation [GJ/ha]

Year	Maize	Triticale	Wheat	Double cropping optimal	Double cropping reduced
2000	215	213	259	293	208
2010	199	205	236	294	209
2020	231	238	273	341	234
2030	282	290	333	416	296

[GJ/ha]

Year	SRC poplar	SRC willow	Miscanthus	Reed canary grass	Giant reed	Switchgrass
2000	124	199	158	135	286	131
2010	137	152	249	174	209	169
2020	159	177	288	202	243	196
2030	194	216	352	246	296	239

Poland — yields traditional arable [GJ/ha]

Year	Rape seeds	Sunflower seeds	Sugar beet	Maize corn	Wheat corn	Barley and triticale corn
2000	55	66	108	203	129	92
2010	66	70	122	181	123	101
2020	73	77	134	210	143	117
2030	81	85	148	244	166	135

Poland — yields whole plants for fermentation [GJ/ha]

Year	Maize	Triticale	Wheat	Double cropping Optimal	Double cropping Reduced
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2030	282	290	333	416	296

[GJ/ha]

Year	SRC poplar	SRC willow	Miscanthus	Reed canary grass	Giant reed	Switchgrass
2000	124	199	158	135	286	131
2010	137	152	249	174	209	169
2020	159	177	288	202	243	196

Source: EEA based on Wiegmann, K., Fritsche, U. & B. Elbersen: 'Environmentally compatible biomass potential from agriculture'. Consultancy report to the EEA, 2005.

Table 5.9 Preferences for bioenergy crops based on relative ranking by environmental zone

Potential crops	BOR-NEM	ATN	ATC-LUS	CON	PAN	MDM-MDN-MDS
Permanent grass	**	**	**	**	**	**
Maize			*	*	*	*
Double cropping		***	***	***	**	**
Mustard seed		**	**	**	**	
Hemp		**	**	**	**	**
Linseed		**	**	**	**	
Clover-Alfalfa			**	**	**	**
Sugarbeet	▨	▨	▨	▨	▨	
Rape	▨	▨	▨	▨	▨	
Sunflower			***	***	***	**
Potato	▨	▨	▨	▨	▨	▨
Other cereals (barley, rye, oats, triticale)	***	***	***	***	***	**
Wheat	*	*	*	*	*	*
Sorghum					***	**
Sugarcane						*
Giant reed					***	**
SRC Eucalypthus			*			*
SRC poplar, willow	**	**	**	**	**	
Reed canary grass	***	***				
Miscanthus		***	***	***	***	**
Switchgrass		***	***	***	***	**

Suitable for growing in environmental zone	▨
Medium to high yield (EnergyGJ/ha)	*
High agri-environmental ranking	**
High yield and agri-environmental ranking	***

To determine the eventual mix the present crop mix per Member State is also taken into consideration together with diversity in land use. The latter implies that if two crops have a similar ranking on agro-environmental and yield efficiency performance, the crop that occurs less frequent is preferable (28). In general, a variety of crops creates higher structural diversity in the landscape, and leads to more environmental niches in space and time for a range of species from different taxa (see Chapter 4).

5.5.2 *Technological developments and smooth transition*

Assumptions about technological development are incorporated in the conversion calculations because the available technologies are an important factor in determining the demand for specific bioenergy crops. In the near to medium future, there will be a great demand for biofuels in order to reach the 2010 target of a 5.75 % share in transport fuels as specified in the Biofuels Directive (2003/30/EC) (29), and the

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(28) Note that when translating the crop 'ranking' to the level of Member States, the existing agricultural crop mixes were taken into account to allow for a 'smooth' inclusion in time in the overall mix.

(29) The Biofuels Directive does not explicitly refer to domestic biofuels, i.e. imports could be taken into account for reaching the 5.75 % share.

10 % target for 2020 of the EU energy package proposed in January 2007. Since biofuel production from biomass currently has a high political priority we assume that in the short to medium term (until 2020) most of the biomass potential will be used for the production of transport fuels. For co-generation and heating purposes we assume that biomass will mostly be delivered by forestry residues and the waste sector (including residues from agriculture). Today, most agricultural potential comes from oil crops which are converted into biofuels (FAME). In future it is expected however, that there will be a shift from first-generation biofuels (plant oil, FAME and ethanol from cereals, sugar beet or potatoes) to second-generation biofuel production by synthetic biofuels (BtL), and ethanol from ligno-cellulosic material (ethanol+). The second-generation biofuels can use various feedstocks. Crops that produce these types of biomasses, e.g. perennial biomass grasses and SRC, are usually characterised by high yields per hectare, and relatively low environmental pressures. This is why they rank prominently in environmental ranking. They should also become economically efficient when used as feedstock for second-generation biofuels. It can therefore be expected that perennial grasses and SRC become more important in crop mixes after 2010 when these technologies enter the market (30).

The shift from ethanol derived from starch crops to ethanol+ will not require the establishment of complete new conversion plants. Instead, it is assumed that existing plants would be adjusted with new modules for ligno-cellulosic digestion (31).

Starch crops would become more attractive than sugar crops as feedstock for future biofuel production. The conversion requirements for the production of ethanol from sugar beet are much more complex. For these types of processes specialised adaptation of existing plants is needed which makes this option less attractive in economic terms. However, given the importance of sugar beet in present crop rotations in many arable production areas of the EU, the social and rural pressure of finding alternatives for the use of sugar beet in the context of declining support under the CAP regime might be high. In the approach adopted, however, these social and rural considerations have not been taken into account. Sugar beet therefore scores low, both from an economic and an environmental perspective, as already stated in Chapter 3.

Gasification and second-generation biofuels become attractive after 2010; this is expressed in the shift in land use for biomass from arable crops to perennials by 2020. A quicker introduction of such technologies may be possible, but this would not be in line with the establishment of these new crops by farmers and operators of biomass conversion plants. For these players, the incorporation of new technologies will take time and money. Thus, it can be expected that a gradual shift from current arable crops to ligno-cellulosic crops is most realistic.

The introduction of co-generation and heating plants depends on financial incentives that promote heating grids as well as market penetration and technical development of small- and medium-sized gasification technologies for solid fuels. In parallel, biogas from double-cropping is quite attractive and can be used in conventional cogeneration systems. For this reason, biogas crops have a prominent position in the optimal crop mix (32).

5.5.3 *Crop mixes per Member State*

Given all technological considerations incorporated with the information on yields, yield increases and environmental crop rankings, the crop mixes per Member State could be determined. The results of these calculations are presented in table 5.10 for the year 2030 and for all time steps in Annex X.

For some countries, e.g. Belgium, Ireland, Greece, Netherlands, Portugal, no crops have been selected because no land potential is considered to be available by 2030 to grow them and/or because all biomass potential will come from grassland cuttings. For northern countries, the following arable biomass crops were included in the final mix: wheat and barley-triticale plus some application of double cropping. Among the perennial crops a mix of SRC and perennial biomass grasses is assumed. For the countries in western and central Europe, cereals dominate the arable crop mix, together with whole plant applications, especially as part of double cropping practices. A limited share of maize and rape is also allowed for these countries, although from

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(30) Even if SRC would be planted now, the first harvest would occur after 2010.

(31) Additionally changes in the energy supply system would be necessary to use the residues for internal process heat generation.

(32) '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.

an environmental perspective they are not the best performing crops. This decision was made because their energy yields are high, especially for maize, they are part of the present crop mix and rotation, and they can deliver extra crop diversity in a heavily cereal dominated rotation. In the perennial mix, miscanthus and switchgrass have the highest share, but SRC also occurs.

For southern European countries, the choice of crops is generally more limited. In the rotational arable category, cereals dominate along with some limited sunflower share and sorghum in whole crop applications. The perennials selected for this part of Europe are only energy grasses.

Table 5.10 Final assumed mix of energy crops by Member State in 2030

	Traditional arable crops						Whole crops					
MS	**Rape seeds**	**Sunflower seeds**	**Sugar beets**	**Maize corn**	**Wheat corn**	**Barley/ triticale corn**	**Maize whole plant**	**Rriticale whole plant**	**Wheat whole plant**	**Double cropping optimal**	**Double cropping reduced**	**Sweet sorghum**
AT	10 %	10 %	0 %	30 %	25 %	25 %	0 %	0 %	0 %	0 %	0 %	0 %
BE	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
DE	10 %	0 %	0 %	10 %	20 %	15 %	0 %	0 %	0 %	20 %	10 %	0 %
DK	0 %	0 %	0 %	10 %	30 %	25 %	0 %	0 %	0 %	20 %	10 %	0 %
ES	0 %	10 %	0 %	10 %	30 %	20 %	0 %	0 %	0 %	0 %	0 %	15 %
FI	0 %	0 %	0 %	0 %	45 %	20 %	0 %	0 %	0 %	10 %	5 %	0 %
FR	0 %	5 %	0 %	15 %	40 %	10 %	0 %	0 %	0 %	10 %	5 %	0 %
GR	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
IE	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
IT	0 %	5 %	0 %	15 %	20 %	15 %	0 %	0 %	0 %	0 %	10 %	10 %
NL	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
PT	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
SE	0 %	0 %	0 %	0 %	30 %	25 %	0 %	0 %	0 %	10 %	5 %	0 %
UK	0 %	0 %	0 %	15 %	40 %	20 %	0 %	0 %	0 %	10 %	5 %	0 %
CZ	15 %	0 %	0 %	10 %	20 %	20 %	0 %	0 %	0 %	0 %	5 %	0 %
EE	0 %	0 %	0 %	0 %	35 %	40 %	0 %	0 %	0 %	0 %	5 %	0 %
HU	10 %	5 %	0 %	5 %	20 %	15 %	0 %	0 %	0 %	10 %	5 %	0 %
LT	0 %	0 %	0 %	0 %	30 %	30 %	0 %	0 %	0 %	10 %	5 %	0 %
LV	0 %	0 %	0 %	0 %	30 %	30 %	0 %	0 %	0 %	10 %	5 %	0 %
PL	15 %	0 %	0 %	10 %	15 %	15 %	0 %	0 %	0 %	15 %	5 %	0 %
SI	10 %	5 %	0 %	5 %	20 %	15 %	0 %	0 %	0 %	0 %	10 %	0 %

	Perennials					
MS	**SRC poplar**	**SRC willow**	**Miscanthus**	**Reed canary grass**	**Giant reed**	**Switchgrass**
AT	0 %	0 %	0 %	0 %	0 %	0 %
BE	0 %	0 %	0 %	0 %	0 %	0 %
DE	0 %	5 %	5 %	0 %	5 %	0 %
DK	0 %	0 %	0 %	5 %	0 %	0 %
ES	0 %	0 %	0 %	0 %	15 %	0 %
FI	0 %	0 %	0 %	10 %	0 %	10 %
FR	5 %	0 %	5 %	10 %	0 %	0 %
GR	0 %	0 %	0 %	0 %	0 %	0 %
IE	0 %	0 %	0 %	0 %	0 %	0 %
IT	0 %	0 %	5 %	0 %	10 %	10 %
NL	0 %	0 %	0 %	0 %	0 %	0 %
PT	0 %	0 %	0 %	0 %	0 %	0 %
SE	5 %	5 %	0 %	10 %	0 %	10 %
UK	0 %	0 %	0 %	5 %	0 %	5 %
CZ	0 %	5 %	10 %	0 %	0 %	15 %
EE	5 %	5 %	5 %	5 %	0 %	0 %
HU	0 %	5 %	10 %	0 %	0 %	15 %
LT	5 %	5 %	5 %	10 %	0 %	0 %
LV	5 %	5 %	5 %	10 %	0 %	0 %
PL	5 %	5 %	0 %	0 %	0 %	15 %
SI	0 %	5 %	10 %	5 %	0 %	15 %

6 Environmentally compatible bioenergy potential

In an environmentally compatible future, higher energy prices and a coupling of the food, feed and biomass markets become a realistic option. The assessment in previous chapters shows that the effect of higher energy prices on the final land and energy potential is quite substantial and can therefore no longer be ignored. For this reason the scenario with higher energy prices (calculated using HEKTOR for France and Germany only) is taken as the standard scenario in the discussion of the results in this chapter.

6.1 Total bioenergy potential

The translation of land potential derived from the crop mixes discussed in Chapter 4 results in a total energy potential for the EU-25 of 47 MtOE in 2010, 96 MtOE in 2020 and 142 MtOE in 2030. This implies that between 2010 and 2030 the energy potential increases by a factor of 2.75. In Table 6.1 the results are presented for the EU-15 and EU-10 (estimated for the EU-8). It is clear that the EU-15 has a greater bioenergy potential than the EU-10 and that this difference increases towards 2030. This relatively stronger increase for the EU-15 is related to the fact that liberalisation of agricultural markets has a stronger effect on these Member States. On the other hand, both total and transport energy consumption in the EU-10 are much lower than in the EU-15, and, at the time of writing, a substantial difference was expected to remain, in spite of increasing convergence. It is thus reasonable to assume that some new Member States will export their biomass or biofuel to EU-15 Member States (33).

In the calculations it is assumed that until 2010 most biomass from agriculture, dedicated crops for sugar, oil and starch, will be used for the production of transport biofuels in order to reach the EC Biofuels Directive (2003/30/EC) target of 5.75 % biofuels in transport fuels. For this same period, in the heat and electricity sector, renewable energy would either be produced from woody residues from forestry as well as from waste and by-products, and wind, geothermal, and solar energy.

6.2 Changes in crop mix

The crop mix is projected to change drastically over time (see Figure 6.1). While in 2010 some 40 % of the agricultural bioenergy potential would be dedicated to bioenergy crops for conventional arable biofuels production, this would decrease rapidly after 2010 with the assumed introduction of advanced conversion technologies. These technologies can make use of other, generally more environmentally friendly crops and cropping practices delivering higher energy yields. Such crops include different types of perennials, e.g. energy grasses — miscanthus, switchgrass and short-rotation coppice, as well as rotational crops harvested as whole plants. Crops used as feedstock for biogas installations (such as maize or double cropping systems) will increase after 2020, particularly in the countries of the Atlantic and Continental zone. In 2030, it is expected that there will be an overall higher share of the more drought resistant perennial biomass crops in the Mediterranean countries, especially reed canary and Switchgrass. A potentially increased

Table 6.1 Bioenergy potentials for EU-25, EU-15 and EU-8 in MtOE

Year	Total EU-15	Total EU-8	Ratio EU-15 : EU-8
2010	27.2	19.5	1.4 : 1
2020	59.8	36.0	1.7 : 1
2030	95.0	47.3	2.0 :1

Note: No data were available for Cyprus and Malta, but these countries are not expected to have any substantial bioenergy potential due to their high population density compared to UAA.

Source: EEA based on Wiegmann, K., Fritsche, U. & B. Elbersen: 'Environmentally compatible biomass potential from agriculture'. Consultancy report to the EEA, 2005.

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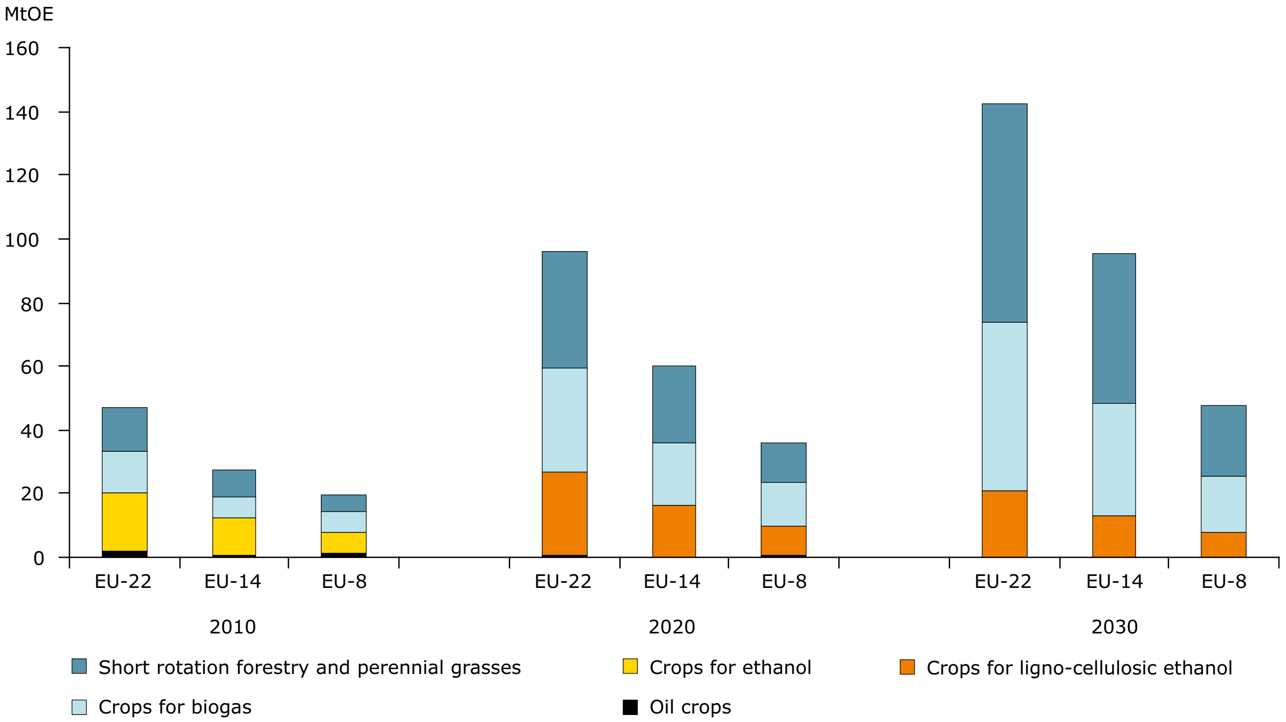
(33) A more detailed discussion on the biomass trade potential is given in Thrän, 2006.

Figure 6.1 Bioenergy potential of EU-23, EU-15 and EU-8



Note: No data were available for Cyprus and Malta. 'Oil crops' comprise rapeseed and sunflower. 'Crops for ethanol' include the potential of grains from maize, wheat, barley/triticale. 'Crops for lignocellulosic 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, Switchgrass and the grass cuttings from permanent grass land. '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.

Source: EEA based on Wiegmann, K., Fritsche, U. & B. Elbersen: 'Environmentally compatible biomass potential from agriculture'. Consultancy report to the EEA, 2005.

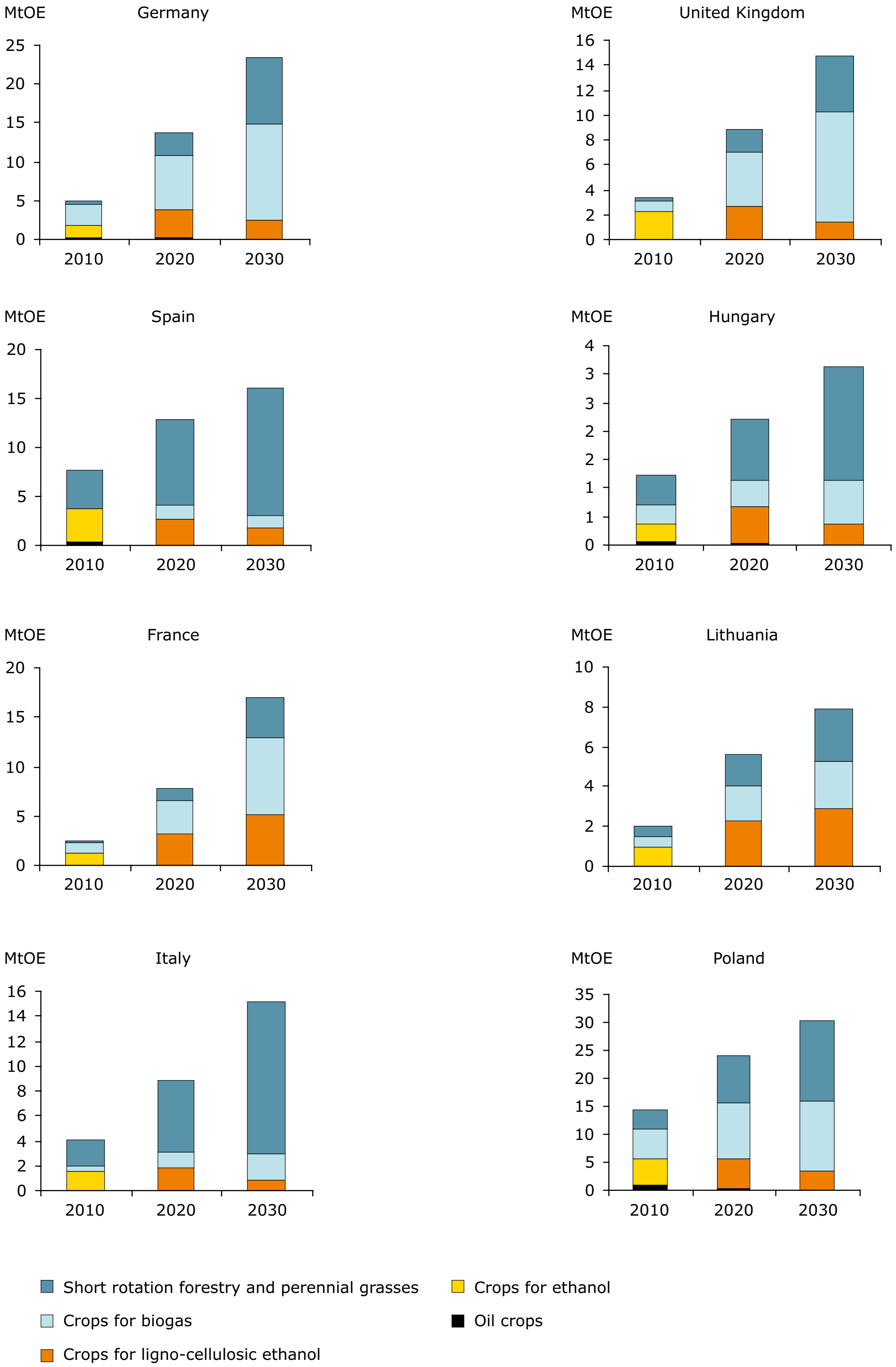
fire risk could be reduced by harvesting the crops before the main summer heat. Furthermore, it can be assumed that most fires on agricultural land would be tackled early on, due to the economic value of the crop and early detection of any fires.

In this study crop mixes were specified at national level. No further assumptions were made about where biomass crops would be grown within a country. However, the overall underlying assumption in this study was that most energy crop production would be spread in a similar way over the countries as arable agriculture is presently divided over area. Apart from perennial cropping systems, bioenergy crops would 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 are grown on a range of high and low productive lands and that yields and income varies accordingly, as is already the case with feed and food products.

6.3 Results for energy potential per Member State

The environmentally-compatible bioenergy potential for selected Member States is presented in Figure 6.2 and for all Member States in Annex XII, Table XII-1. Approximately 85 % of this potential will be produced in only seven Member States (Spain, France, Germany, Italy, The United Kingdom; Lithuania and Poland). Population size and density as well as economic competitiveness of the agricultural systems (measured in income per hectare) 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 although a substantial amount of land is released, this is permanent grassland which, according to the environmental criteria of this study,

Figure 6.2 Bioenergy potential for selected EU Member States



Source: EEA based on Wiegmann, K., Fritsche, U. & B. Elbersen: 'Environmentally compatible biomass potential from agriculture'. Consultancy report to the EEA, 2005. Figures for France and Germany are based on CAPSIM and HEKTOR; all others only on CAPSIM.

cannot be transformed into intensive bioenergy potential. This is the case for Ireland where the model predicts that all 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 would also be the Member States where increased global price competition leads to lower domestic food and feed production. Exceptions include Germany and France. Here, food production at world market prices is assumed to be possible. The rise in bioenergy production will therefore mainly be the result of the increased carbon permit price that would make biomass production more attractive. The exceptions in the increasing bioenergy potential trend are Denmark and Finland. Both countries show a decline, probably related to the expectation that both countries are becoming more competitive on the feed and food markets.

Additional factors which increase the bioenergy potential in most Member States are related to the growth in specific crop yields, and to the development of new technologies which make the production of bioenergy more efficient.

In Portugal, the explanation for the relatively small increase in potential lies in the small amount of land released from agriculture according to the CAPSIM model calculations, as food and feed demand for domestic purposes would still be growing strongly in this country through 2010 and 2020. Little or no arable land was therefore released from agriculture to be used for energy crops.

In Spain, Lithuania and Poland the growth in bioenergy potential starts to decrease from 2020 onwards, while in Hungary, The United Kingdom and Italy the increase is more or less linear between now and 2030.

6.4 Use of biomass from grassland and other extensive land use types

The use of grassland cuttings for energy purposes may be a good opportunity to conserve semi-natural grasslands from natural succession and therefore prevent the loss of species-rich open habitats. A high biodiversity loss is likely to occur if extensive olive groves or dehesas are converted into intensive arable production or no longer managed. For this reason, the study assumes that abandoned olive groves (and dehesas/montados) should be treated in the same way as permanent grassland. Their tree stock should be maintained and grass allowed to grow under or between the trees. Both grass cuttings and material from traditional tree pruning could be harvested as biomass feedstock for energy generation. In this section, the potential bioenergy contribution from these types of habitats is calculated.

In order to give an overview, the available land from former grassland, olive groves and dehesas/montados is considered as grassland. As no specifc information was available on the average quantity of wooden residues from olive groves and/or dehesas/montados, the biomass potential could only be calculated on the basis of average grassland yields for the relevant environmental zones.

Table 6.2 provides a potential that assumes a fermentation of grass cuttings, with the energy potential representing the lower heating value of the produced biogas. Specific grassland yields are taken from the modified CAPSIM model. In the calculation the yields do not increase over time, reflecting the fact that usually low productive grassland, olive groves and dehesas/montados would be abandoned.

Biogas from grass cuttings could contribute up to 6 % of the bioenergy potential in the EU-25. As the mobilisation potential for grass biomass (34) and the economy of this path are unknown at present, further detailed analysis is however needed.

Table 6.2 Bioenergy potential from fermentation of grass cuttings (lower heating value of biogas in MtOE) in EU-25 in comparison to bioenergy potential of total agricultural potential (based on CAPSIM data)

	2010	2020	2030
EU-25 grassland potential	2.0	5.9	8.4
EU-25 total agricultural potential	46.8	95.8	142.4
% grass of total	4 %	6 %	6 %

Source: EEA based on Wiegmann, K., Fritsche, U. & B. Elbersen: 'Environmentally compatible biomass potential from agriculture'. Consultancy report to the EEA, 2005.

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(34) The mobilisation rate depends on economic conditions, harvest and transport aspects such as options for mechanisation, distance to processing plants, or energy density per unit biomass.

7 Analysis of alternative assumptions and discussion of results

7.1 Sensitivity analysis and robustness of the approach

The land and bioenergy potential calculated in this report depends on numerous scenario assumptions. This section presents the results of a sensitivity analysis that investigated the effect of changing certain key parameters. These key parameters are the following:

1. share of environmentally orientated farming
2. higher fossil fuel prices and CO_2 allowances
3. yield increases.

Ad 1) In the environmentally compatible future of this study, the assumption is made that a significant part of the agricultural land area will be under environmentally orientated farm management. This includes three types of extensive farmland categories:

a. High Nature Value (HNV) farmland which would at least keep its present share of farmed area but may also increase;
b. Organic farming which would be the main growth factor for achieving a combined HNV-organic farmland share of 30 % of the UAA by 2030 in most Member States, with the exception of Belgium, the Netherlands, Luxembourg and Malta where this share only needs to reach 20 %;
c. Ecological compensation areas/set aside in intensively used farming areas; from 2010 onwards this category should reach a minimum of 3 % of the intensively used farmland and would serve as ecological 'stepping stones' to increase the survival and/or re-establishment of farmland species.

The implementation of these three elements of environmentally-orientated farming has a significant influence on the land potential for bioenergy by limiting productivity increases and therefore total agricultural production. This can be illustrated by comparing the results of the environmentally compatible future and a scenario where no increase of the environmentally orientated farmland share is assumed.

Ad 2) In the environmentally compatible future, the assumption is made that there is a financial reward for environmental services in the form of higher CO_2 allowance payments. In addition, it is assumed that prices for fossil energy are relatively high, giving biofuels a competitive advantage. These two assumptions are incorporated in the environmentally compatible future through the application of the HEKTOR model to France and Germany (for further details see Section 3.4). In the sensitivity analysis the combined effect of higher fossil fuel prices and CO_2 allowance payments is assessed by comparing it to results for the biomass potential under a scenario where no high energy prices and CO_2 allowance payments are assumed.

Ad 3) The calculation of the future biomass potential depends significantly on the assumptions made regarding the yield increase for different biomass crops. These consist of a 1 % yield increase per year for rotational arable biomass crops and of 1–2.5 % per year for dedicated biomass crops (e.g. perennial biomass grasses and SRC). The sensitivity analysis assesses what the effect of a lower yield increase would be on the available potential.

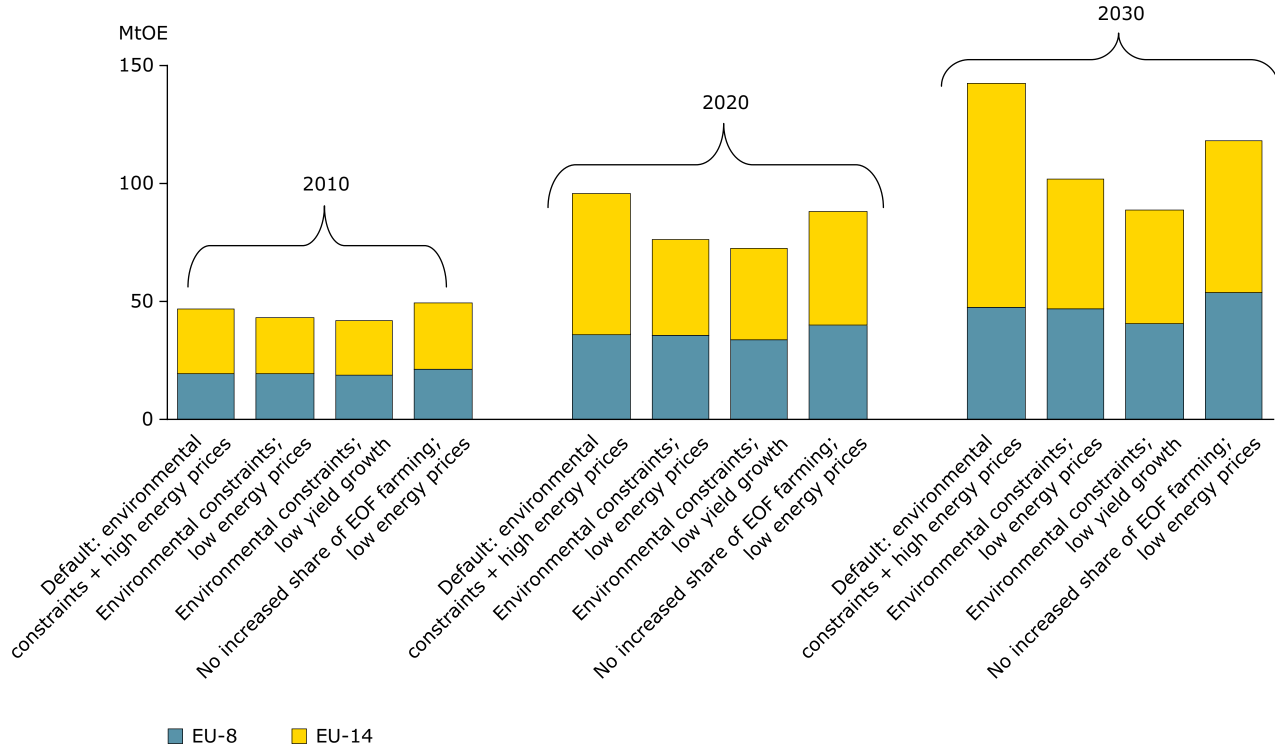
In order to show the effects of these three key parameters on the potentials, four different scenarios are used (see Table 7.1). The default in Table 7.1 is the scenario applied in this study to calculate the environmentally compatible biomass potential in this study. This is compared with three other scenarios which include different assumptions in relation to the three key model parameters, i.e. the environmentally orientated farmland share, the fossil prices and CO_2 allowance payments as well as yield increases.

Figure 7.1 shows the results of the comparison on the overall bioenergy potential in different scenarios. Higher prices for fossil energy and CO_2 allowances as well as yield assumptions had a stronger effect on the potential than the share of environmentally orientated farming. The higher fossil energy and CO_2 allowance price added an additional 5.0 million hectare of arable land by 2030 (modelled for France and Germany only) to the total EU-25 land

Table 7.1 Assumptions in alternative scenarios

Scenarios	Share of environmentally orientated farming	High fossil energy prices and payments for CO_2 allowances	Yield increases
Default	Increased future share	High prices + CO_2 payment	1–2.5 %
Environmental constraints + low energy prices	Increased future share	Low prices	1–2.5 %
Environmental constraints + low yield increase	Increased future share	High prices	1 %
No increased share of EOF farming + low energy prices	No increased future share	Low prices	1–2.5 %

Figure 7.1 Overall effect of different scenario assumptions



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

potential. In this study, the price for CO_2 allowances to come to the calculated potential of 159 MtOE in 2030 was assumed to amount to at least 30 % of the commodity price. Consequently, a lower CO_2 allowance price or a higher increase in world global food prices could lower the relative attractiveness of bioenergy crops. Furthermore, it would reduce the available land for bioenergy. The analysis shows that for reaching an environmentally compatible biomass production, a higher price needs to be paid. Thus, this price difference can be regarded as the price paid for the environmental constraints, which can be seen as a tool for internalising potential external environmental costs. Figure 7.1 shows that high energy prices lead to an increase of 29 % of the modelled potential compared to a scenario with low energy pricers. Due to resource constraints this analysis could not be updated according to recent food and fossil fuel price developments.

The assumptions concerning future yield increases also matter as a low yield increase of 1 % for *all* crops would reduce the bioenergy potential by 9 % in 2010, by 23 % in 2020 and by 38 % in 2030. The effect of a yield increase in the default scenario is heightened by the chosen crop mixes which change over time. While in the first decade arable crops would still dominate (only a 1 % yield increase was assumed), the balance shifts to perennial crops by 2030 (yield increases between 1-2.5 % were assumed, depending on the type of perennial).

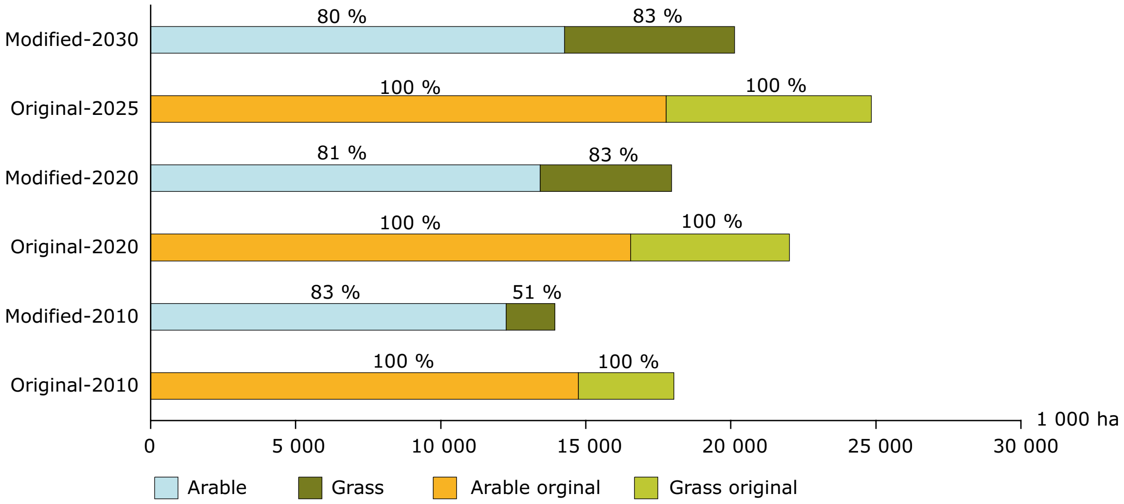
The implementation of elements of environmentally-orientated farming has a significant influence on the land potential for bioenergy. However, its effect on total potential is smaller than for the other two key parameters. To quantify the effect of the introduction of the high share of environmentally orientated farming on the total land potential for biomass production, the difference between the original CAPSIM-Animlib scenario and the environmentally compatible CAPSIM-Animlib scenario was calculated (see Section 3.2 for further details on these scenarios). These calculations show that the implementation of a minimum share of environmentally orientated farming has a significant influence on the land potential for bioenergy, as it reduces productivity and therefore total agricultural production. In 2020 the land potential in the environmentally-compatible scenario is approximately 81 % of the arable land potential that would be available without an increased share of environmentally orientated farming (see Figure 7.2). It should be noted, however, that new analysis on the distribution and character of high nature value farmland in Europe (JRC and EEA, forthcoming) shows that the share of arable land in this farmland category is much smaller than assumed for this study, especially in northern and eastern Europe. This could not be taken into account for the sensitivity analysis in this report but is likely to reduce the impact of the 30 % share of EOF farmland on the total estimated bioenergy potential.

Analysis of the combined effects of the key factors in the scenarios at national level indicates that most EU Member States will release agricultural land in the future. This is a consequence of both market liberalisation (modelled in the CAPSIM animlib scenario) and yield increases. Nevertheless, the effects of market liberalisation may not lead to released land in those countries with a competitive agricultural sector, such as The Netherlands, France and Germany, which show high *export* rates for some agricultural products. However, if competition from bioenergy markets is assumed due to high prices for both fossil energy and CO_2 allowances, a larger amount of land would be used for bioenergy at the expense of land used for exports of food/feed crops. The impact of this assumed competition increases the land availability for biomass crops in France and Germany by 0.4 million hectares in 2010, rising to 4.8 million hectares in 2030. This is equivalent to an extra 4 and 41 MtOE of bioenergy in 2010 and 2030, respectively.

Other factors influencing the modelling results:

A range of additional factors influence the modelling results, but cannot be subjected to sensitivity analysis as relevant data or modelling approaches

Figure 7.2 **Effect of an increased future share of environmentally orientated farming (including 30 % of environmentally orientated farming and 3 % set aside/ecological compensation areas in intensive arable areas) on total land potential for biomass production**



Note: The 'original' crop and grass area figures are equivalent to the original 2025 CAPSIM Animlib calculations (see also Section 3.2.1).

Source: EEA based on Wiegmann, K., Fritsche, U. & B. Elbersen: 'Environmentally compatible biomass potential from agriculture'. Consultancy report to the EEA, 2005.

are not available. Firstly, in many parts of the EU, especially the new Member States and the Mediterranean, there are significant areas of land no longer being used for agriculture and therefore no longer incorporated into agricultural statistics. This was not taken into account in the study, as the analysis was restricted to the statistically recorded utilised agricultural area (UAA). However, it is well known that in the new Member States the area of land that can potentially be used for arable agriculture was not fully recorded as UAA in 2000 (DG Agriculture, 2002). This implies that the land availability for bioenergy production assessed in this study may have been under-estimated. An additional, more detailed analysis should examine the amount and nature of this non-utilised land.

Secondly, the necessary expert element in the choice of final crop mix per Member State introduces some additional uncertainty in the calculation of final potential bioenergy yield. Different crop choices and bioenergy pathways would most likely have resulted in a different final bioenergy potential. However, this is not deemed to matter much in the light of the other uncertainty factors considered above and could not be investigated with the available resources.

Thirdly, the assessment of the environmentally-compatible crop mixes or nature conservation aspects should take local circumstances into account, as these determine the actual environmental impact of different crops. In this study crop mixes were only specified at national level and no further assumptions were made about the location of bioenergy crops within the Member State. A thorough application of the environmental constraints introduced in this study would require their adaptation to local environmental conditions. Again the precise effect of such additional differentiation is difficult to assess and would have required more resources than were available.

7.2 Overall effect and comparison with other potential studies

To compare the overall results with other studies, the land potential is chosen as a starting point. Most of the reference studies calculate the bioenergy potential assuming higher prices for energy and CO_2 allowances, and consider competition with exports of feed and food.

Table 7.2 shows the results of the comparison with the studies. Land potentials range from 20 to 59 million hectare, and the land potential estimated in this study (20 million hectare) is the lowest. However, two other studies which also incorporated environmental considerations (Thrän *et al.*, 2006; WBGU, 2004) show similar though somewhat higher land potentials (22 and 29 million hectare, respectively).

The comparison with other studies shows that the HEKTOR model application is only one of several which apply a bottom-up approach. However, the HEKTOR approach explicitly assumes that domestic food and feed demands in all Member States are fulfilled while direct and indirect export subsidies are gradually phased out. Overall, bottom-up analysis delivers more transparent results for assessing environmentally-oriented potentials.

The results of this study give the lower end estimates of environmentally-orientated bioenergy potentials within the EU-25. This seems to be caused by the fact that other studies are generally more optimistic about land availability and the yield potentials for biomass crop production. In addition, the assumption of a 30 % share for environmentally

Table 7.2 Studies concerning land potential for energy crops in the EU

Authors	Potential	Time horizon
Faaij, 1997	40 mio ha in EU-15	2010 onwards, food and fibre first
VIEWLS, 2004	35–44 mio ha in EU-10	2020; food and fibre first
WBGU, 2004	22 mio ha in EU-25	ecological constraints (fallow/released land)
Yamamoto, 2001	30 mio ha in Europe	By 2025, food and fibre first
Thrän *et al.*, 2006	59 mio ha in EU-25	2020 bottom up
Thrän *et al.*, 2006	29 mio ha in EU-25	2020 bottom up + ecological constraints: lower yields and nature conservation
This study	**20 mio ha in EU-25**	**2030 bottom up + environmental constraints**

8 How to realise an 'environmentally compatible' bioenergy future?

8.1 Introduction

The analysis presented in this report has shown that there is a large potential for bioenergy production from agricultural biomass. Due to strong political support, the production of biofuels from agricultural biomass, in particular, has been increasing very rapidly in recent years (see Section 2.2). There are serious concerns, however, that large-scale bioenergy production from agricultural biomass could lead to additional pressure on the environment and farmland biodiversity (e.g. BirdLife, 2006). Forecasts for mineral fertiliser consumption to 2016 predict that increased biomass production for energy purposes will lead to an increase in nitrogen fertiliser consumption for the first time in ten years (EFMA, 2006). This report has investigated ways of ensuring that even strongly increased biomass production remains 'environmentally compatible'. For this purpose a set of environmental constraints was developed and is described in Section 2.2 and Chapter 4.

This chapter discusses the key components that underlie the 'environmentally compatible bioenergy future' developed in the report. It analyses how likely their implementation is and gives further insight into the logic of the environmentally compatible bioenergy scenario. Section 8.3 provides examples for environmentally-orientated bioenergy production. Given the resource constraints faced in this study the analysis presented is not exhaustive and should ideally be followed up with more detailed studies.

8.2 Key factors for an environmentally compatible bioenergy production

Applying the environmental framework conditions developed in this study would support environmentally compatible biomass production in agriculture. However, most of the environmental conditions proposed are not directly addressed by current bioenergy policies. So how realistic is it that they can be achieved? How can they be implemented? This section reviews the logic and likelihood of five key environmental framework conditions proposed in the study. The related potential policy measures and research activities are discussed in Chapter 9.

1) *Maintain or reach a 30 % share of 'environmentally orientated' farming*

Achieving a 30 % share of 'environmentally orientated' farming (EOF) by 2030 in most Member States (20 % for Belgium, Netherlands, Luxembourg and Malta) seems ambitious. However, this includes both organic farming and HNV farmland, and many countries are currently not far off this target. Most Member States in the Mediterranean as well as Austria, Ireland, the United Kingdom, Estonia, Latvia, Slovakia and Slovenia already have a share well above 20 % and some even above 30 % (see Section 3.2.1). Other Member States, e.g. Belgium, Denmark, Luxembourg and The Netherlands, have not reached a share of 10 % of 'environmentally orientated' farmland on the basis of data available at the time of analysis.

For those countries that already hold a high share of HNV farmland, the main policy focus should be on maintaining this share. Further increasing this share to the required 30 % of the UAA can either be achieved by bringing back recently abandoned HNV farmland areas into agricultural management or by increasing the share of organic farming.

Countries with a very low share of HNV farmland will have difficulties following a strategy to restore HNV farmland. Most HNV farmland is based on traditional forms of extensive farming practices adapted to the natural constraints. Nature values occurring within these systems are intimately connected to traditional extensive practices. If these practices disappear because of intensification (including land improvements to remove natural constraints) and land abandonment, the nature values disappear. In most instances it is almost impossible to bring back such extensive traditional practices and the nature values connected to them. In these cases it would then be a better option to stimulate the shift of conventional farming to organic farming. Ambitious policy targets for organic farming have been set in many Member States that currently do not have a 30 % (or 20 %) share of environmentally orientated farming (EEA, 2006a).

2) *Set aside 3 % of intensively used farmland as ecological compensation areas by 2030*

Reaching European biodiversity objectives on farmland not only requires measures to preserve areas and farming systems of special nature value but also action in intensive farming areas. For example, a study by Vickery *et al.* (2004) shows that declines in farmland bird populations in the United Kingdom are related to the quantity and quality of habitats available, especially in intensive agricultural landscapes. Vickery shows that the creation of non-cropped habitats and field margins as well as so called 'arable pockets' in grassland regions and 'grassland pockets' in arable regions could be effective measures for supporting bird biodiversity. The importance of maintaining a network of habitats in the wider landscape is confirmed by a range of studies, such as by Vos *et al.* (2001); Bouwman *et al.* (2002), and Opdam *et al.* (2003). Overall, re-creating 'stepping stones' in intensive farming areas will support species adapted to arable landscapes and help to maintain connections between elements of European ecological networks, such as the Natura 2000 conservation sites.

A share of 3 % set aside/ecological compensation areas appears feasible given the past extent of set aside linked to CAP market measures and the need to reach EU biodiversity objectives in the wider countryside. In fact, other studies suggest a share of 5 % ecological compensation areas for achieving EU commitments under the Convention on Biological Diversity (McCracken, 2007). In addition, less productive field margins would be particularly suitable as ecological compensation areas. Furthermore, it would be possible to combine conservation objectives with a certain removal of biomass from such areas (as grassland cut in late summer or autumn, or via the removal of woody material to retain early successional stages). Given the likely advances in the development of second generation biofuel technology, such areas could therefore even make a contribution, albeit somewhat limited, to bioenergy production.

3) *Maintain extensive land use categories in their current land cover*

Permanent grasslands, olive groves and dehesas/montados make up an important part of the most biodiversity rich farmland in Europe and are of High Nature Value in practically all cases. Leaving permanent grassland unploughed is a realistic assumption, as maintaining permanent grasslands is already part of the Cross Compliance statutory requirements (within a 10 % limit per Member State). The high potential CO_2 release from ploughing up permanent grassland (or eliminating agro-forestry land cover) also requires the maintenance of extensive land use categories from a climate change perspective (e.g. JEC, 2006). Furthermore, permanent grassland areas are often not found on soils that are very well suited for arable agriculture, so ploughing these up for rotational arable biomass cropping would not always be possible or would require enormous land improvement measures. The use of such land for ligno-cellulose crops would be feasible as these generally grow well on sub-optimal soils as long as mechanisation for establishment of the plantation is possible and sufficient water is available. However, this should generally be avoided, so as to maintain the environmental quality of these land use types.

The future agricultural land use of olive groves and dehesas/montados is more difficult to predict. Although over the last decades parts of these systems were converted to (irrigated) arable land, this development now appears to have slowed down. In spite of a strong demand for olive oil only intensive olive production systems may prove financially attractive in the future. The economic future of dehsa/montado systems appears more uncertain and a loss of these habitats because of increased pressure on the land from increased biomass demand seems a real possibility. Consequently, support for these land use types through appropriate policy measures would be an important factor. Nevertheless, dehesas/montados need to be maintained in order to achieve the 30 % share of EOF, which is part of the environmentally compatible bioenergy scenario developed in this report.

4) *Choose environmentally optimal crop mixes and cropping practices*

A careful selection of biomass crops was seen as one of the main instruments needed to enhance the environmentally compatible incorporation of biomass crops in Europe. The future crop mix is expected to change, as a higher share of targeted biomass crops including more perennials is used and specialised cropping systems are introduced. The method in this study uses implicit regionalisation and differentiation concerning:

a. perennials (short rotation coppice and perennial grasses);
b. traditional arable crops (cereals, oil crops and root crops as well as fruit and whole crop use);
c. a special cropping system, the double cropping system.

The choice of these three cropping 'lines' was based on the currently available expert knowledge on bioenergy production systems. The prioritisation of crops for an environmentally compatible mix by environmental zone should be considered as a first approximation. This approach can certainly be further improved by involving more expert knowledge, field-based experience and specialised local knowledge.

From an environmental perspective, it can be concluded that perennial biomass crops generally exert less environmental pressures than arable crops. Moreover, they may even provide benefits to farmland biodiversity in intensively farmed regions under appropriate management practices. Secondly, perennial biomass crops deliver relatively high energy yields (joules per hectare). Thirdly, bioenergy products based on ligno-cellulose feedstock have a higher net CO_2 emission reduction capacity compared to fossil alternatives than rotational arable crop-based pathways and would benefit particularly from the introduction of a carbon credit market. Not surprisingly, therefore, the crop mixes specified per environmental zone show that in all zones perennial crops are most attractive from an environmental and economic perspective as soon as second generation biofuel applications become economically viable, which is expected at least by 2020.

In the ***Atlantic, Lusitanian, Continental and Pannonian environmental zones*** the choice of environmentally compatible perennial and rotational arable biomass crops is greatest. These zones also coincide with those regions that would deliver the largest contribution to the biomass potential for Europe. Environmentally suitable perennials for these zones include Miscanthus, Switchgrass, SRC willow and poplar, Reed canary grass and Giant reed. The use of grass cuttings from abandoned grasslands could also be considered as a perennial source of biomass and would provide a synergy relationship with nature management for maintaining farmland biodiversity. For arable biomass crops the highest priority from an environmental perspective is on hemp, mustard seed, clover-alfalfa, linseed, sunflower and cereal mixes (but not wheat). However, from an economic perspective and also from the perspective of their CO_2 reduction capacity, these crops do not perform very well. Higher yielding crops with a medium environmental impact such as oilseed rape, wheat, maize and sorghum are therefore preferred, provided their environmental performance is improved through the application of innovative farming practices, such as double cropping, mixed cropping and mulch systems. In a search for compromise between environment and economy, the eventual arable crop mix for these zones by 2030 therefore builds on oilseed rape, sunflower, maize, wheat, mixed cereals of barley and triticale and sorghum (NB: the latter is only grown in the Lusitanian and Pannonian zones). All these crops should be cultivated under innovative environmentally-friendly farming practices where possible.

In the more northern ***Boreal and Nemoral zones***, the number of suitable perennials is limited to Reed canary grass and SRC willow, whereas the most environmentally suitable arable crops are linseed and different cereals (not wheat). Double cropping systems are not suited for these zones because of the short growing season. If economic considerations are also taken into account, only different types of cereals (oats, barley, rye, triticale) would be suitable for arable biomass crops in these zones. Consequently, biomass cropping possibilities for these northern zones are limited. However, large forest production in this region makes it much more feasible to develop bioenergy applications using wood and wood by-products as feedstock and further invest in some targeted biomass production with SRC willow plantations, whether combined with waste water treatment or not.

In the ***Mediterranean and the Pannonian zone***, the environmental evaluation leads to arable crops with a relatively low water requirement and high water use efficiency (WUE). These would include cereals (excluding wheat), clover-alfalfa mixes, and sorghum. There are also some limited (but as yet largely untested) possibilities for perennials such as Miscanthus, Switchgrass and Giant reed. However, a clear choice for an environmentally compatible crop mix for the Mediterranean, even when applying innovative farming practices, was not possible from the present choice of conventional arable biomass crops. Conventional arable crops generally need irrigation to reach high enough yields while any additional demand for irrigation water would cause further pressure on the already scarce water resources of the Mediterranean.

Two major conclusions were drawn for this region: Firstly, environmentally compatible bioenergy production can only be reached if biomass feedstocks from crops are combined with by-products and the use of biomass residues from forests and abandoned shrub lands. The use of residues, including grassland cuttings, may also help to prevent forest fires, and enhance biodiversity in abandoned lands. Secondly, for the identification of best 'environmentally compatible' biomass crop mixes for the Mediterranean considerable research and field trials are still required with novel crops. Several novel crops for this arid region have already been identified. Besides Miscanthus, switchgrass and Giant reed, they include Jerusalem Artichoke, *Brassica carinata*, *Cynara cardunculus*, and Prickly pear. However, there is very little experience with growing them in Europe and converting them into energy products. Therefore, a good assessment of their agri-environmental performance and yield capacity is not yet possible (see also JRC & EEA, 2006).

6) ***Develop advanced biomass conversion technologies and bioenergy pathways***

Several factors would drive the development of biomass conversion technologies and bioenergy pathways. Firstly, EU policy targets for biofuel production from biomass are likely to ensure that in the short to medium term (until 2020) most biomass potential will be used for the production of transport fuels. During this period biomass for electricity generation and heating purposes will largely be delivered by forestry residues and the waste sector (incl. residues from agriculture). Secondly, gasification and second-generation biofuel technologies will become attractive from 2010 onwards. This will temper the demand for oil, starch and sugar feedstock (delivered by arable crops) and push the demand for ligno-cellulose biomass away from perennials. Therefore, it is logical to assume that from 2010 onwards land use will start to shift towards a higher share of perennials. Thirdly, from 2010 onwards biogas is assumed to become widely implemented and used in conventional cogeneration systems. For this reason, biogas crops, including those grown in double-cropping faming practices delivering the whole crop as biomass, obtain a more prominent position in the optimal crop mix.

The assumed shifts in crop mixes as well as biomass conversion technologies and bioenergy pathways are quite ambitious. However, much higher efficiency of second generation technology coupled with the need to greatly reduce greenhouse gas emissions and to use the capital invested in bioenergy production efficiently are likely to drive this process quite strongly. Model calculations of the greenhouse gas emissions of different bioenergy pathways and the relative costs of CO_2 avoidance using different technological approaches show the strength of the logic to go beyond first generation approaches and the focus on transport biofuels (EEA, forthcoming). This is likely to be further incentivised by the foreseen introduction of tradeable carbon permits; these would also affect the bioenergy sector.

8.3 Practical examples of environmentally compatible bioenergy cropping systems

Most parts of this report describe the model assumptions and results of an assumed environmentally compatible bioenergy production. This section gives practical examples of environmentally beneficial approaches, either based on practical experience or scientific knowledge. Three main approaches to gaining maximum environmental benefit from bioenergy cropping are reviewed:

a) combining biomass production with waste water treatment approaches;
b) developing synergies with nature conservation via the use of grass biomass;

Box 8.1 Willow plantations for waste water treatment (35)

If located, designed and managed wisely, energy crop plantations can, besides producing renewable energy, also generate local environmental benefits. Examples are willow plantations leading to soil carbon accumulation, increased soil fertility, reduced nutrient leaching and erosion, removal of cadmium from the soil, etc. Another opportunity is to use willow plantations as vegetation filters for the treatment of nutrient-rich, polluted water, such as municipal wastewater and drainage water. The purification efficiency of willow vegetation filters has been demonstrated in several countries, e.g. Sweden, Poland, Denmark, and Estonia, since the beginning of the 1990s.

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(35) Information supplied by: Pål Börjesson; Environmental and Energy Systems Studies, Department of Technology and Society, Lund University, Gerdagatan 13, SE-223 62 Lund, Sweden; E-mail: Pal.Borjesson@miljo.lth.se.

Box 8.1 Willow plantations for waste water treatment — contd.

The average nutrient content in municipal wastewater normally corresponds fairly well to the nutrient requirements in willow cultivation. An annual municipal wastewater load of 600 mm equivalent, containing about 100 kg N, 20 kg P, and 65 kg K, will supply not only the required water, but also the requirements of N and other macro-nutrients. The wastewater is pumped to the willow vegetation filter or to the storage ponds in the winter, so that the nutrient is recirculated to the willow plantation. The root systems will then take up 75-95 % of the nitrogen (N) and phosphorus (P) in the wastewater. The generation of sewage sludge will also be significantly reduced when willow vegetation filters are used, by up to 80 %.

Water deficiency is often a growth-limiting factor in willow cultivation, even in countries with significant precipitation throughout the year. The regional variation in biomass yields can be significant due to differences in water availability during the vegetation period. Thus, the biomass yield response to wastewater irrigation will be more significant in regions with relatively low precipitation during the vegetation period. In Sweden, for example, the biomass yield can increase by 4 to 8 tonnes dry matter per hectare per year, or 30 to 100 percent compared to average yields for well-managed, rain-fed willow plantations on good soils.

Willow vegetation filters are attractive from an economic point of view. This is due to reduced willow cultivation costs and also to the fact that willow vegetation filters provide a treatment option that is lower in cost than conventional treatment at sewage plants. The nitrogen treatment cost could be 3 to 6 lower per kg N in vegetation filters, compared to treatment in conventional sewage plants, where the nitrogen treatment cost normally amount to approximately EUR 10 per kg N. The cultivation cost could be reduced by EUR 1.2 to 1.8 per GJ biomass, due to reduced costs of fertilisation and increased biomass yields. This reduction is equivalent to 30–50 % of the cultivation cost in conventional plantations.

Despite the various benefits of willow vegetation filters, several potential barriers exist against their large-scale implementation. Some of these are due to lack of knowledge, such as regarding the risk of the spread of pathogens. Others concern the allocation of benefits and risks among the actors involved. Such defective allocation could be overcome by developing mutual agreements between the sewage plant operator, the energy plant operator and the willow producer (farmer), which have been put in place for some cases in Sweden.

Biodiversity is estimated to slightly increase in open farmland when willow replaces annual food crops. For example, the diversity and occurrence of soil fauna, especially decomposers, will increase, as will the number of bird species and larger mammals. However, over larger areas, such as regions including a variety of landscape types, the total diversity is unlikely to change much, as the insects, mammals etc. that exist in willow plantations are normally common in biotopes outside agricultural areas.

Related publications:

Börjesson P, Berndes G. The prospects for willow plantations for wastewater treatment in Sweden. Paper accepted for publication in Biomass and Bioenergy, 2005.

Hasselgren K. Use of municipal waste products in energy forestry — Highlights from 15 years of experience. *Biomass and Bioenergy* 1998; 15: 71–74.

Aronsson P. Nitrogen retention in vegetation filters of short-rotation willow coppice. Doctoral thesis, Dept. of Short Rotation Forestry, Swedish University of Agricultural Sciences, Uppsala, Sweden, 2000.

c) innovative cropping systems that protect water and soil resources in arable bioenery crops.

Box 8.1 describes the multi-functional use of SRC willow plantations in combination with waste water treatment approaches. Such applications are particularly suited for areas with a good water supply in the Nemoral, Atlantic North, Atlantic Central, Continental and Alpine South zones.

Box 8.2 discusses the use of grassland cuttings for bioenergy generation. This is an interesting option for the many parts of Europe where the abandonment of semi-natural grasslands leads to a loss in biodiversity because of the disappearance of extensive grassland management practices.

Many farming systems in Europe are quite intensive and specialised. In such farming regions crop diversity could be increased by adding one or more novel biomass crops to the rotation. In addition, bioenergy crops may allow different management practices that could, for example, reduce input use or increase soil cover, thus reducing erosion risks. Box 8.3 provides four examples of innovative biomass cropping systems. These cannot always be

Box 8.2 Utilising cuttings from permanent (semi-natural) grasslands for bioenergy production

Most grassland in Europe depends on human management via grazing or hay-making. Extensive agricultural practices create particularly species-rich (semi-natural) grassland (see also Section 2.1). However, these are often not economically attractive in modern farming systems and hence abandoned. The abandonment of grazing or mowing on these grasslands may not only reduce species richness but could also lead to both increased fire hazards due to the accumulation of dry dense biomass and loss of landscape character because of the invasion by shrubs. As the removal of biomass through human intervention is an essential element in maintaining the diversity of the grassland systems, mechanical harvesting of biomass could replace traditional practices. In this concept natural diversity is maintained while producing biomass for heat, electricity and biofuels. The challenge is to design biomass production and processing chains that fit the requirements of maintaining high nature-value grasslands, while at the same time fulfilling the requirements of an efficient low cost biomass production and processing chain. However, new technologies and new biomass chains could allow the harvesting of significant amounts of biomass feedstock from nature-rich grasslands while at the same time maintaining their diversity.

From a nature management perspective, biomass production systems on high nature value grasslands should avoid causing damage to the habitat from, for example, the use of heavy machinery, disturbance of desired species (e.g. by destroying birds nests), monotisation of grassland structure or the elimination of landscape elements. The biomass harvest/management would need to fit into natural cycles (i.e. generally take place in late summer/early autumn) and should leave the original nutrient and water table status in place.

From the perspective of efficient biomass production, requirements will include low nutrient and ash content, year-round availability, good biomass storability (i.e. low moisture content), and low transport cost (i.e. high bulk density). The biomass price that can be paid will depend of the efficiency with which biomass can be removed, transported, stored, pre-processed and converted into high added value (energy) products. Considerable research and practical experimentation is required to make this process efficient and adaptable for local conditions.

The above conditions for an efficient yet nature-friendly use of grassland biomass are not easily met. They may be most easily matched on larger-scale and productive grassland sites. However, there are numerous examples of species-rich and fairly productive grassland complexes that have gone, or are going, out of production for economic or social reasons, also within Natura 2000 sites (e.g. Rösch *et al.*, 2006; IEEP, 2007). Large-scale structural and economic change will affect dairy production in the Austrian Alps, for example, and lead to a surplus of grass biomass that cannot be used in traditional agricultural production (Pötsch, 2006).

Projects for biogas production from grass biomass are already implemented in a number of European regions at a scale that is economically efficient (e.g. Pötsch, 2006; Erdmanski-Sasse, 2007). Several research projects look into options for the energetic use of grass biomass from semi-natural grasslands. These aim to combine the objective of nature management with the utilisation of biomass for energy at both the theoretical and practical level. A wide variety of options are available for utilising this biomass for energy and other products. These options include several thermal conversion options like gasification, pyrolysis, hyro-thermal-upgrading (HTU) or biogas production (DVL/NABU, 2007).

Another option is the biorefinery concept which can generate a variety of products, including transportation fuels. In Switzerland, the Netherlands, Germany and Denmark biorefinery systems have been or are being developed that produce several products from grass and similar biomass. Typical products from grass include: (1) fibres, which are used for materials or thermal conversion for heat and electricity; (2) proteins, which have applications in animal feed; (3) sugars, which are converted to bio-ethanol, and (4) mineral concentrates, which can be used as fertilizer.

Box 8.3 Examples of innovative biomass production systems

1) Mulch systems – minimum or no till systems
The key factor in this system is that tillage is not applied at all or reduced to a minimum. The main result of this practice is total or near to total soil coverage all year round. This type of system is particularly well suited to biomass production where the quantity and/or the starch of the crop are more important than the quality. If crops are grown for biomass, especially for biogass or ligno-cellulose applications, the main harvested product should be (dry) biomass. Whether this biomass has a uniform composition is not so important, so the resulting 'contamination' of the harvested crop with herbs and grasses is not a problem.

The main environmental gain compared to conventional rotational arable cropping systems is that it increases the soil organic matter content and the water holding capacity, as year round soil coverage and very limited mechanisation means it reduces soil erosion. If used for biomass production the requirement for pesticides and herbicide use will also be very low, as weeds constitute biomass too. Mulch practices would be particularly advantageous in maize production and seem to be gaining ground in certain countries.

2) Double cropping
In agriculture double cropping is the practice of growing two or more crops in the same space during a single growing season. Double cropping is found in many agricultural traditions and has been adapted to modern farming systems in the last two decades, e.g. in Germany (Scheffer und Karpenstein-Machan, 2002; Heinz, 1999; Karpenstein-Machan, 1997). The system provides a number of environmental benefits e.g. by reducing nitrate leaching, and combining the production of high biomass quantities with a whole year green cover, limited input use and cultivation efforts. Both crops are harvested green to produce silage for biogas. The fundamental characteristics of double cropping systems are:

- reduced ploughing;
- near all-year round crop coverage;
- at least two crops and two harvests a year on the same field;
- green crop harvesting (for silage) reduces the growing period of one crop leaving time for production of an extra (biomass) crop;
- closed cycles of nutrients by using fermentation residues for bioenergy production (anaerobic fermentation);
- reduced herbicide application is possible because weeds can be used too;
- double cropping as arable can be integrated in the crop rotation;
- a positive effect on biodiversity can arise from of larger structural diversity in the fields (i.e. growing of numerous different crops, e.g. cereals, rapeseed, poppy seed, hemp, sunflower, alfalfa, maize);
- negative impacts on the environment can be caused by higher mechanisation intensity because of twice annual harvesting. This will often have negative effects on breeding birds and insects (DVL/NABU, 2007). It may also lead to increased soil compaction particularly after a late harvest of the second crop in autumn.
- minimum tillage before seeding of the second crop reduces mechanisation intensity but often requires herbicide application;
- the system is restricted to regions with enough water availability and a long enough growing season (e.g. Atlantic Central, Continental, Lusitanian and some selected places in Mediterranean Mountain zone).

Overall, more research on environmental effects and the practical applicability of double cropping systems in different regions of Europe are needed. This short introduction to the double cropping system illustrates the principle as it applies to energy crops, and the differences that distinguish it from traditional arable cropping.

3) Multiple cropping
To increase the efficiency of biomas cropping systems several researchers are looking into multiple cropping systems which involve the growing of two or three crops simultaneously on the same land; one being the main crop and the others the subsidiaries. The main biomass output produced in this system is either oil or starch.

Examples of crop mixes applied are:

- winter rye with winter peas or winter barley
- maize with sunflower or sorghum
- leindotter with peas or sunflower.

Box 8.3 Examples of innovative biomass production systems — contd.

A multiple cropping system has many advantages:

- a bigger mix of crops enhances crop diversity and structural diversity which enhances farmland biodiversity;
- if mixes include legumes for nitrogen fixation no or very low fertilizer inputs are required;
- crops have a higher stress tolerance and there is more yield security (although average yields are lower than in conventional arable cropping);
- there is a lower need for pesticides and herbicides inputs because there is lower pest pressure (no monoculture), better soil cover and lower crop quality levels need to be reached.

The introduction of mixed cropping systems would require further technical developments to support the seeding and harvesting of the multiple crops.

Good results were shown by Paulsen *et al.* (2003 and 2006) with a mix of Leindotter (*Camelina sativa*) as the main oil crop, peas and other crops. Research for mixed cropping is by now well established in different countries (Aufhammer, 1999; *Weik et al.,* 2002). Its practical application on the farm requires further testing and extension however.

4) Row, strip or alley cropping
In this system, perennial biomass crops (SRC or tall biomass grasses) are grown in linear strips in arable agricultural landscapes, e.g. around fields and along rivers and canals. They deliver ligno-cellulose material for different bioenergy purposes (e.g. gasification, bio-electricity, Fischer-Tropsch biofuels). The main environmental advantages of creating such strips is that they increase landscape diversity which will enhance biodiversity in farmlands, they help to prevent (wind) erosion and decrease nitrate leaching to surface waters. The prevention of wind erosion may also lead to crop yield increases. Research into these systems was carried out by the Agroscope (SAFE) project in the Swiss Federal Research Station for Agroecology and Agriculture. A specific application of this system suggested for the Mediterranean is creating strips of holm oak.

Further information can be found at: http://www.montpellier.inra.fr/safe/.

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Weik, L.; Kaul, H.-P.;Kübler, E. & Aufhammer W. (2002): Grain Yields of Perennial Grain Crops in Pure and Mixed Stands. Journal of Agronomy and Crop Science, Vol. 188, 342–349.

directly implemented in practice at the moment but do highlight which elements should be stimulated through policy incentives and research when providing support to 'environmentally compatible' biomass cropping. The practical implementation of environmentally-friendly arable biomass production systems is being investigated by a number of projects and organisations. Examples include the EVA project: http://www.energiepflanzen.info/cms35/EVA.1594.0.html and the North Sea Bioenergy Network: http://www.3-n.info/index.php?con_kat=81&con_art=430&con_lang=1).

9 Discussion of policy framework and outlook

9.1 Introduction

This report has developed an environmentally compatible scenario for bioenergy production from agricultural biomass in the EU-25. This shows that the agriculture sector can make a significant contribution to reaching EU renewable energy targets without compromising EU environmental objectives in the biodiversity (36) field for example. A key conclusion of the study is however 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. In fact, the environmental framework conditions developed in the report are unlikely to be realised without considerable efforts within bioenergy research, agriculture and energy policies at national and EU level as well as a positive response by energy producers and consumers.

Recent work and a workshop for the Federal Environmental Agency in Germany has shown that there is considerable concern about the implications of bioenergy production (including biogas) for water protection. This relates to the conversion of grassland or set-aside land to arable biomass crops, potential inappropriate application of biogas digestate on farmland and indirect environmental effects via land use intensification on arable and grassland (Osterburg and Nitsch , 2007) (37).

This chapter provides a brief evaluation of possible policy measures both within and outside the bioenergy sector that are relevant to meeting the environmental constraints set out in Chapter 2. Policy measures that are helpful to the achievement of the first three framework conditions are covered in Section 9.2. The next section discusses technological and policy measures that could support an environmentally compatible direction in agricultural bioenergy production. In addition, Section 9.4 reviews the need for further research in the areas covered by this study and highlights some issues that require scientific and policy attention.

9.2 Possible policy measures for maintaining environmentally orientated agriculture

Three framework conditions of the environmentally compatible scenario developed in this report mainly affect general agricultural production:

- the maintenance or expansion of 'environmentally orientated' farming systems to 30 % (or 20 %) of UAA per Member State (HNV farmland and organic farming);
- a ban on converting permanent grasslands, olive groves and dehesas/montados to arable crops; and
- the setting aside of 3 % of intensive farmland areas as 'ecological compensation area'.

A range of policy and market measures can be taken to make these environmental constraints a reality. These cannot be reviewed in full here but three approaches are mainly used (38):

a) the introduction of minimum environmental standards that farmers have to adhere to;
b) targeted support for specific environmental management requested from farmers; and
c) increasing the value added or market prices of agricultural outputs that derive from environmentally friendly farming approaches.

A key example for approach a) is the policy instrument of cross compliance (Regulation 1782/2003) that was made compulsory with the 2003 CAP reform. It already includes a standard

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(36) For relevant policy targets please consult: Community biodiversity strategy (COM (1998)42); Biodiversity Action Plan (BAP) for Agriculture (COM (2001)162 (03); EU Action plan for halting the loss of biodiversity (COM (2006)216).

(37) Further information and presentations from the workshop on 'The use of biomass for energy — new problems for water protection?' can be found on the following website (in German): http://www.umweltbundesamt.de/wasser-und-gewaesserschutz/index.htm.

(38) A fourth approach builds on the introduction of market-based instruments to better reflect environmental costs in the price of commodities. While favoured by economic theory, such instruments are currently hardly used in the agricultural domain at EU level or by Member States.

that limits the loss of permanent pastures (to a maximum of 10 %) and requires a certain minimum management of agricultural land. Similar to current set-aside policy, it would be possible to require a minimum percentage of 'ecological compensation areas' for certain or all types of farming. Secondly, one could also imagine translating the concept of Nitrate Vulnerable Zones to areas with a high proportion of HNV farmland. Such an approach could set limits to using certain intensive crops (possibly for biomass purposes) and inputs such as specific agro-chemical products or biogas digestate. In Nitrate Vulnerable Zones such limits are already applicable to nitrogen fertilisers and manure management. However, such measures only maintain the status quo and do not lead to active improvement or management. In addition, they are often difficult to implement, especially where no strong economic incentive is associated with the standard to be achieved.

Approach b) is the concept behind many of the rural development measures under the second pillar of the EU Common Agricultural Policy (CAP). Relevant measures with environmental objectives are agri-environment schemes, support for less favoured areas, support payments for environmental restrictions in areas designated as part of the Natura 2000 network, or support for environmental investments on farms. In this study it is not possible to review the potential and effectiveness of individual measures; relevant analysis can be found in EEA (2006a) or IEEP (2007). A key challenge for this type of approach is to ensure the effective targeting of individual measures to relevant areas or farming systems.

Organic farming is a key example for approach c) as organic farmers are compensated for lower yields due to environmental farm management by higher market prices for their products. However, the environmental benefits associated with high nature value farming systems tend not to be rewarded on the market, if such farms do not participate in specific quality marketing schemes (such as regional quality labels or indeed organic farming). Consequently, support for developing added value from the outputs of HNV farming systems could be a valuable tool, e.g. via diversification or marketing measures under EU rural development programmes. Finally, the success of a market approach depends to a large degree on consumer interest. Consequently, raising public awareness about the beneficial effects of environmentally orientated farming practices would be needed.

An important cross-cutting measure that supports all three approaches is the provision of appropriate training and advice for farmers, so as to enable them to improve the environmental quality of their farm management (39).

Overall, considerable progress has been made at EU level to develop policy instruments with the potential to meet environmental objectives and targets identified earlier in this report. However, the degree of agri-environmental policy implementation differs strongly in each Member State, and it is currently not clear, for example, to what extent these instruments really target organic farming and High Nature value farmland areas (EEA, 2006a).

A key component of effective policy implementation is the availability of appropriate spatial and environmental information, which can be used to tailor and target policy instruments on the farming systems and areas of highest environmental interest. Relevant work at EU level is being carried out by the EU Joint Research Centre (JRC) and the EEA to further improve the methodology for the mapping of HNV farmland (further information can be found at: http://eea.eionet.europa.eu/Public/irc/envirowindows/hnv/information.

Furthermore, DG Agriculture has published a study on the HNV farming and forestry systems indicator under the Common Monitoring and Evaluation Framework (40). This will help Member States to further identify and monitor trends inHNV farming systems with the view to evaluating the impact of rural development programmes on these systems. This type of detailed information will be an important further step for developing appropriate policy measures.

9.3 Supporting environmentally compatible bioenergy cropping practices

The environmentally compatible bioenergy potential modelled in this report depends not only on clear environmental constraints for general agricultural

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(39) For example, the EEA carried out the CIFAS study on behalf of the European Commission to help develop farm advisory systems for supporting environmental farm management in the context of environmental cross-compliance. Further information is available on the project website: http://ew.eea.europa.eu/cifas.

(40) The report can be found under: http://ec.europa.eu/agriculture/analysis/external/evaluation/index_en.htm.

Table 9.1 Possible policy measures to influence the environmental effect of bioenergy cropping

Measure	Advantages	Disadvantages	Implementation questions
1) Environmental certification of bioenergy production	Creates incentives for behavioural change Promotes an optimal use of resources	May not be easy to establish Criteria may be difficult to define Does not cover indirect land-use change	Voluntary or obligatory? What are the precise environmental baselines and standards? Are these just input and resource saving measures; or could they also prescribe crop mixes? Who organises and pays for controls?
2) Cross compliance standards for bioenergy crops	Uses existing instrument Could apply widely to farmers Already has environmental scope	Only enforces minimum standards Effectiveness uncertain where link to economic incentives does not exist	Existing legislation needs to be adapted and standards drawn up. Could this be linked to energy feed-in tariffs? Only to cover input use etc., or could they also proscribe certain crop rotations? What is the interaction with national legislation defining manure storage capacity etc.?
3) Area specific standards, e.g. limiting the use of certain crops in specific areas, or prescribing a minimum share of ecological compensation areas	Potentially a very direct and strong instrument Protects areas of high environmental interest Can introduce environmental elements in intensively farmed landscapes	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 and demonstration projects	Increases general awareness and goodwill of farmers Should improve input management efficiency Can lead to longer term behavioural change among farmers	Effect strongly depends on farmer uptake Implementation of advice or demonstration practices not ensured	Do we know enough on how to manage energy crops from an environmental perspective? How to ensure sufficient advisory capacity and outreach? Who and how to run demonstration farms and projects?
5) Favouring certain crop mixes via specific crop support	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 or carbon credits for specific conversion systems	Can encourage innovative, efficient 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? How to set the standards for the systems to be supported? Focus on biodiversity management, greenhouse gas balance or other factors?
7) Rural development measures for local 'crops to energy' networks; including LEADER approaches	Would ensure local sourcing Could benefit bioenergy heating and electricity 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 rural development programme menus? How to tackle the integrated aspect of such local systems?
8) Regional planning/ SWOT analysis/ Programmes of measures under the Water Framework Directive (WFD)	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 of decisions	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? What are the resources and legal options for implementing programmes of measures under the WFD?
9) Monitoring and evaluation	Increases knowledge about environmental effects of bioenergy crops Key to better policy (planning)	Potential impact only in the long term 'knowing' does not equal 'acting' Reluctance to spend money in this area	How to design these appropriately? Which budgetary resources? How to integrate into policy decisions?

land use but also on the fast introduction of advanced technologies, specific bioenergy crop mixes and efficient bioenergy pathways. This section reviews possible policy instruments and implementation options for promoting an environmentally compatible approach to bioenergy production in agriculture and suggests practical guidelines to achieve an environmentally friendly biomass crop production. The proposals presented here should be considered as a starting point only. Further work is required in this area, in particular with regard to the national or regional development of standards and policy measures.

Table 9.1 suggests a range of potential policy measures to minimise or improve the environmental effect of bioenergy cropping. Many of these are quite ambitious, whereas others are more conservative; all of them are developed from existing policy instruments. Their implementation would require a significant policy effort from EU to regional level. The table contains additional columns, therefore, with observations on advantages, disadvantages and implementation questions for each measure. No further detailed discussion is provided as the proposals are of exploratory nature only. However, the first four potential measures are particularly suited to 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.

Among the measures proposed, the development and implementation of an environmental certification scheme for bioenergy production is currently being undertaken at EU level. Box 9.1 summarises bioenergy land use and cropping issues that are discussed in this report and appear relevant to such a scheme. These cannot be regarded as concrete proposals for individual standards because that would require a higher level of detail, but they may provide useful check points in the development of certification rules. The development of such a scheme would require guidance at European level. It would ideally involve relevant national and regional authorities, stakeholders on the farming and environmental side as well as energy companies and consumer

Box 9.1 Land use and cropping practices of potential relevance to the certification of energy cropping systems

Potential negative impacts:

- Avoid converting low intensity farmland to biomass cropping (e.g. permanent and semi-natural grasslands, dehesas/montados, extensive olive groves etc.) if this requires the ploughing up and/or draining of such land. Cutting of grasslands or use of traditional tree prunings for biomass would however be an option for such land use systems.
- Do not introduce more intensive crops in the crop rotation: e.g. preference for perennial biomass crops (e.g. willow SRC and tall biomass grasses) above arable crops.
- Do not introduce biomass crops if this requires a relative increase (as compared to the present situation) in irrigation, pesticide and fertilizer inputs and mechanisation.
- Avoid changes to landscape structure, such as removal of hedges or field boundaries when introducing biomass crops.

Potential positive impacts:

- Try to introduce a mix of biomass crops in order to maintain and/or increase landscape diversity and prevent a further tightening of the crop rotation.
- Try to introduce innovative low input-high yielding farming practices such as mulch systems, double cropping, mixed cropping, strip cropping.
- Aim for reduction in mechanization intensity, such as less tillage and ploughing.
- Identify drought resistant-high yielding crops for arid zones that suit existing farming systems.
- Explore win-win solutions for biomass cropping in which biomass is produced while e.g. farmland biodiversity is enhanced, land use is extensified, environmental problems prevented (e.g. soil erosion and fire risk). This can involve currently non-productive land if the biomass use supports habitat management and avoids negative impacts.

groups, who would have significant influence on its successful implementation.

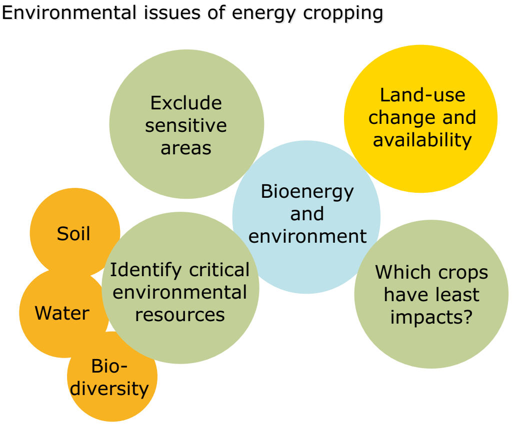
9.4 Conclusion and outlook

Increasing the share of renewable energy sources, including the production of bioenergy from agriculture, is an important policy objective for the European Union. Given the environmental pressures arising from current agricultural production, the development of bioenergy cropping systems and bioenergy pathways needs to proceed in a manner that takes account of the risks associated with large-scale bioenergy production. This is also recognised in the Biofuels Progress Report of the European Commission (SEC(2006)1721) which states that:

The greenhouse gas benefits of biofuel policy can be further increased, and environmental risks minimised, through a simple system of incentives/support that, for instance, discourages the conversion of land with high biodiversity value for the purpose of cultivating biofuel feedstocks; discourages the use of bad systems for biofuel production; and encourages the use of second-generation production processes. The system should be designed to avoid any discrimination between domestic production and imports and should not act as a barrier to trade. Its impacts should be assessed and its operation should be monitored with a view to making it more sophisticated in future.

This study has attempted to develop framework conditions and approaches that would make agricultural bioenergy production environmentally compatible. The resulting conceptual assessment framework is described in Figure 9.1.

Figure 9.1 Environmental assessment framework for estimating the environmentally compatible bioenergy potential



Energy production from agricultural biomass has implications for achieving policy objectives in three different policy areas: energy, agriculture and environment policy. It affects energy policy because it contributes to a higher share of renewable sources in total energy consumption, which improves overall security of supply. In addition, generating energy from biomass can lead to greenhouse gas savings over the lifecycle of different energy production processes.

Bioenergy is relevant to agriculture policy because:

- energy crops can be a new source of income for farmers;
- the reformed CAP aims for a diversified and environmentally friendly agriculture;
- the likelihood of competition between food and energy uses of agricultural output can lead to increasing food prices for consumers.

Lastly, bioenergy production also strongly affects environment policy, due to the reduction of greenhouse gas emissions, as well as its influence on the shape and intensity of major land uses in Europe (agriculture and forestry). Any resulting land-use change has a major impact on soil and water resources as well as biodiversity and landscapes.

The fact that bioenergy production has links to three different policy areas requires analysis of potential conflicts and synergies between different policy objectives that are affected by large-scale bioenergy cropping. Some of the different policy objectives can be reconciled, while for others trade-offs and priorities need to be accepted. The shape and scale of the bioenergy sector will crucially influence the potential for the integration of the three policy areas listed above. On the other hand, the need to find synergies between different policy areas in the EU should also inform policy making in each individual policy area, thereby guiding the development of bioenergy production in an environmental direction.

This report contributes an analysis of potential risks and synergies between biomass production and environmental objectives related to agricultural land use. It also reviews potential policy measures and energy cropping approaches that can support an environmentally compatible future of bioenergy production within the agricultural sector. However, complete analysis of relevant policy measures and their implementation is beyond the scope and remit of this study. Further work is required in a number of areas that will determine the environmental impact of bioenergy production in Europe and elsewhere. Some of these issues are briefly discussed below.

9.4.1 *Modelling the agricultural land potential within environmental constraints*

The estimates of land available for bioenergy cropping could be further improved by using additional scenario approaches and models. This could build on different and improved CAPSIM scenarios and adapt the HEKTOR scenarios and models to all EU Member States. In addition, the role of the conversion of land for non-agricultural use, including urbanisation and infrastructural development, as a factor diminishing the energy potential could be further investigated. More spatially explicit modelling is a key requirement in future approaches.

A further differentiation of the environmental constraints employed in this study may also be appropriate. Part of the released/available permanent grassland could be used for targeted (permanent) biomass crops. What are the implications for life-cycle greenhouse gas balances in such conversions given the high carbon loss when ploughing up grassland? If maintained in grass, how much biomass could be removed from it without damaging the ecological quality of the grassland habitats? What is the potential of woody biomass from other extensive land use categories, e.g. dehesas/montados?

Finally, a significant amount of land is abandoned (previously arable and extensive grasslands) and often no longer incorporated within agricultural statistics. This applies particularly to the new Member States. Practical approaches need to be developed to estimate the location, extent and quality in terms of suitability for biomass production and environmental sensitivity of this land in relevant Member States. Fallow land needs to be considered separately in this context, especially in the Iberian Peninsula, since the length and type of fallow is known to be of high importance for farmland biodiversity.

9.4.2 *Developing environmentally optimal energy cropping systems*

The prioritisation of crops for an environmentally compatible mix by environmental zone in this study is only a first approximation. This approach can certainly be further improved, involving more expert knowledge, field-based experience and taking into account specific local circumstances. Research on alternative farming practices, new crop mixes and farming systems involving feed/food and biomass production in one rotation is also needed. The double cropping and mixed cropping practices are just one new development. Although promising, they still require much more practical investigation, including field trials in different locations around Europe. Such research needs to take into account energy yields, environmental considerations and the potential effect of future climate change.

For southern Europe research is needed to identify new, suitable biomass crop mixes and farming practices, in particular for arid regions. To date, only a limited range of options for suitable crops appears to be available in these regions. Arable biomass crops may increase water abstraction which is undesirable in regions where water is already the main agronomic constraint. Most current perennial biomass crops are either not suited to biomass production in particularly arid summers, and can bring a certain increase in fire risk.

9.4.3 *Optimisation of biomass conversion pathways*

A holistic environmental assessment of energy cropping systems should not only include the environmental impacts of agricultural practices but also involve the bioenergy conversion chain, and its greenhouse gas and energy efficiency. Two key criteria that need to be translated into decisions at energy crop level are an efficient greenhouse gas (GHG) balance and the creation of optimal recycle paths in all steps of the chain. Further research is needed into recycle path options in the full biomass conversion to energy conversion pathways which can be used to improve the sustainability of biomass cropping systems. Examples include the use of ash remaining in conversion plants as fertiliser to maintain soil fertility or the use of by-products from bio-ethanol plants, DDGS (Dried Distillers Grains) as feedstuff.

9.4.4 *Considering the global dimension*

The sustainable biomass potentials for Europe need to be placed in a wider global context, including both agricultural and energy markets. Imports of both biomass and bioenergy from outside the EU are already a reality. Various studies show an extreme range of global bioenergy potentials ranging from 10 000 to 160 000 PJ/year (Thrän *et al.*, 2006; VIEWLS, 2004;

Yamamoto, 2001; Fischer and Schrattenholzer (2000); Hoogwijk (2003); Berndes, G. *et al.*, 2003). In most of these studies, the potential in South America and Africa is much higher than their own current primary energy demand. Given this, it is clear that environmental criteria for biomass do not only apply to EU-produced feedstock but also to imported biomass and bio-energy products. The agricultural development of (virgin) land, the clearing of (tropical) forests, potential monocultures, effects of pesticide and fertiliser inputs, mitigation effects (Life Cycle assessments) and effects on local employment are all aspects that need to be critically considered with regard to both domestically produced and imported biomass/bio-energy. In the international context it would also be important to investigate cropping approaches and bioenergy pathways that combine environmentally sustainable land use with high greenhouse gas savings and energy yields (see for example Tilman *et al.*, 2006).

In addition, bioenergy production will not only have impacts through direct cultivation of energy crops but also via direct and indirect competition with food and feed production (e.g. von Lampe, 2006; OECD/FAO, 2007). A sustainability assessment of bioenergy pathways should therefore also involve analysis of the influence of biomass demand and supply on global agricultural markets and land-use trends (e.g. Bringezu *et al.*, 2007). This would require a cross-sectoral approach in which food, feed and bioenergy markets are coupled, and which takes into account the influence of increases in energy and CO_2 allowance prices.

9.4.5 *Developing an effective policy framework*

The quote from the EU biofuels progress report at the beginning of his section shows that policy-makers are aware of the need to guide the development of bioenergy production in an environmentally compatible direction. A range of measures is available for that purpose in the EU, see also the review in Section 9.2. Nearly all the potential policy instruments listed in Table 9.1 build on examples in other policy areas, in particular EU agri-environment and rural development policy. It appears worthwhile, therefore, to analyse the experience with similar policy instruments in these two policy domains in order to get a better understanding of the likely success and the resource requirements of different policy options in the bioenergy domain. This could help to target policy effort and implementation on measures that are likely to be effective in tackling the issues they are meant to address.

The design and implementation of environmental certification schemes for bioenergy production currently receives considerable political interest. Certification approaches seem particularly important in dealing with the sustainability aspects of biomass and biofuel imports. They can be very effective in building up a market for environmentally orientated production, as the example of organic farming in the EU shows. They face a difficult challenge, however, in a situation where additional (biomass) demand leads to indirect land-use change.

Many policy instruments need cooperation between policy-makers, consumers and producers to succeed. In the bioenergy context cooperation also needs to work between three policy areas: energy, agriculture and environment. This is probably the single most crucial aspect for the further development of EU energy production from agricultural biomass in an environmental perspective. It is essential for biofuel production to 'promote environmental sustainability and combating climate change' as specified in the Presidency conclusions of the European Council of 8/9 March 2007 (41).

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(41) European Council conclusions of 8/9 March 2007: http://www.consilium.europa.eu/ueDocs/cms_Data/docs/pressData/en/ec/93135.pdf.

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List of abbreviations and names for novel bioenergy crops

ATC	Atlantic Central Zone
ATN	Atlantic North Zone
BFH	Bundesanstalt für Forst- und Holzforschung, Hamburg
BOR	Boreal Zone
BtL	biomass-to-liquids (biofuel from Fischer-Tropsch synthesis)
CAP	Common Agricultural Policy (of the EU)
CLC	Corine land cover
CON	Continental Zone
DM	dry matter
EAP	Environment Action Programme
EEA	European Environment Agency
EnZ	Environmental Zone
EOF	Environmentally-orientated Farming
EU	European Union
FAO	United Nations Food and Agriculture Organisation, Rome
FAME	fatty acid methyl ether
GJ	GigaJoules
ha	hectare
HEKTOR	HektarKalkulator (land-use model of Öko-Institut)
HNV	High Nature Value farmland
HU	Hohenheim University
IE	Institut für Energetik und Umwelt, Leipzig
IEA	International Energy Agency
LCC	Corine land cover classes
LHV	lower heating value (also net calorific value)
LUS	Lusitanian Zone
MED	Mediterranean Zone
mio.	million
MJ	MegaJoules
MS	Member States of the European Union
MtOE	million tonnes of oil equivalent
PAN	Pannonian Zone
PJ	PetaJoules
PRIMES	energy model of the EU (DG TREN)
SRC	short-rotation coppice
SRF	short-rotation forestry
UAA	Utilised Agricultural Area
UK	United Kingdom
WUE	Water Use Efficiency

Index of English and Latin plant names for novel biomass crops

English	**Latin**
Cynara	*Cynara cardunculus*
Carinata	*Brassica carinata*
Castor bean	*Ricinus communis*
Jatropha	*Jatropha curcas*
Jerusalem artichoke	*Helianthus tuberosus*
Sweet sorghum	*Sorghum bicolor*
Prickly pear	*Opuntia ficus-indica*
Giant reed	*Arundo donax*
Switchgrass	*Panicum virgatum*
Reed canary grass	*Phalaris arundinacea*

Annex I Yield increases in the original CAPSIM Animlib scenario

Table I-1 Yield increase of the Animlib scenario in the original CAPSIM model

	2000–2011	2011–2020	2020–2025	2000–2011	2011–2020	2020–2025
		EU-8			EU-15	
Soft wheat	-	0.58 %	0.76 %	-	0.57 %	0.98 %
Durum wheat	2.58 %	1.68 %	– 6.33 %	1.03 %	0.67 %	0.48 %
Rye and meslin	1.19 %	0.54 %	0.82 %	0.71 %	0.57 %	0.83 %
Barley	1.34 %	0.83 %	1.07 %	0.84 %	0.63 %	0.84 %
Oats	1.34 %	0.96 %	0.84 %	0.54 %	0.44 %	0.40 %
Grain maize						
Other cereals	3.94 %	2.60 %	0.59 %	0.73 %	0.40 %	0.71 %
Paddy rice						
Pulses	1.02 %	0.33 %	0.33 %	0.97 %	0.15 %	0.12 %
Potatoes	1.77 %	1.16 %	1.16 %	0.47 %	0.35 %	0.69 %
average sugar beets A-C	-	-	-	-	-	-
Rape and turnip rape	0.20 %	0.37 %	0.39 %	1.40 %	0.70 %	0.98 %
Sunflower seed	0.65 %	0.76 %	– 0.50 %	0.51 %	0.70 %	0.96 %
Soya beans	3.99 %	2.58 %	1.19 %	1.05 %	1.03 %	0.83 %
Vegetables	0.27 %	0.27 %	1.14 %	1.14 %	– 0.79 %	– 0.05 %
Fodder maize	2.45 %	0.96 %	0.51 %	0.66 %	0.58 %	0.75 %
Grass-grazing	– 2.01 %	0.62 %	– 3.31 %	– 1.25 %	– 0.64 %	– 0.89 %

Source: EFMA.

Annex II Application of the correction factors for yields and environmental 'stepping stones'

With the information concerning HNV farmland and organic farming, a share of environmentally orientated farming arable land and grassland is calculated as shown in the next table. Please note that related data reflect the state of knowledge at the time of analysis.

Finally, the correction factors for the yields per crop by country and year were calculated as shown in the last column of Table II-2.

When looking at the difference between the original baseline (Animlib) scenario and the adapted

Table II-1 Calculation of the arable land and grassland in ENVIRONMENTALLY ORIENTATED FARMING, Belgium given as example

No.	Category	Belgium	Source and calculation
(1)	Share of organic farming in UAA	1.0 %	IRENA. 2005
(2)	Share of arable land in total UAA	62.3 %	FSS 2000
(3)	Share HNV/UAA	1.0 %	Corine LC 2000
(4)	Arable land in HNV farmland	0.0 %	Corine LC 2000
(5)	Share of environmentally orientated farming	2.0 %	*(5) = (2) + (3)*
(6)	Share of environmentally orientated farming arable	0.6 %	*(6) = (1)*(2) + (3)*(4)*
(7)	Share of environmentally orientated farming perm. grassland	1.4 %	*(7) = 1 – (6)*

Source: EFMA

Table II-2 Adaptation factors for yields with the 30 %-ENVIRONMENTALLY ORIENTATED FARMING-aim and for the area (wheat in Belgium in the year 2010 as example)

No.	Category		Source and calculation*
(A)	Yield	kg/ha	CAPSIM
(B)	Yields org.farming	%	Offermann. 2003
(C)	Org/ext yield	kg/ha	(1)*(2)
(D)	HNV yield	kg/ha	Org. yield 2000
(E)	Corrected yield (overall)	kg/ha	(E) = (1)*(2)*(B)+ (3)*(4)*(D)+ (1-(6))*(A)
(F)	Correction factor for area from 2010 on	%	(F) = (A)/(E)
(G)	CAPSIM area	1 000 ha	CAPSIM
(H)	CORRECTED AREA	1 000 ha	(H) = (G)*(F)

*(1) to (6) = Lines from Table 2-5
(1)*(2)*(B) : organic farming
(3)*(4)*(D) : HNV
(1-(6))*(A) : conventional

Source: EFMA.

environmentally compatible Animlib scenario, the result for the Belgium example is as follows:

In the original CAPSIM model, the UAA from 2001 to 2020 decreases from 1.52 Mio ha to 1.48 Mio ha (non-food, set aside and fallow land excluded ([40]). The difference is land that could potentially be used for biomass crops.

Additional fallow and set aside land could also potentially be used for energy crops. In Belgium this is 27 700 ha in 2001, increasing to 31 300 ha in 2025. Finally, there are 4 200 ha for non-food production in 2001 and 3 800 ha in 2025. In this category industrial crops and fibres are summarised.

For the scenario with more environmentally orientated farming CAPSIM is modified. The extensification of agriculture entails a higher land demand and consequently some changes in the UAA. Thus, the decrease of UAA is less than in the original scenario and less land is released: the UAA (non-food and set aside land excluded) in the base year 2001 is again 1.52 Mio ha and increases up to 1.54 mio ha in 2030. There is no incremental land left for the cultivation of energy crops.

The other entries for balance are again the fallow/set-aside and land for non-food production like in the original CAPSIM data. As these figures do not develop very dynamically, the extrapolation of the original data (2025) to the year 2030 does not bring any changes. For this reason the original CAPSIM data is used in the scenario with more environmentally orientated farming.

Estimating the share of environmental compensation areas in intensive farmland

For determining the 3 % share of environmental compensation areas in intensive arable landscapes, the land use categories cereals, oilseeds and other arable crops in 2010 were analysed. For these categories an estimate was made of the part of total cropping area that would be grown very intensively. Thereafter, the 3 % share was applied to the intensive cropland area estimated. This share is assumed to be reached by 2010 and after that date the total amount of land for 'stepping stones' is assumed to remain constant.

Table II-3 Estimated share of intensive land in arable use category in 2010 (includes cereals, oilseed and other arable crops) by Member State

Member State	Share of intensive land
Belgium, Denmark, Germany, the Netherlands, Finland, Sweden, the United Kingdom, Czech Republic	70 %
Greece, Spain, France, Austria, Portugal, Ireland, Italy	50 %
Estonia, Hungary, Lithuania, Latvia, Estonia, Poland, Slovena, Slovak Republic	40 %

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(40) Non-food production on set aside, set aside and fallow land build part of the land potential. Set aside land includes both obligatory and voluntary set-aside.

Annex III Land availability for biomass

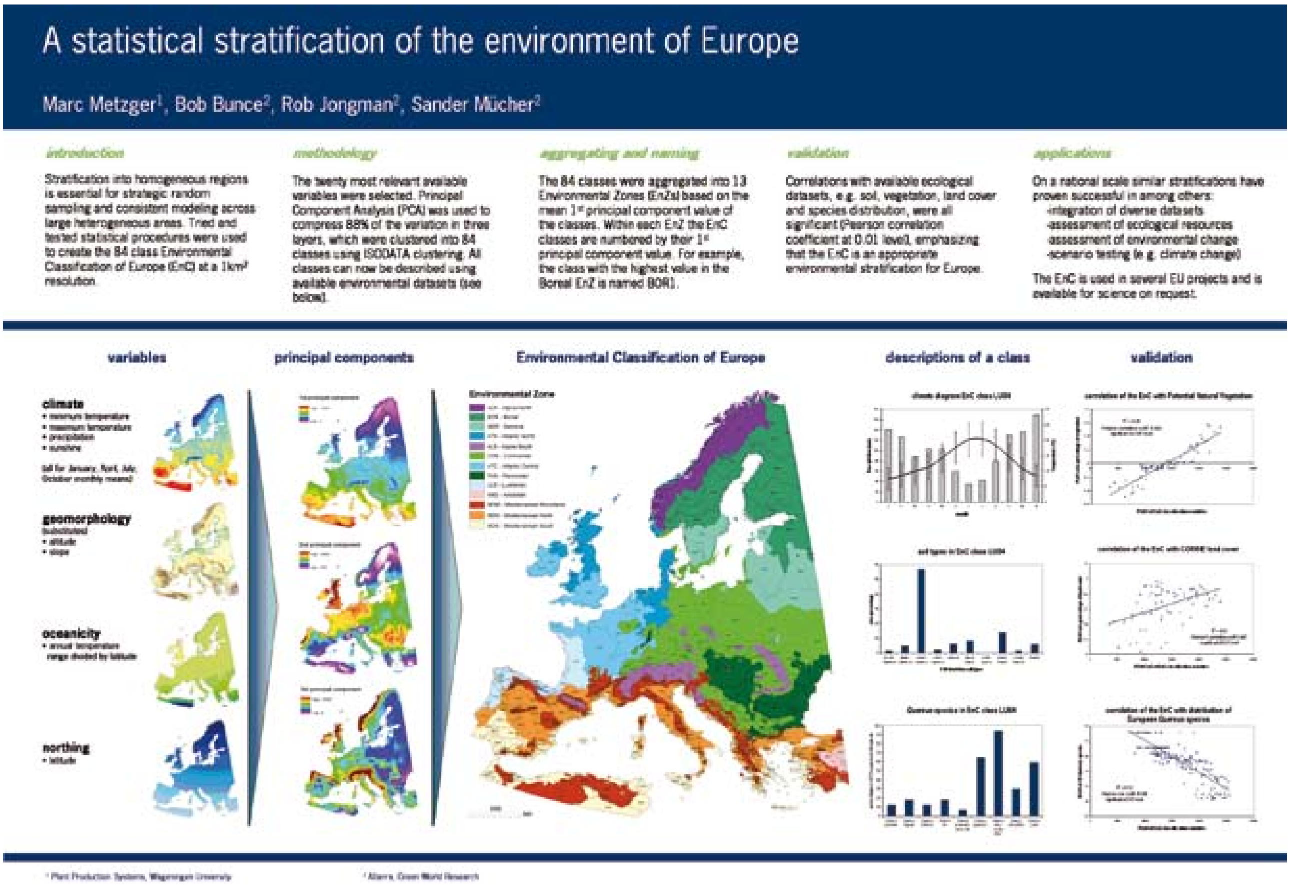
Table III-1 Land availability for biomass crop production in the EU-15 (EU-14)

	Land available (*1 000 ha)	**Belgium**	**Denmark**	**Germany**	**Greece**	**Spain**	**France**	**Ireland**	**Italy**	**Netherlands**	**Austria**	**Portugal**	**Finland**	**Sweden**	**United Kingdom**
2010	Available arable land	0.0	73.7	290.3	356.4	2705.6	535.8	0.0	1074.2	0.0	204.5	250.3	486.5	134.5	824.1
	Only available as grass (former grassland+olive groves)	152.3	29.7	264.1	0.0	0.0	453.6	0.0	116.8	51.6	8.1	0.0	0.0	77.8	0.0
	Total	152.3	103.4	554.4	356.4	2 705.6	989.4	0.0	1 191.1	51.6	212.6	250.3	486.5	212.3	824.1
2020	Available arable land	0.0	0.0	0.0	298.1	2 582.4	262.4	0.0	1 785.5	0.0	266.2	168.7	299.2	168.4	1 117.5
	Only available as grass (former grassland+olive groves)	161.5	45.0	482.0	0.0	0.0	1 058.3	344.1	137.7	139.2	20.7	0.0	0.0	109.1	1 114.0
	Total	161.5	45.0	482.0	298.1	2 582.4	1 320.7	344.1	1 923.2	139.2	286.9	168.7	299.2	277.5	2 231.5
2030	Available arable land	0.0	0.0	0.0	266.2	2 459.2	0.0	0.0	2 164.8	0.0	298.1	124.6	173.8	177.6	1 584.4
	Only available as grass (former grassland+olive groves)	168.2	53.7	572.6	0.0	0.0	1 208.0	409.2	172.3	183.4	28.2	0.0	0.0	133.2	1 831.0
	Total	168.2	53.7	572.6	266.2	2 459.2	1 208.0	409.2	2337.2	183.4	326.3	124.6	173.8	310.8	3 415.4

Table III-2 Land availability for biomass crop production in the EU-10 (EU-8)

	Land available (*1 000 ha)	**Czech Republic**	**Estonia**	**Hungary**	**Lithuania**	**Latvia**	**Poland**	**Slovenia**	**Slovak Republic**
2010	Available arable land	302.7	88.3	413.2	525.0	83.3	3 823.2	3.2	81.1
	Only available as grass (former grassland + olive groves)	0.0	42.7	56.8	0.0	83.8	332.9	9.4	0.0
	Total	302.7	131.0	470.0	525.0	167.1	4 156.1	12.6	81.1
2020	Available arable land	314.3	154.2	511.6	882.3	144.3	4 321.2	16.2	140.0
	Only available as grass (former grassland+olive groves)	0.0	54.9	231.2	0.0	130.0	492.3	0.0	0.0
	Total	314.3	209.2	742.8	882.3	274.2	4 813.5	16.2	140.0
2030	Available arable land	301.0	159.3	547.4	1 054.6	182.7	4 525.1	35.7	212.8
	Only available as grass (former grassland + olive groves)	10.6	62.4	296.9	0.0	177.5	520.6	14.6	14.8
	Total	311.6	221.7	844.3	1 054.6	360.2	5 045.7	50.3	227.6

Annex IV Environmental zones: production and characteristics



A statistical stratification of the environment of Europe

Marc Metzger[1], Bob Bunce[2], Rob Jongman[2], Sander Mücher[2]

introduction

Stratification into homogeneous regions is essential for strategic random sampling and consistent modeling across large heterogeneous areas. Tried and tested statistical procedures were used to create the 84 class Environmental Classification of Europe (EnC) at a 1km² resolution.

methodology

The twenty most relevant available variables were selected. Principal Component Analysis (PCA) was used to compress 88% of the variation in three layers, which were clustered into 84 classes using ISODATA clustering. All classes can now be described using available environmental datasets (see below).

aggregating and naming

The 84 classes were aggregated into 13 Environmental Zones (EnZs) based on the mean 1st principal component value of the classes. Within each EnZ the EnC classes are numbered by their 1st principal component value. For example, the class with the highest value in the Boreal EnZ is named BOR1.

validation

Correlations with available ecological datasets, e.g. soil, vegetation, land cover and species distribution, were all significant (Pearson correlation coefficient at 0.01 level), emphasizing that the EnC is an appropriate environmental stratification for Europe.

applications

On a national scale similar stratifications have proven successful in among others:
- integration of diverse datasets
- assessment of ecological resources
- assessment of environmental change
- scenario testing (e.g. climate change)

The EnC is used in several EU projects and is available for science on request.

variables

climate
- minimum temperature
- maximum temperature
- precipitation
- sunshine

(all for January, April, July, October monthly means)

geomorphology
(substituted)
- altitude
- slope

oceanicity
- annual temperature range divided by latitude

northing
- latitude

principal components

Environmental Classification of Europe

descriptions of a class

validation

[1] Plant Production Systems, Wageningen University

[2] Alterra, Green World Research

Table IV-1 Overview of characteristics by environmental zone

Characteristics	**Alpine North**	**Boreal**	**Nemoral**	**Atlantic North**	**Alpine South**	**Continental**	**Atlantic Central**	**Pannonian**	**Lusitanian**	**Mediterranean Mountains**	**Mediterranean North**	**Mediterranean South**
Mean altitude (m)	572	216	127	190	1253	435	140	160	371	905	433	277
Mean slope (degrees)	5.0	1.0	0.4	2.0	7.8	2.1	0.7	0.9	2.6	4.6	2.4	2.3
Length growing season (days)	130	157	196	255	220	227	296	250	353	298	335	363
sum of active temperatures (+ 10 °C)	1 416	1 966	2 717	3 198	3 005	3 294	3 849	4 099	4 749	4 548	5 104	6 021
Mean annual precipitation (mm)	1 317	624	679	1356	1144	743	892	570	1118	794	734	529
% urban (1)	0.1	1.0	1.6	4.9	1.8	1.0	8.0	6.5	3.4	2.5	2.7	2.9
% forest (1)	39.5	59.9	28.9	13.8	49.8	33.0	15.7	15.3	27.8	41.0	17.5	10.0
% agricultural land use (1)	51.0	30.4	27.6	79.4	40.2	63.0	75.0	75.8	67.5	54.9	78.5	85.6
% arable of agricultural land use (1)	0.0	15.0	48.5	30.5	7.6	61.8	45.8	72.9	27.8	20.5	44.2	26.9
% rainfed of arable (1)	0.0	15.0	48.5	30.5	7.5	61.8	45.8	72.8	27.4	18.6	38.4	22.3
% Irrigated of arable (1)	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.3	1.9	5.8	4.6
% grassland of agricultural land use (1)	3.0	3.2	11.9	41.3	46.1	16.8	36.4	10.2	19.3	20.8	5.7	7.1
% HNV farmland of agricultural land use (1 + 2)	0.1	14.9	43.0	29.2	34.7	8.7	3.8	14.4	33.9	60.9	27.9	40.3
Most important intensity systems (% UAA) (3)												
High input (3)	0	42	100 (only based on Swedish FADN data!)	41	28	60	58	..	43	26	18	8
Medium input (3)	0	45	0	31	60	39	33	..	43	47	39	25
Low input (3)	0	6	0	28	12	1	9	..	14	27	42	67
Most important land use systems (% UAA) (3):												
Cropping cereals (3)	0	26	0	21	24	48	25	..	20	21	36	11
Cropping fallow land (3)	0	14	0	1	6	0	2	..	7	19	22	15
Cropping mixed crops (3)	0	7	0	5	6	11	10	..	3	5	10	5
Cropping specialist crops (3)	0	0	0	2	2	0	5	..	11	4	12	14
Grazing livestock forage crops (3)	0	21	23	9	19	16	11	..	12	9	6	10
Grazing livestock permanent grass (3)	0	0	0	59	43	24	42	..	19	34	10	43
Grazing livestock Temporary grass (3)	0	33	77	3	0	2	5	..	28	9	4	0
Permanent Crops (3)	0	0	0	0	0	0	0	..	0	0	1	1
Mixed cropping livestock (3)	0	0	0	0	0	0	0	..	0	0	0	1
Most important environmental pressures (4):												
Erosion	Low	Low	Low	Medium	High	Medium	Medium	Medium	Medium	High	High	High

Characteristics	Alpine North	Boreal	Nemoral	Atlantic North	Alpine South	Conti-nental	Atlantic Central	Pannonian	Lusitanian	Mediter-ranean Mountains	Mediterra-nean North	Mediterra-nean South
Soil compaction	Low	Medium	Medium	Medium	Low	Medium	High	Low	Medium	Low	Low	Low
Eutrophication	Low	Medium	Medium	Medium/ High	Medium	Medium	High	Low	Medium	Low	Low	Low
Pesticide pollution	Low	Low	Medium	Medium	Low	Medium	High	Low	Medium	Low	Medium	Medium
Water abstraction	Low	Low	Low	Low	Low	Low	Low	Medium	Medium	High	High	High
Fire risk	Low	Low	Low	Low	Medium	Low	Low	Medium	Medium	High	High	High
Land abandonment	High	High	Medium	Medium	High	Medium	Low	High	Medium	High	High	High
Habitat fragmentation	Low	Low	Low	Low	Medium	Medium	High	Low	Medium	Low	Medium	Medium

(¹) Corine land cover 2000.

(²) Corine land cover 2000. HNV map is selection of HNV land cover classes (selection from Erling. *et al.,* 2003, and further adjustments from JRC).

(³) IRENA typology of Farming systems (indicator 13: Cropping and livestock patterns. Ind. 15 Intensification/Extensification; source data: FADN 2000. The farming types are only available for the EU-15. This means that for the zones that are partly or fully located in the new Member States the farming system information is only applicable to the farming systems in the EU-15 (e.g. Continental. Nemoral. Mediterranean Mountains and Alpine South) or is missing completely (e.g. Pannonian).

(⁴) Pressures from MIRABEL I project and additional expert knowledge.

Sources: FAO: FAOSTAT average national yield 2000–2005.

Annex V Potential crops for bioenergy production specified per Environmental Zone

Table V-1 Potential biomass crops per Environmental Zone

General description	Small summer farming area in the south	Summer farming in the south	Summer farming									
Double cropping	No	No	Only along the coasts with lower yields	Yes with lower yields	In valleys –yes	Only in wetlands/ moist areas	Yes	With irrigation	Yes	Yes, in valleys and with lower yields –yes	Only with (intensive) irrigation –no	Only with (intensive) irrigation –no
Elements of crop mixes	**Alpine north**	**Boreal**	**Nemoral**	**Atlantic North**	**Alpine South**	**Continental**	**Atlantic Central**	**Pannonian**	**Lusitanian**	**Medit. Mountains**	**Medit. North**	**Med. South**
Common arable crops												
Wheat	-	Wheat	Wheat	Wheat	Wheat+	Wheat	Wheat	Wheat	Wheat	Wheat	Wheat	Wheat
Oil seed rape	-	Rape	Rape	Rape+	Rape+	Rape	Rape+	Rape	Rape+			
Sugarbeet	-	Sugarbeet	Sugarbeet	Sugarbeet	Sugarbeet	Sugarbeet	Sugarbeet	Sugarbeet	Sugarbeet			
Barley	-	Barley	Barley	Barley+	Barley+	Barley	Barley+	Barley	Barley+	Barley	Barley	
Sunflower	-				Sunflower	Sunflower	Sunflower+	Sunflower	Sunflower+	Sunflower	Sunflower	Sunflower
Potato	-	Potato	Potato	Potato	Potato	Potato	Potato	Potato	Potato	Potato	Potato	Potato
Maize	-				Maize+	Maize	Maize+	Maize	Maize+	Maize	Maize	Maize
Sorghum bicolor	-							Sorghum	Sorghum+		Sorghum	Sorghum
Triticale	-		(Triticale)	Triticale+	Triticale+	Triticale	Triticale	Triticale	Triticale			
Rye	-	Rye	Rye	Rye+	Rye+	Rye	Rye+	Rye	Rye+	Rye	Rye	Rye
Oats	-	Oats	Oats	Oats+	Oats+	Oats	Oats+	Oats	Oats+	Oats	Oats	Oats
Clover/alfalfa	-			Clover	Clover	Clover	Clover	Clover	Clover	Alfalfa	Alfalfa	
'New' arable crops												
Hemp	-			Hemp+	Hemp+	Hemp	Hemp+	Hemp	Hemp+	Hemp		
Mustard	-			Mustard	Mustard	Mustard	Mustard	Mustard	Mustard+			
Linseed	-	Linseed	Linseed	Linseed+	Linseed+	Linseed	Linseed+	Linseed+	Linseed+			
Castor bean											Castor Bean	Castor Bean
Brassica carinata										Brassica Carinata	Brassica Carinata	Brassica Carinata
Sugar cane											Sugar Cane	Sugar Cane
Prickly pear											Prickly Pear	Prickly Pear
Cynara cardunculus										Cynara Cardunculus	Cynara Cardunculus	Cynara Cardunculus
Jerusalem artichocke										Jerusalem artichocke	Jerusalem artichocke	Jeruzalem artichocke
Perennial crops (ligno-cellulosic crops)												
Green grass	-	Grass	Grass	Grass	Grass	Grass	Grass	Grass	Grass			
Giant reed	-						Giant reed		Giant reed	Giant reed	Giant reed	Giant reed
Miscanthus	-			Miscanthus	Miscanthus	Miscanthus	Miscanthus	Miscanthus	Miscanthus	Miscanthus	Miscanthus	Miscanthus
Switchgrass				Switchgrass	Switchgrass	Switchgrass	Switchgrass	Switchgrass	Switchgrass	Switchgrass	Switchgrass	Switchgrass
Reed canary grass		Reed C.g.	Reed C.g.	Reed C.g.		Reed C.g.	Reed C.g.	Reed C.g.	No			
Cynara cardunculus											Cynara cardunculus	Cynara cardunculus
Short rotation coppice varieties (ligno-cellulosic crops)												
Poplar/aspen				Src Poplar	Src Poplar	Src Poplar	Src Poplar	Src Poplar	Src Poplar			
Willow		Src Willow	Src Willow	Src Willow	Src Willow	Src Willow	Src Willow	Src Willow	Src Willow			

Sources: FAO: FAOSTAT average national yield 2000–2005.

Annex VI Environmental pressures per crop

Table VI-1 Estimate of environmental pressures per crop, crop-by-crop analysis (crops listed without any order, comparison follows in annex VII) — Part A

Permanent grass		Reason	Maize	Reason
Erosion	A	Whole year coverage	C	Long period of uncovered soil, row crop
Soil compaction	A	No or extensive machinery use (only for fertilisation and cutting)	C	Poorly developed root system; late harvesting on wet soils and sometimes followed by sowing of winter crop
Nutrient inputs to ground and surface water	A	In the semi-natural grasslands no N-application. In the improved N-application can range from low to medium; medium to good nitrogen fixation in grass; low leaching risk because of permanent coverage	B/C	N-application rates are generally high but also good N-fixation by crop. Especially in Central and southern Europe N-surpluses in maize are reported to be high. Leaching risk is high because of low soil coverage (row crop)
Pesticide pollution of soils and water	A	Not in extensive permanent grasslands, but limited use in the more intensive types	B	C4 plant –poor competitive ability until the crop canopy has closed; subject to many diseases and pests
Water abstraction	A	Adapted grass species/varieties available	B	Medium water requirement and high water efficiency. In Mediterranean will require irrigation because typical summer crop
Contribution to fire risk	B	Medium risk in summer dry regions (but depends on sward management)	A	Harvested before dried up
Link to farmland biodiversity	A	In older and/or extensive grasslands no chemical inputs which are very species rich (in floristic and faunistic terms) More intensive and improved grassland types have lower floristic diversity, but may still be important habitats for farmland and wintering birds	B/C	Generally negative impacts on quality of habitats. Most severe impact in southern regions because of irrigation requirement leading to water abstraction. Provides some shelter opportunities for fauna in autumn
Diversity of crop types	A	High several grassland clover species in one field especially in older- semi-natural types	C	Very common crop in most parts of EU (except in North Europe)

Double cropping*		Reason	Hemp	Reason
Erosion	A	Minimised tillage	A/B	Deep drilling
Soil compaction	A	Minimised tillage	A	Deep rooting
Nutrient inputs to ground and surface water	A	Moderate demand; good fixation and leaching is limited through good soil coverage and limited tillage	A	Low demand; good fixation and whole crop removal
Pesticide pollution of soils and water	B	Some herbicide applications needed to limit ploughing/tillage	A	Limited pesticide application
Water abstraction	B	Normally a whole plant silage crop followed by maize with a high water requirement	B	Needs deep soils with good water supply, but high WUE (high yields!). Not suited for mediterranean
Contribution to fire risk	-	Harvested before dried up	-	-
Link to farmland biodiversity	B	Direct impacts on habitat quality through medium pesticide and nitrogen applications. But more room for weeds. Maybe cut several times a year leading to direct wildlife disturbance	B	Low input use so limited direct impacts on habitat quality. High water demand, but not a problem in temperate climate zones where it grows; attractive shelter crop. But highly competitive and therefore possible suppression of wild herbs
Diversity of crop types	A	Medium high as mixed species and higher weed thresholds support biodiversity	A	Currently not common

* For details on Double Cropping, see Box 8.3.

Table VI-1 Estimate of environmental pressures per crop, crop-by-crop analysis (crops listed without any order, comparison follows in annex VII) — Part B

Linseed (oil)		Reason	Clover Alfalfa	Reason	Sugar beet	Reason
Erosion	B	Some risk, because of medium coverage. But winter linseed has better coverage	A	Whole year covered	C	Root crop. Limited coverage row crop
Soil compaction	A	Winter cover crop, large taproots, can alleviate the effects of soil compaction	A/B	Machinery use should be extensive	C	Heavy machinery and harvested mass lead to soil compaction
Nutrient inputs to ground and surface water	B	Low- to medium N-demand, but N-application rates range strongly between countries. Since N-removal at yield is very low because of low yields the N-loss can be very high at high application rates	B	N losses after ploughing (leguminous crop) but less N-mineralisation than in permanent grassland	C	Generally high N-application rates not compensated by high yields in combination with limited coverage (risk for erosion) also high risk for leaching
Pesticide pollution of soils and water	B	Low competitive in growth rate, so herbicide application may be high	A	Low herbicide application	C	Poor competitive ability at young stage
Water abstraction	A	Low water demand but also low WUE because of low yields	A	High water requirement (needs moist soils as droughty rooting) and WUE is medium to low. Can be grown without irrigation in wet climates, but not very suited for Mediterranean climates	B/C	Medium water requirement and high WUE. Not suited for Mediterranean unless irrigated
Contribution to fire risk	-	-	A/B	Some limited risk as dry in fire risk season	-	-
Link to farmland biodiversity	B	Low to medium pesticide and nitrogen applications leading to some direct negative impacts on habitat quality. But open crop structure with weeds, may provide fodder in autumn	A	Low pesticide and nitrogen inputs so direct impacts on habitat quality are very limited; but is feed source (nectar) and can provide shelter	B/C	Direct negative impacts on habitat quality through high pesticide and nitrogen applications.But can provide nesting habitat and shelter in autumn
Diversity of crop types	A	High, as currently not common	A	Higher than arable Introduces more than one species	B	Common in intensive areas. But not self tolerant

Alfalfa (irrigated) for southern Europe, too

Source: EEA based on Wiegmann, K., Fritsche, U. & B. Elbersen: 'Environmentally compatible biomass potential from agriculture'. Consultancy report to the EEA, 2005.

	Oilseed rape	Reason	Sun-flower	Reason	Potatoes	Reason
Erosion	A	Early sowing with high soil coverage	B/C	Limited coverage but reduced tillage possible	C	Root crop and row crop
Soil compaction	A	Intensive rooting	A	Well developed root system	C	Heavy machinery and harvested mass lead to soil compaction
Nutrient inputs to ground and surface water	C	Generally high nitrogen applications rates and bad nitrogen recovery at yield	A	Limited nitrogen application and very good fixation by crop	B/C	Low demand and good fixation by the crop and high yields especially in North, west and central EU (not south). But relatively high leaching risks in the winter, intensive machinery use, erosion
Pesticide pollution of soils and water	C	Various pests and diseases	B	Different diseases; insects and snails	B	Sensitive to diseases and pests. Combination of pesticide use required. But mechanical pest control possible
Water abstraction	B	Medium to high water requirement and medium WUE. Success greatly influenced by water supply. Not suited for water stressed regions	B/C	Medium to high water requirement and medium WUE. May grow without irrigation, even under dry circumstances but yield will be very minimal. Irrigation is often applied to this crop in Mediterranean as it increases yields significantly	A/B	Medium water requirement and high WUE. In dry regions requires irrigation
Contribution to fire risk	-	-	A	Harvested before dried up	-	-
Link to farmland biodiversity	B/C	Direct negative impacts on habitat quality through high pesticide and nitrogen applications. Some feed source (pollen). Crop to dense to provide shelter or room for weeds	A/B	Medium pesticide use but low nitrogen input heaving some impacts on habitat quality. When not irrigated, no adverse effects on water abstraction otherwise adds to water stress. Feed source (pollen), space for weeds and potential winter stubble	B/C	High pesticide use but medium nitrogen leaching risk. High erosion and soil compaction risk. Overall negative impacts on habitat quality, especially soil. When not irrigated, no adverse effects on water abstraction otherwise adds to water stress. Can provide autumn shelter
Diversity of crop types	A/B	In some Member States very common, already leading to strong monotonisation	A (B/C)	Depends on region. Very common in Bulgaria, Romania, Spain and Portugal	A/B	In some Member States very common

	Other Cereals (barely, rye, oats, triticale)		Wheat	Reason	Sorghum	Reason
Erosion	A/B	Covered soil, certainly in case of winter cereals, but spring cereals are more erodable	B	Winter wheat is often planted late in autumn with limited soil cover	B	Generally medium coverage. But also provides opportunity for summer cultivation in dry regions
Soil compaction	A	Intensive rooting; harvest in dry weather	A/B	Late sowing on wet soils leads to plough pans (most in Northwestern Europe). But also intensive rooting and harvest usually in dry winter (especially in Southern Europe)	A	Deep rooting
Nutrient inputs to ground and surface water	B	Low (rye, oats, triticale) to medium (barley) demands and medium fixation and low removal at yield	A/B	Higher Nitrogen demand then other cereals but high fixation and higher yields. But high quality wheat needs extra Nitrogen application late in vegetation period when absorption is lower under dry weather conditions	B	Medium nitrogen input required and medium absorption and yield. Basic NPK-dressing necessary
Pesticide pollution of soils and water	B	Lower but normal pesticide application because of shorter growing period	B/C	Intensive crop several (6–12) pesticide applications in winter wheat in Northern Europe, less in southern Europe	B/C	Numerous diseases. not very competitive in the begin
Water abstraction	A/B	Generally low water demand in Barley Oats, Rye, but higher in oats	B	Highest water demand of all cereals	B	Medium water requirement and medium WUE. Grown in areas too dry for maize. But for a high yield irrigation is required
Increased fire risk	A	Harvested before dried up and crop does not coincide with summer heat	A	-	A	Harvested before dried up and crop does not coincide with summer heat
Link to farmland biodiversity	B	Low to medium pesticide and nitrogen applications leading to some direct negative impacts on habitat quality. But can have open structure; nesting habitat when spring crop and some more space for weeds	B/C	Medium to high pesticide and nitrogen applications leading to direct negative impacts on habitat quality. Dense crop, limited nesting, shelter, no weeds	B	Medium pesticide and nitrogen applications leading to direct negative impacts on habitat quality. But can be open crop and feed source
Diversity of crop types	B	Depends on type of cereal but generally less common then wheat	C	Most common	A/B	Not common except in a selection of southern regions

	Castor Bean	Reason	Cynara cardunculus	Reason	Brassica carinata	Reason
Erosion	A/B	Medium soil coverage	A/B	Medium soil coverage, but may be established without tillage	A	Similar to rape, early sowing with high soil coverage
Soil compaction	A	No heavy machinery and planting and harvest on dry soils	A	Intensive rooting; harvest in dry winter	A	Intensive rooting
Nutrient inputs to ground and surface water	?	?	A	Low Nitrogen input	C	Similar to oilseed rape; generally high nitrogen applications rates and bad nitrogen recovery at yield
Pesticide pollution of soils and water	?	?	A	Very resistant against pests	?	?
Water abstraction	B	Medium water consumption, WUE unknown	B	Very low water demand	B	Medium to high water requirement and medium WUE. Less suited for water stressed regions
Increased fire risk	A	Not very dry	C	Dry in fire risk season. Burns well with oil inside	A	Not dry in fire risk season
Link to farmland biodiversity		?	B/C	Low pesticide and nitrogen applications so no direct negative impacts on habitat quality. Also very limited water abstraction. Has open structure; provides nesting and shelter and space for weeds	B/C	Direct negative impacts on habitat quality through high pesticide and nitrogen applications. Some feed source (pollen). Crop to dense to provide shelter or room for weeds
Diversity of crop types	A	Not common at all	A	Not common at all	A	Not common at all

	Prickly pear	Reason	Sugar cane	Reason	Jerusalem artichoke	
Erosion	C	Low coverage	A	Dense soil coverage	A	Dense soil coverage
Soil compaction	A	No tillage required	A	Intensive rooting.Harvest on dry soil	A	Intensive rooting. Harvest on dry soil
Nutrient inputs to ground and surface water	?	?	B	Medium to high Nitrogen input but high removal at yield	B	Medium to high Nitrogen input but high removal at yield
Pesticide pollution of soils and water	?	?	?	?	?	?
Water abstraction	A	Steppe crop (cactus)	B/C	High water requirement and high water efficiency. Only possible in Mediterranean and will require irrigation	B/C	High water requirement and medium to high WUE. In Mediterranean will require irrigation
Increased fire risk	-	-	B	Burns well when dry and dense	A	Not high risk
Link to farmland biodiversity	?	?	B/C	High water demand, leading to high water abstraction. Dense crop leaves no room for shelter and weeds	B/C	High water demand, leading to high water abstraction. Provides room for shelter but quite dense. Feed when flowering (nectar)
Diversity of crop types	A	Not common at all	A	Not common at all	A	Not common at all

	Giant reed *Arundo donax*	**Reason**	**Miscanthus**	**Reason**	**SRC** eucalyptus	**Reason**
Erosion	A	Permanent crop	A	Permanent crop	C	Tree, but no undergrowth
Soil compaction	A	Deep rooting; permanent crop	A	Deep rooting; permanent crop	A	Deep rooting; permanent crop
Nutrient inputs to ground and surface water	A/B	Higher nutrient-demand than Miscanthus	A	Low nutrient requirement	B	No high nitrogen input, grows wel even on very poor soils
Pesticide pollution of soils and water	A	Very competitive	A	Practical no pesticide need, only at establishment	A	Very competitive
Water abstraction	B/C	Well-drained soils where abundant moisture is available. suspected of altering hydrological regimes & reducing groundwater availability by transpiring large amounts of water from semi-arid aquifers	A	Drought resistant (not as extreme as Switchgrass) and very efficient water use (C4), but because of deep roots ground water abstraction possible	C	Very high water requirement, but also high WUE. Because of deep rooting does not require irrigation, but because of large water needs, negatively influences water regimes and reduces ground water& aquifers
Increased fire risk	C	Giant reed is highly flammable throughout most of the year and appears highly adapted to 'extreme' fire events	B	Burns easily when dry, but dry in winter and not in summer when highest risk for fires	C	Is highly flammable throughout most of the year and appears highly adapted to 'extreme' fire events. Burns very well with high oil content
Link to farmland biodiversity	A	No or low pesticide and nitrogen applications so no direct negative impacts on habitat quality. Can be nesting habitat and provides winter shelter	A	No or low pesticide and nitrogen applications so no direct negative impacts on habitat quality; can provide winter shelter; birds nesting inside plants	C	Very adverse effects on water abstraction. Presently already an important reason for increased water stress in many Mediterranean regions. Very competitive for other plants
Diversity of crop types	A	Currently not very common. Birds nesting inside plants	A	Currently not very common	C	Currently very common in the south

	SRC poplar, willow	**Reason**	**Reed Canary Grass** *Phalaris arundinacea*	**Reason**	**Switchgrass** *Panicum virgatum*	**Reason**
Erosion	A	Permanent crop	A	Permanent crop	A	Permanent crop
Soil compaction	A	Deep rooting; permanent crop	A	Deep rooting; permanent crop	A	Deep rooting; permanent crop
Nutrient input to ground and surface water	A	High nitrogen uptake	A/B	Higher nutrient-demand than miscanthus	A	Low nutrient requirement
Pesticide pollution of soils and water	A	Very competitive	A	Very low input necessary	A	Practical no pesticide need, only at establishment
Water abstraction	B	Unclear situation regarding requirement of water	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
Increased fire risk	-	-	-	-	B	Burns easily when dry, but dry in winter and not in summer when highest risk for fires
Link to farmland biodiversity	A	No or low pesticide and nitrogen applications so no direct negative impacts on habitat quality; nesting habitat and provides winter shelter; birds nesting inside plants	A	No or low pesticide and nitrogen applications so no direct negative impacts on habitat quality; potential nesting habitat and provides winter shelter; birds nesting inside plants	A	No or low pesticide and nitrogen applications so no direct negative impacts on habitat quality; can provide winter shelter; birds nesting inside plants
Diversity of crop types	A	Currently not very common	A	Currently not very common	A	Currently not very common

Sources: FAO: FAOSTAT average national yield 2000–2005.

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Annex VII Ranking of different crops by environmental risk

This annex presents the ranking of different crops by environmental risk in each environmental zone. This is derived from an integration of plant demands and the importance of a given pressure for an environmental zone. Environmental zones clustered if crop mix and problems are the same. The letter A indicates low environmental risk, Band C stands for medium and high environmental risk respectively.

Source: EEA based on Wiegmann, K., Fritsche, U. & B. Elbersen: 'Environmentally compatible biomass potential from agriculture'. Consultancy report to the EEA, 2005 (excel sheet 'description of plants').

Table VII-1 Risk Matrix for Boreal and Nemoral Zone

	Arable crops						Perennials		
Boreal and Nemoral	**Linseed (oil)**	**Other Cereals (oats, barley, rye, triticale)**	**Wheat**	**Oilseed Rape**	**Sugar beet**	**Potatoes**	**Permanent grass**	**Reed canary grass**	**SRC-willow**
Erosion	B	B	B	A	C	C	A	A	A
Soil compaction	A	A	B	A	C	C	A	A	A
Nutrient leaching to ground and surface water	B	B	B	C	C	B/C	A	B	A
Pesticide pollution of soils and water	B	B	B	C	C	B/C	A	A	A
Water abstraction	A	A	B	B	A	A/B	A	C	B
Increased fire risk	-	-	-	-	-	-	...		
Link to farmland biodiversity	B	B	B/C	B/C	B	C	A	A	A
Diversity of crop types	A	B	C	A/B	B	B	A	A	A

Source: EFMA.

Table VII-2 Risk Matrix for Atlantic North

	Arable crops									Perennials				
Atlantic North	**Hemp**	**Double cropping**	**Mustard seed**	**linseed**	**Other cereals (Barley, rye, oats, triticale)**	**Wheat**	**Oilseed rape**	**Potatoes**	**Sugar beet**	**Permanent grass**	**Miscanthus**	**Switchgrass**	**Reed canary grass**	**SRC willow and poplar**
Erosion	A	A	A/B	B	B	B	A	C	C	A	A	A	A	A
Soil	A	A	A	A	A	B	A	C	C	A	A	A	A	A
Nutrient leaching to ground and surface water	A	A	A/B	B	B	B	C	B/C	C	A	A	A	A/B	A
Pesticide pollution of soils and water	A	B	A	B	B	B	C	C	C	A	A	A	A	A
Water	B	B	B	A	A	B	B	A	B	A	A	A	B	B
Increased fire risk	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Link to farmland	B	B	A	B	B	B/C	B/C	C	B	A	A	A	A	A/B
Diversity of crop types	A	A	A	A	B	C	A/B	B	B	A	A	A	A	A

Source: EFMA.

Table VII-3 Risk Matrix for Alpine South

	Arable crops											
Alpine South	**Hemp**	**Double cropping**	**Mustard seed**	**Clover Alfalfa**	**Linseed**	**Sun flower**	**Other cereals (Barley, rye, oats, triticale)**	**Oilseed rape**	**Wheat**	**Potatoes**	**Sugar beet**	**Maize**
Erosion	A	A	A/B	A	B	B/C	B	A	B	C	C	C
Soil compaction	A	A	A	A/B	A	A	A	A	B	C	C	C
Nutrient leaching to ground and surface water	A	A	A/B	B	B	A	B	C	B	B/C	C	C
Pesticide pollution of soils and water	A	B	A	A	B	B	B	C	B	C	C	B
Water abstraction	B	B	B	A	A	B	A	B	B	A	B	B
Increased fire risk	-	-	-	A/B	-	-	-	-	-	-	-	..
Link to farmland biodiversity	B	B	A	A	B	A	B	B/C	B/C	C	B	C
Diversity of crop types	A	A	A	A	A	A	B	B	C	B	B	C

Source: EFMA.

Alpine South	Perennials Permanent grass	Miscanthus	Switchgrass	SRC willow and poplar
Erosion	A	A	A	A
Soil compaction	A	A	A	A
Nutrient leaching to ground and surface water	A	A	A	A
Pesticide pollution of soils and water	A	A	A	A
Water abstraction	A	A	A	B
Increased fire risk	C	B	B	A
Link to farmland biodiversity	A	A	A	A/B
Diversity of crop types	A	B	A	B/C

Source: EFMA.

Table VII-4 Risk Matrix for Continental and Pannonian Zone

Continental/Pannonian	Arable crops Hemp	Double cropping (not in Pannonian)	Mustard seed	Clover Alfalfa	Linseed	Sun-flower	Sorghum (only in Pannonian)	Other cereals (Barley, rye, oats, triticale)	Oilseed rape	Wheat	Potatoes	Sugar beet	Maize
Erosion	A	A	A/B	A	B	B/C	B	B	A	B	C	C	C
Soil compaction	A	A	A	A/B	A	A	A	A	A	B	C	C	C
Nutrient leaching to ground and surface water	A	A	A/B	B	B	A	B	B	C	B	B/C	C	C
Pesticide pollution of soils and water	A	B	A	A	B	B	B	B	C	B	C	C	B
Water abstraction	B	B	B	A	A	B	B	A	B	B	A	B	B
Increased fire risk	-	-	-	A/B	-	-		-	-	-	-	-	-

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* Very common in Romania and Bulgaria.

Sources: FAO: FAOSTAT average national yield 2000–2005.

Continental/Pannonian	Perennials Perm. grass	Miscanthus	Switchgrass	Reed Canary grass	SRC willow and poplar
Erosion	A	A	A	A	A
Soil compaction	A	A	A	A	A
Nutrient leaching to ground and surface water	A	A	A	B	A
Pesticide pollution of soils and water	A	A	A	A	A
Water abstraction	A	A	A	B	B
Increased fire risk	B	B	B	A	A
Link to farmland biodiversity	A	A	A	A	A/B
Diversity of crop types	A	B	A	A	B/C

Sources: FAO: FAOSTAT average national yield 2000–2005.

Table VII-5 Risk Matrix for Atlantic and Lusitanian Zone

	Arable crops												
Atlantic central/ Lusitanian	**Hemp**	**Double cropping**	**Mustard seed**	**Clover Alfalfa**	**Linseed**	**Sun-flower**	**Sorghum (only in Lusithanian)**	**Other cereals (Barley, rye, oats, triticale)**	**Oilseed rape**	**Wheat**	**Potatoes**	**Sugar beet**	**Maize**
Erosion	A	A	A/B	A	B	B/C	B	B	A	B	C	C	C
Soil compaction	A	A	A	A/B	A	A	A	A	A	B	C	C	C
Nutrient inputs into ground and surface water	A	A	A/B	B	B	A	B	B	C	B	B/C	C	C
Pesticide pollution of soils and water	A	B	A	A	B	B	B	B	C	B	C	C	B
Water abstraction	B	B	B	A	A	B	B	A	B	B	B	B	C
Increased fire risk	-	-	-	A/B	-	-		-	-	-	-	-	-
Link to farmland biodiversity	B	B	A	A	B	A	B	B	B/C	B/C	C	B	C
Diversity of crop types	A	A	A	A	A	A	A/C*	B	B	C	B	B	C

* Very common in Romania and Bulgaria.

Sources: FAO: FAOSTAT average national yield 2000–2005.

	Perennials					
Atlantic central/Lusitanian	**Perm. grass**	**Miscanthus**	**Switchgrass**	**SRC willow and poplar**	**Giant reed (only in Lusitanian)**	**SRC Eucalypthus (only in Lusithanian)**
Erosion	A	A	A	A	A	C
Soil compaction	A	A	A	A	A	A
Nutrient leaching to ground and surface water	A	A	A	A	B	A
Pesticide pollution of soils and water	A	A	A	A	A	A
Water abstraction	A	A	A	B	C	C
Increased fire risk	B	B	B	A	C	C
Link to farmland biodiversity	A	A	A	A/B	B	C
Diversity of crop types	A	B	A	B/C	A	C

Sources: FAO: FAOSTAT average national yield 2000–2005.

Table VII-6 Risk Matrix for Mediterranean Mountains

	Arable crops										
Mediterranean Mountains	**Clover alfalfa**	**Hemp**	**Double cropping**	**Sun-flower**	**Other cereals (Barley, rye, oats, triticale)**	**Jerusalem Artichoke**	**Brassica carinata**	**Cynara Cardunculus**	**Wheat**	**Potatoes**	**Maize**
Erosion	A	A	A	B/C	B	A	A	A/B	B	C	C
Soil compaction	A	A	A	A	A	A	A	A	B	C	C
Nutrient leaching to ground and surface water	B	A	A	A	B	B	C	A	B	C	C
Pesticide pollution of soils and water	A	A	B	B	B	?	?	A	B	C	B
Water abstraction	A	B	B	B	A	B/C	B	B	B	B	C
Increased fire risk	B	A	-	A	A	A	A	C	A	A	A
Link to farmland biodiversity	A	B	B	A	B	B/C	B/C	B/C	B/C	B	C
Diversity of crop types	A	A	A	A	B	A	A	A	C	B	C

Source: EEA based on Wiegmann, K., Fritsche, U. & B. Elbersen: 'Environmentally compatible biomass potential from agriculture'. Consultancy report to the EEA, 2005.

	Perennials					
Mediterranean mountains	**Perm. grass**	**Miscanthus**	**Switchgrass**	**SRC willow and poplar**	**Giant reed**	**SRC Eucalypthus**
Erosion	A	A	A	A	A	C
Soil compaction	A	A	A	A	A	A
Nutrient leaching to ground and surface water	A	A	A	A	B	A
Pesticide pollution of soils and water	A	A	A	A	A	A
Water abstraction	A	A	A	B	C	C
Increased fire risk	B	B	B	A	C	C
Link to farmland biodiversity	A	A	A	A/B	B	C
Diversity of crop types	A	B	A	B/C	A	C

Source: EEA based on Wiegmann, K., Fritsche, U. & B. Elbersen: 'Environmentally compatible biomass potential from agriculture'. Consultancy report to the EEA, 2005.

Table VII-7 Risk Matrix for Mediterranean North

	Arable crops												
Mediterranean North	**Clover alfalfa**	**Sun-flower**	**Other cereals (Barley, rye, oats, triticale)**	**Castor bean**	**Jerusalem Artichoke**	**Brassica carinata**	**Cynara Cardunculus**	**Prickly pear**	**Sorghum**	**Wheat**	**Sugar cane**	**Potatoes**	**Maize**
Erosion	A	C	B	A/B	A	A	A/B	C	B	B	A	C	C
Soil compaction	A	A	A	A	A	A	A	A	A	B	A	C	C
Nutrient leaching to ground and surface water	B	A	B	?	B	C	A	?	B	B	B	C	C
Pesticide pollution of soils and water	A	B	B	?	?	?	A	?	B	B	?	C	B
Water abstraction	A	B	A	A	B/C	B	B	A	B	B	C	B	C
Increased fire risk	B	A	A	A	A	A	C	-		A	B	A	A
Link to farmland biodiversity	A	A	B	?	B/C	B/C	B/C	?	B	B/C	B/C	B	C
Diversity of crop types	A	A	B	A	A	A	A	A	A	C	A	B	C

Source: EEA based on Wiegmann, K., Fritsche, U. & B. Elbersen: 'Environmentally compatible biomass potential from agriculture'. Consultancy report to the EEA, 2005.

	Perennials					
Mediterranean North	**Perm. grass**	**Miscanthus**	**Switchgrass**	**Cynara Cardunculus**	**Giant reed**	**SRC Eucalypthus**
Erosion	A	A	A	A/B	A	C
Soil compaction	A	A	A	A	A	A
Nutrient leaching to ground and surface water	A	A	A	A	B	A
Pesticide pollution of soils and water	A	A	A	A	A	A
Water abstraction	A	A	A	B	C	C
Increased fire risk	B	B	B	C	C	C
Link to farmland biodiversity	A	A	A	B/C	B	C
Diversity of crop types	A	B	A	A	A	C

Source: EEA based on Wiegmann, K., Fritsche, U. & B. Elbersen: 'Environmentally compatible biomass potential from agriculture'. Consultancy report to the EEA, 2005.

Table VII-8 Risk Matrix for Mediterranean South

	Arable crops											
Mediterranean South	**Sun-flower**	**Other cereals (Barley, rye, oats, triticale)**	**Castor bean**	**Jerusalem Artichoke**	**Brassica carinata**	**Cynara Cardunculus**	**Prickly pear**	**Sorghum**	**Wheat**	**Sugar cane**	**Potatoes**	**Maize**
Erosion	C	B	A/B	A	A	A/B	C	B	B	A	C	C
Soil compaction	A	A	A	A	A	A	A	A	B	A	C	C
Nutrient leaching to ground and surface water	A	B	?	B	C	A	?	B	B	B	C	C
Pesticide pollution of soils and water	B	B	?	?	?	A	?	B	B	?	C	B
Water abstraction	B	A	A	B/C	B	B	A	B	B	C	B	C
Increased fire risk	A	A	A	A	A	C	-		A	B	A	A
Link to farmland biodiversity	A	B	?	B/C	B/C	B/C	?	B	B/C	B/C	B	C
Diversity of crop types	A	B	A	A	A	A	A	A	C	A	B	C

Source: EEA based on Wiegmann, K., Fritsche, U. & B. Elbersen: 'Environmentally compatible biomass potential from agriculture'. Consultancy report to the EEA, 2005.

	Perennials					
Mediterranean South	**Perm. grass**	**Miscanthus**	**Switchgrass**	**Cynara Cardunculus**	**Giant reed**	**SRC Eucalypthus**
Erosion	A	A	A	A/B	A	C
Soil compaction	A	A	A	A	A	A
Nutrient leaching to ground and surface water	A	A	A	A	B	A
Pesticide pollution of soils and water	A	A	A	A	A	A
water abstraction	A	A	A	B	C	C
Increased fire risk	B	B	B	C	C	C
Link to farmland biodiversity	A	A	A	B/C	B	C
Diversity of crop types	A	B	A	A	A	C

Source: EEA based on Wiegmann, K., Fritsche, U. & B. Elbersen: 'Environmentally compatible biomass potential from agriculture'. Consultancy report to the EEA, 2005.

Annex VIII Nitrogen pressure per crop

Table VIII-1 Estimated risk for nitrogen loss per crop type

	Sweden and Finland							
	Minimum application kg N/ha (1)	Maximum application kg N/ha (2)	Harvested kg N (per ton yield) (3)	Minimum yield (ton ha) (4)	Maximum yield (ton ha) (5)	N-loss min yield (6)	N-loss max yield (7)	Average N-loss (8)
Wheat	85	125	22	3.5	6	– 8	7	– 0.5
Barley	72	78	15	3	4	– 27	– 18	– 22.5
Rye	68	70	15	2.2	5.3	– 35	9.5	– 12.8
Oats	68	70	16	3	4	– 20	– 6	– 13.0
Potato	70	83	4	24	28	26	29	27.5
Sugar beet	100	120	2	32	48	– 36	– 24	– 30.0
Oilseed rape	80	110	30	1	2.5	– 50	– 35	– 42.5
Linseed	20	60	3	0.7	2	– 17.9	– 54	– 36.0

(6) N-loss assuming minimum N-application (1) and yield (4); (6) = ((3)*(4)) – (1)
(7) N-loss assuming maximum N-application (2) and yield (5); (7) = ((3)*(5)) – (2)
(8) Average N-loss: (8) = ((6) + (7))/2

Source: EFMA.

Table VIII-2 Estimated risk for nitrogen loss per crop type

	Luxembourg, Belgium, Germany, Netherlands and Denmark							
	Minimum application kg N/ha (1)	Maximum application kg N/ha (2)	Harvested kg N (per ton yield) (3)	Minimum yield (ton ha) (4)	Maximum yield (ton ha) (5)	N-loss min yield (6)	N-loss max yield (7)	Average N-loss (8)
Wheat	148	190	22	7	8	6	– 14	– 4.0
Barley	78	150	15	5	6	– 3	– 60	– 31.5
Rye	80	120	15	4.5	5	– 12.5	– 45	– 28.8
Oats	80	120	15	4.2	5.2	– 17	– 42	– 29.5
Grain maize. incl. corn cob maize	70	150	14	6	9	14	– 24	-5.0
Potato	120	168	3.5	36	46	6	– 7	– 0.5
Sugar beet	100	145	1.8	55	64	– 1	– 29.8	– 15.4
Oilseed rape	100	180	30	3	4	– 10	– 60	– 35.0
Sunflower	20	70	28	2	2.5	36	0	18.0
Linseed	20	50	0.6	1.2	5.3	– 19.28	– 46.82	– 33.1

(6) N-loss assuming minimum N-application (1) and yield (4); (6) = ((3)*(4)) – (1)
(7) N-loss assuming maximum N-application (2) and yield (5); (7) = ((3)*(5)) – (2)
(8) Average N-loss: (8) = ((6) + (7))/2

Source: EFMA.

Table VIII-3 Estimated risk for nitrogen loss per crop type

	France, Spain, Italy, Greece and Portugal							
	Minimum application kg N/ha (1)	Maximum application kg N/ha (2)	Harvested kg N (per ton yield) (3)	Minimum yield (ton ha) (4)	Maximum yield (ton ha) (5)	N-loss min yield (6)	N-loss max yield(7)	Average N-loss (8)
Wheat	70	164	22	1.4	7	– 39.2	– 10	– 24.6
Barley	75	120	15	1.2	6.5	-57	– 22.5	– 39.8
Rye	60	105	15	1	5	-45	– 30	– 37.5
Oats	60	105	15	1	4.8	-45	– 33	– 39.0
Grain maize. incl. corn cob maize	160	230	14	5.5	9	-83	– 104	– 93.5
Potato	100	200	3.5	15	42	– 47.5	– 53	– 50.3
Sugar beet	140	180	1.8	58	78	– 35.6	– 39.6	– 37.6
Oilseed rape	100	110	30	2.5	3.5	– 25	-5	– 15.0
Sunflower	14	50	28	1.4	2.5	25.2	20	22.6
Pulses	5	40	4	1.2	3	– 0.2	– 28	– 14.1

(6) N-loss assuming minimum N-application (1) and yield (4); (6) = ((3)*(4)) – (1)
(7) N-loss assuming maximum N-application (2) and yield (5); (7) = ((3)*(5)) – (2)
(8) Average N-loss: (8) = ((6) + (7))/2

Source: EFMA.

Table VIII-4 Estimated risk for nitrogen loss per crop type

	United Kingdom and Ireland							
	Minimum application kg N/ha (1)	Maximum application kg N/ha (2)	Harvested kg N (per ton yield) (3)	Minimum yield (ton ha) (4)	Maximum yield (ton ha) (5)	N-loss min (6)	N-loss max (7)	Average N-loss (8)
Wheat	160	180	22	6	8	– 28	– 4	– 16.0
Barley	110	127	15	5.3	5.9	– 30.5	– 38.5	– 34.5
Rye	90	110	15	4.5	6.2	– 22.5	– 17	– 19.8
Oats	90	110	15	5.5	6.2	– 7.5	– 17	– 12.3
Potato	120	160	3.5	39	44	16.5	– 6	5.3
Sugar beet	100	180	1.8	47	57	– 15.4	– 77.4	– 46.4
Oilseed rape	150	190	30	2.8	3.4	– 66	– 88	– 77.0
Linseed	20	50	0.6	0.6	1.7	– 19.64	– 48.98	– 34.3

(6) N-loss assuming minimum N-application (1) and yield (4); (6) = ((3)*(4)) – (1)
(7) N-loss assuming maximum N-application (2) and yield (5); (7) = ((3)*(5)) – (2)
(8) Average N-loss: (8) = ((6) + (7))/2

Sources: FAO: FAOSTAT average national yield 2000–2005.

Table VIII-5 Estimated risk for nitrogen loss per crop type

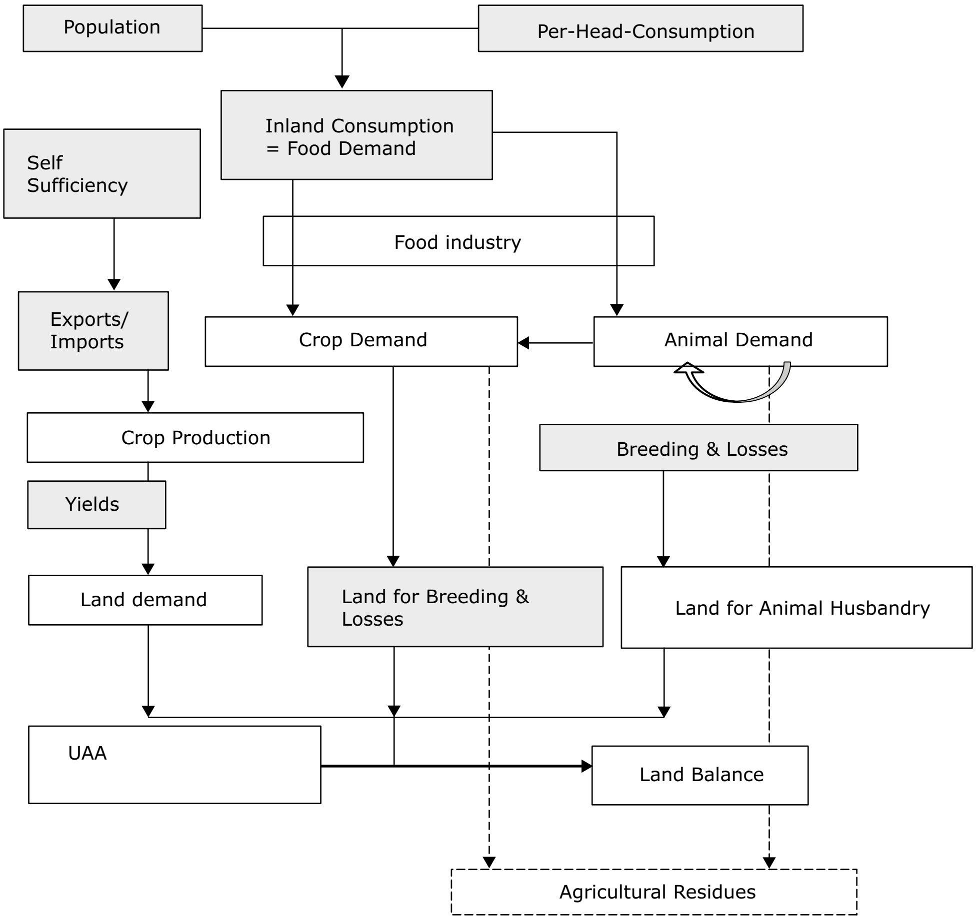
Austria								
	Minimum application kg N/ha (1)	Maximum application kg N/ha (2)	Harvested kg N (per ton yield) (3)	Minimum yield (ton ha) (4)	Maximum yield (ton ha) (5)	N-loss min (6)	N-loss max (7)	Average N-loss (8)
Wheat	105	105	22	4.3	5.9	– 10.4	24.8	7.2
Barley	95	95	15	3.8	5.2	– 38	– 17	– 27.5
Rye	60	60	15	3.3	4.7	– 10.5	10.5	0.0
Oats	60	60	15	3.6	4.6	– 6	9	1.5
Grain maize. incl. corn cob maize	110	110	14	8.4	9.9	7.6	28.6	18.1
Potato	105	105	3.5	26.5	31.6	– 12.25	5.6	– 3.3
Sugar beet	88	88	1.8	57	65	14.6	29	21.8
Oilseed rape	125	125	30	1.8	3.4	– 71	– 23	– 47.0
Sunflower	45	45	28	2.5	2.8	25	33.4	29.2
Linseed	2	2	0.6	0.7	1	– 1.58	– 1.4	– 1.5

(6) N-loss assuming minimum N-application (1) and yield (4); (6) = ((3)*(4)) – (1)
(7) N-loss assuming maximum N-application (2) and yield (5); (7) = ((3)*(5)) – (2)
(8) Average N-loss: (8) = ((6) + (7))/2

Sources: FAO: FAOSTAT average national yield 2000–2005.

Annex IX HEKTOR Model

Figure IX-1 Detailed Flow chart for HEKTOR



▒ Grey box: based on statistical data, dynamic over time by an analysis of trends

☐ White box: based on own calculations

Table IX-1 Degree of self-sufficiency for the EU-25 assumed in the CAPSIM model

	2001	2011	2020	2025
Cereals	108 %	105 %	107 %	109 %
Oilseeds and pulses	51 %	51 %	52 %	52 %
Other arable crops	98 %	99 %	99 %	99 %
Perennials	63 %	63 %	62 %	62 %
Fodder	100 %	100 %	100 %	100 %

Table IX-2 Increase of commodity prices relative to the year 2000

	2010	2020	2020
Rapeseed oil	110 %	121 %	200 %
Round wood	115 %	132 %	152 %
Sugar	115 %	127 %	200 %
Wheat, maize	113 %	125 %	138 %

Annex X Crop mix for energy crops per Member State and time step

Table X-1 Actual crop mix by Member State, the year 2000

2000	Oilseed rape	Sunflower seeds	Sugar beet	Maize total	Wheat total	Barley, rye etc.	Other oilseeds
EU-15							
AT	1.4 %	0.6 %	1.4 %	7.4 %	8.9 %	11.2 %	0.6 %
BE	0.3 %	0.0 %	6.2 %	14.8 %	13.8 %	5.3 %	1.0 %
DE	5.0 %	0.1 %	2.7 %	9.1 %	17.7 %	21.8 %	0.3 %
DK	2.4 %	0.0 %	2.2 %	2.9 %	22.7 %	34.0 %	0.0 %
ES	0.1 %	3.9 %	0.6 %	2.8 %	11.7 %	19.0 %	0.6 %
FI	2.4 %	0.0 %	1.2 %	0.0 %	5.9 %	38.5 %	0.1 %
FR	3.1 %	2.0 %	1.5 %	11.7 %	18.2 %	7.8 %	0.0 %
GR	0.0 %	0.3 %	0.9 %	4.4 %	17.7 %	3.5 %	7.6 %
IE	0.0 %	0.0 %	0.7 %	0.4 %	2.0 %	4.5 %	0.0 %
IT	0.2 %	1.8 %	1.7 %	10.0 %	17.0 %	3.8 %	0.0 %
NL	0.0 %	0.0 %	5.7 %	12.1 %	6.9 %	3.9 %	0.3 %
PT	0.0 %	1.3 %	0.2 %	8.4 %	7.0 %	4.6 %	0.0 %
SE	1.1 %	0.0 %	2.0 %	0.0 %	13.9 %	28.6 %	0.2 %
UK	2.5 %	0.0 %	1.2 %	0.8 %	12.8 %	8.7 %	0.3 %
EU-8							
CZ	7.7 %	0.7 %	1.7 %	6.6 %	21.4 %	15.0 %	1.3 %
EE	3.6 %	0.0 %	0.0 %	0.1 %	7.8 %	27.0 %	0.0 %
HU	2.0 %	5.8 %	1.0 %	22.6 %	18.6 %	10.0 %	0.5 %
LT	1.9 %	0.0 %	0.9 %	0.5 %	12.0 %	20.1 %	0.2 %
LV	0.5 %	0.0 %	0.6 %	0.0 %	6.7 %	11.2 %	0.0 %
PL	2.8 %	0.0 %	2.0 %	2.6 %	16.1 %	36.9 %	0.1 %
SI	0.2 %	0.0 %	1.1 %	13.7 %	7.2 %	3.4 %	0.5 %
SK	4.6 %	2.8 %	1.4 %	10.6 %	18.1 %	11.6 %	0.3 %

Source: CAPSIM.

	Traditional arable crops						Whole crops					
MS	**Rape seeds**	**Sunflower seeds**	**Sugar beets**	**Maize corn**	**Wheat corn**	**Barley/ triticale corn**	**Maize whole plant**	**Triticale whole plant**	**Wheat whole plant**	**2-culture opt.**	**2-culture opt.**	**Sweet sorghum**
AT	10 %	10 %	0 %	30 %	25 %	25 %	0 %	0 %	0 %	0 %	0 %	0 %
BE	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
DE	10 %	0 %	0 %	10 %	20 %	15 %	0 %	0 %	0 %	20 %	10 %	0 %
DK	0 %	0 %	0 %	10 %	30 %	25 %	0 %	0 %	0 %	20 %	10 %	0 %
ES	0 %	10 %	0 %	10 %	30 %	20 %	0 %	0 %	0 %	0 %	0 %	15 %
FI	0 %	0 %	0 %	0 %	45 %	20 %	0 %	0 %	0 %	10 %	5 %	0 %
FR	0 %	5 %	0 %	15 %	40 %	10 %	0 %	0 %	0 %	10 %	5 %	0 %
GR	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
IE	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
IT	0 %	5 %	0 %	15 %	20 %	15 %	0 %	0 %	0 %	0 %	10 %	10 %
NL	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
PT	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
SE	0 %	0 %	0 %	0 %	30 %	25 %	0 %	0 %	0 %	10 %	5 %	0 %
UK	0 %	0 %	0 %	15 %	40 %	20 %	0 %	0 %	0 %	10 %	5 %	0 %
CZ	15 %	0 %	0 %	10 %	20 %	20 %	0 %	0 %	0 %	0 %	5 %	0 %
EE	0 %	0 %	0 %	0 %	35 %	40 %	0 %	0 %	0 %	0 %	5 %	0 %
HU	10 %	5 %	0 %	5 %	20 %	15 %	0 %	0 %	0 %	10 %	5 %	0 %
LT	0 %	0 %	0 %	0 %	30 %	30 %	0 %	0 %	0 %	10 %	5 %	0 %
LV	0 %	0 %	0 %	0 %	30 %	30 %	0 %	0 %	0 %	10 %	5 %	0 %
PL	15 %	0 %	0 %	10 %	15 %	15 %	0 %	0 %	0 %	15 %	5 %	0 %
SI	10 %	5 %	0 %	5 %	20 %	15 %	0 %	0 %	0 %	0 %	10 %	0 %

	Perennials					
MS	**SRC poplar**	**SRC willow**	**Miscanthus**	**Reed canary grass**	**Giant reed**	**Switchgrass**
AT	0 %	0 %	0 %	0 %	0 %	0 %
BE	0 %	0 %	0 %	0 %	0 %	0 %
DE	0 %	5 %	5 %	0 %	5 %	0 %
DK	0 %	0 %	0 %	5 %	0 %	0 %
ES	0 %	0 %	0 %	0 %	15 %	0 %
FI	0 %	0 %	0 %	10 %	0 %	10 %
FR	0 %	0 %	5 %	10 %	0 %	0 %
GR	0 %	0 %	0 %	0 %	0 %	0 %
IE	0 %	0 %	0 %	0 %	0 %	0 %
IT	0 %	0 %	5 %	0 %	10 %	10 %
NL	0 %	0 %	0 %	0 %	0 %	0 %
PT	0 %	0 %	0 %	0 %	0 %	0 %
SE	5 %	5 %	0 %	10 %	0 %	10 %
UK	0 %	0 %	0 %	5 %	0 %	5 %
CZ	0 %	5 %	10 %	0 %	0 %	15 %
EE	5 %	5 %	5 %	5 %	0 %	0 %
HU	0 %	5 %	10 %	0 %	0 %	15 %
LT	5 %	5 %	5 %	10 %	0 %	0 %
LV	5 %	5 %	5 %	10 %	0 %	0 %
PL	5 %	5 %	0 %	0 %	0 %	15 %
SI	0 %	5 %	10 %	5 %	0 %	15 %

Table X-3 Crop mix for energy crops by Member State, the year 2020

	Traditional arable crops						Whole crops					
MS	**Rape seeds**	**Sunflower seeds**	**Sugar beets**	**Maize corn**	**Wheat corn**	**Barley/ triticale corn**	**Maize whole plant**	**Triticale whole plant**	**Wheat whole plant**	**2-culture opt.**	**2-culture opt.**	**Sweet sorghum**
AT	5 %	5 %	0 %	5 %	10 %	10 %	0 %	15 %	15 %	10 %	0 %	0 %
DE	5 %	0 %	0 %	0 %	5 %	5 %	0 %	5 %	10 %	25 %	10 %	0 %
ES	0 %	0 %	0 %	0 %	0 %	0 %	5 %	15 %	20 %	0 %	5 %	25 %
FI	0 %	0 %	0 %	0 %	0 %	0 %	0 %	10 %	20 %	15 %	10 %	0 %
FR	0 %	0 %	0 %	0 %	0 %	0 %	0 %	10 %	35 %	15 %	10 %	0 %
GR	0 %	0 %	0 %	0 %	0 %	0 %	0 %	10 %	15 %	0 %	0 %	5 %
IT	0 %	0 %	0 %	0 %	0 %	0 %	0 %	15 %	20 %	0 %	5 %	25 %
SE	0 %	0 %	0 %	0 %	0 %	0 %	0 %	15 %	20 %	10 %	15 %	0 %
UK	0 %	0 %	0 %	0 %	0 %	0 %	0 %	15 %	20 %	15 %	10 %	0 %
CZ	5 %	0 %	0 %	0 %	0 %	0 %	0 %	15 %	20 %	0 %	15 %	0 %
EE	0 %	0 %	0 %	0 %	0 %	0 %	0 %	10 %	25 %	5 %	10 %	0 %
HU	5 %	0 %	0 %	0 %	0 %	0 %	0 %	15 %	20 %	0 %	15 %	0 %
LT	0 %	0 %	0 %	0 %	0 %	0 %	0 %	10 %	25 %	15 %	10 %	0 %
LV	0 %	0 %	0 %	0 %	0 %	0 %	0 %	10 %	25 %	15 %	10 %	0 %
PL	5 %	0 %	0 %	0 %	0 %	0 %	0 %	10 %	10 %	20 %	10 %	0 %
SI	0 %	0 %	0 %	0 %	0 %	0 %	0 %	15 %	20 %	0 %	15 %	0 %
SK	0 %	0 %	0 %	0 %	0 %	0 %	0 %	20 %	20 %	0 %	10 %	0 %

	Perennials					
MS	**SRC poplar**	**SRC willow**	**Miscanthus**	**Reed canary grass**	**Giant reed**	**Switchgrass**
AT	0 %	0 %	15 %	5 %	0 %	5 %
BE	0 %	0 %	0 %	0 %	0 %	0 %
DE	5 %	5 %	10 %	0 %	10 %	5 %
DK	0 %	0 %	0 %	0 %	0 %	0 %
ES	0 %	0 %	5 %	0 %	25 %	0 %
FI	5 %	5 %	5 %	15 %	0 %	15 %
FR	5 %	5 %	10 %	5 %	0 %	5 %
GR	0 %	0 %	20 %	0 %	25 %	25 %
IE	0 %	0 %	0 %	0 %	0 %	0 %
IT	0 %	0 %	5 %	0 %	20 %	10 %
NL	0 %	0 %	0 %	0 %	0 %	0 %
PT	0 %	0 %	0 %	0 %	0 %	0 %
SE	10 %	10 %	0 %	10 %	0 %	10 %
UK	5 %	5 %	0 %	15 %	0 %	15 %
CZ	0 %	10 %	15 %	0 %	0 %	20 %
EE	5 %	10 %	10 %	20 %	0 %	5 %
HU	5 %	10 %	10 %	0 %	0 %	20 %
LT	5 %	5 %	5 %	20 %	0 %	5 %
LV	5 %	5 %	5 %	20 %	0 %	5 %
PL	10 %	10 %	0 %	0 %	0 %	25 %
SI	5 %	10 %	10 %	0 %	0 %	25 %
SK	10 %	10 %	10 %	10 %	0 %	10 %

Source: own assumptions.

Table X-4 Crop mix for energy crops by Member State, the year 2030

	Traditional arable crops						Whole crops					
MS	**Rape seeds**	**Sunflower seeds**	**Sugar beets**	**Maize corn**	**Wheat corn**	**Barley/ triticale corn**	**Maize whole plant**	**Triticale whole plant**	**Wheat whole plant**	**2-culture opt.**	**2-culture opt.**	**Sweet sorghum**
AT	0 %	0 %	0 %	0 %	0 %	0 %	0 %	10 %	20 %	20 %	5 %	0 %
BE	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
DE	0 %	0 %	0 %	0 %	0 %	0 %	0 %	5 %	5 %	25 %	5 %	0 %
DK	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	10 %	0 %
ES	0 %	0 %	0 %	0 %	0 %	0 %	0 %	10 %	10 %	0 %	10 %	30 %
FI	0 %	0 %	0 %	0 %	0 %	0 %	0 %	5 %	25 %	15 %	10 %	0 %
FR	0 %	0 %	0 %	0 %	0 %	0 %	0 %	10 %	20 %	20 %	0 %	0 %
GR	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	10 %	10 %
IE	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
IT	0 %	0 %	0 %	0 %	0 %	0 %	0 %	5 %	5 %	5 %	0 %	25 %
NL	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	20 %	0 %
PT	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	15 %	0 %
SE	0 %	0 %	0 %	0 %	0 %	0 %	0 %	5 %	10 %	15 %	20 %	0 %
UK	0 %	0 %	0 %	0 %	0 %	0 %	0 %	5 %	5 %	20 %	15 %	0 %
CZ	0 %	0 %	0 %	0 %	0 %	0 %	0 %	10 %	10 %	0 %	20 %	0 %
EE	0 %	0 %	0 %	0 %	0 %	0 %	0 %	10 %	20 %	10 %	15 %	0 %
HU	0 %	0 %	0 %	0 %	0 %	0 %	0 %	5 %	10 %	0 %	20 %	0 %
LT	0 %	0 %	0 %	0 %	0 %	0 %	0 %	10 %	20 %	10 %	15 %	0 %
LV	0 %	0 %	0 %	0 %	0 %	0 %	0 %	10 %	20 %	10 %	15 %	0 %
PL	0 %	0 %	0 %	0 %	0 %	0 %	0 %	5 %	5 %	20 %	10 %	0 %
SI	0 %	0 %	0 %	0 %	0 %	0 %	0 %	5 %	5 %	0 %	20 %	0 %

	Perennials					
MS	**SRC poplar**	**SRC willow**	**Miscanthus**	**Reed canary grass**	**Giant reed**	**Switchgrass**
AT	0 %	0 %	25 %	10 %	0 %	10 %
BE	0 %	0 %	0 %	0 %	0 %	0 %
DE	10 %	15 %	10 %	0 %	15 %	10 %
DK	0 %	0 %	0 %	0 %	0 %	0 %
ES	0 %	0 %	10 %	0 %	30 %	0 %
FI	5 %	5 %	5 %	15 %	0 %	15 %
FR	5 %	5 %	10 %	10 %	0 %	10 %
GR	0 %	0 %	30 %	0 %	30 %	30 %
IE	0 %	0 %	0 %	0 %	0 %	0 %
IT	0 %	0 %	10 %	0 %	25 %	15 %
NL	0 %	0 %	0 %	0 %	0 %	0 %
PT	0 %	0 %	0 %	0 %	0 %	0 %
SE	15 %	15 %	0 %	10 %	0 %	10 %
UK	10 %	10 %	0 %	20 %	0 %	15 %
CZ	5 %	15 %	15 %	0 %	0 %	25 %
EE	10 %	10 %	10 %	5 %	0 %	10 %
HU	10 %	15 %	10 %	0 %	0 %	30 %
LT	10 %	10 %	10 %	5 %	0 %	10 %
LV	10 %	10 %	10 %	5 %	0 %	10 %
PL	15 %	15 %	0 %	0 %	0 %	30 %
SI	10 %	15 %	15 %	0 %	0 %	30 %

Source: own assumptions.

Annex XI Regional approaches to finding optimal farming practices for energy cropping

Climate and altitude are important factors for the agronomic capacity of regions; this is why they have been used to divide Europe into 13 environmental zones (see Annex IV). When looking at the main characteristics of the environmental zones (see Annex IV, Table IV-1) it is clear that the pedo-climatic characteristics differ strongly. The same applies for the environmental pressures these zones are confronted with. Optimal solutions for sustainable biomass cropping can only be found by taking account of regional conditions. Overall, the regional division of Europe used in this study is too rough to take account of all relevant regional characteristics. It should therefore only be taken as a first guideline for assessing sustainable biomass solutions in a local context.

Although there are very few studies that show field survey based effects of biomass crop production on environment and farmland biodiversity, there are many more studies that show the effects of arable cropping on environment and also farmland biodiversity. In the last decades increased food production in Europe has caused many negative impacts on the environment because of further intensification of land use (e.g. Buckwell & Armstrong-Brown, 2004; Wadsworth *et al*., 2003; Boatman *et al*., 1999; MAFF, 1998; Pretty, 1998; EPA, 1999; Campbell and Cooke, 1997). This increased food production went hand in hand with losses of very large areas of permanent grassland, dry steppe grasslands and wetlands, which were replaced by arable agriculture with a huge loss of biodiversity. Carey (2005) refers to serious declines in some species; declines associated with arable farmland in the late 20th century. Evidence is found in many studies based on national monitoring and long-term studies of birds, butterflies, beneficial invertebrates and annual arable flowers (Birdlife International, 2004; Vickery *et al*., 2004; Asher *et al*., 2001; Baillie *et al*., 2001; Donald *et al*. 2001, 2002; Aebischer, 1991; Donald, 1998; Sotherton, 1998 etc.). All in all, it is clear that a decline in farmland biodiversity across Europe coincided with an increase in the intensity of agricultural production. Heath *et al*. (2000) showed for example that the decline in farmland-birds and the intensification of agriculture are correlated.

Alpine North, Boreal and Nemoral zone
EU countries with dominant agricultural land use in these zones are Sweden, Finland and all the Baltic States. It is evident from crop prioritisation that only a limited number of arable and perennial crops are suitable for biomass production for these zones. For arable crops, rape, sugarbeet and potato perform badly from an environmental perspective. Therefore, an increased demand for biomass should not lead to an increase of their cropping area. From an environmental perspective, different cereal types and linseed would be better, and perennial crops like reed canary grass and SRC willow would be the best. Since in these zones good arable cropping land is already relatively scarce and the growing season is short, arable biomass crops would compete strongly with feed and food crops, increasing the chances for intensification. Perennials would be the best option as these can be grown on the sub-optimal soils, wasteland and/or abandoned lands, and will therefore not compete with food and feed production. Perennials like SRC willow may also be very suited to multifunctional applications. A relevant example are plantations that deliver ligno-cellulose material for biogas and second generation bio-ethanol production (in the future) and are used for waste-water treatment at the same time. Such synergetic applications are already in place in Sweden, Poland, Denmark and Estonia and are described in more detail in next section (Box 8.3).

Atlantic North
The main EU regions covering this zone are Denmark, Northern parts of Germany, Scotland, Northern England, Wales and Northern Ireland. It is a region where agricultural land use is still relatively important (almost 80 %) in terms of land use share. Of the agricultural land grassland is most the most dominant in this zone and arable land also takes around 1/3 of the UAA. In some regions, however, such as northern Germany and Denmark, arable is more dominant; these regions are also where the highest increase in biomass cropping can be expected. From crop prioritisation it became clear that the range of arable and perennial crops suitable for biomass production is not very large for this zone. Like in the other most northern bound zones, from the arable crops oil seed rape, sugarbeet

and potato perform badly from an environmental perspective. Thus, increased demand for biomass should not lead to an increase in their cropping area. However, the area grown with rape has already increased tremendously in this zone because of the biofuels demand. A better choice from an environmental perspective would be hemp, mustard seed, linseed and different cereal types, especially rye, oats, barley and triticale. Cereals are the best option in a compromise between economy (yield) and environment. The double cropping practice would also be an option in this zone, although yields would not be as high as in southern zones such as Atlantic Central and Continental. Perennial crops would be the best crop option from an environmental perspective and the types most suited for this zone would be permanent grass, miscanthus, switchgrass, reed canary grass and SRC willow and poplar.

Environmental risks in this zone are connected mostly to intensity of farming on the one hand and abandonment in extensive, often high nature value, farming areas on the other. The first creates problems with soil and water quality through eutrophication, pollution with pesticides and soil compaction while the latter causes changes in landscape and habitats often leading to loss of biodiversity. An additional demand for land for biomass crop production in this zone could therefore increase the pressure on land and could lead to a further intensification of land use in the already intensive arable production parts. However, it could also cause undesirable land use changes in the more extensive farmland areas often coinciding with HNV farmland. With the introduction of biomass crops in this zone measures should be taken to prevent further rotation tightening, monotonisation of the (arable) land use, higher input use and mechanisation. The introduction of innovative production systems, such as mulch systems, double cropping, multiple cropping and row and strip intercropping (see Box 8.3), could be sustainable options for biomass production in this zone. They could even provide opportunities for extensification in the more intensive arable parts. In the more remote and mountainous parts of this region, where HNV farming is still important, the introduction of perennials like SRC willow and poplar could be an option, but only if it does not lead to the ploughing of semi-natural grasslands or other valuable habitats (moors and heathlands). These SRC plantations may also be suited to multifunctional applications in which they deliver ligno-cellulose material for biogas and (in future) second generation bio-ethanol production, but at the same time are used for waste-water treatment (see Box 8.3). The harvesting of grass from abandoned grazing land could also be an interesting biomass option with multifunctional purposes (see Box 8.2).

Alpine South

Main EU regions covering this zone include all Alpine parts of Austria, France and Italy and Slovenia, the higher Pyrenees on the border with France and Spain and the Carpathian mountain ranges of eastern Europe. Generally, agriculture in this zone is strongly constrained by topography (steep slopes and altitude) and climate (cold and long snow cover above 1000 meters). Only a small part of the land is agricultural (40 %) and arable land use enjoys a very small part of the UAA (8 %). This implies that there is practically no room for biomass cropping in this region and if introduced it would strongly compete with other agricultural and non-agricultural land uses.

The choice of arable biomass crops suited for this region is quite wide, but the most environmentally sustainable arable crop options are hemp, mustard seed, clover/alfalfa, linseed, sunflower and cereal mixes. Cereals and sunflower and some rape are the best options in a compromise between economy (yield) and environment. The double cropping practice would also be an option in this zone. Perennial crops would be the best crop option from an environmental perspective and the types most suited for this zone would be permanent grass, miscanthus, switchgrass, and SRC willow and poplar.

Both intensification in the valleys and land abandonment in the mountains is a problem in this region. Large scale introduction of biomass cropping is not an option due to the very limited amount of arable land available. Significant bioenergy cropping could certainly add to the already high pressure on land in this zone. If biomass crops are introduced at small scale, this should be accompanied by measures that prevent an increase of environmental pressure through further intensification or the conversion of semi-natural grasslands to arable land, in particular on steep slopes. The introduction of innovative production systems such as mulch systems, double cropping, multiple cropping and row and strip intercropping (see Box 8.3) could also be sustainable options for biomass production in this zone. The harvesting of grass from abandoned grazing land could also be an interesting biomass option with multifunctional purposes (see Box 8.2), but large scale practices cannot be expected given the remote character of the region which causes overly high transport costs, making such applications economically difficult.

Continental and Pannonian zone
These zones cover large parts of Europe, practically all new Member States, the southern most parts of Sweden and the Baltic States as well as two thirds of Germany. Agricultural land use is clearly dominated by arable activities and covers two thirds of total land use in the continental zone and more than 75 % of land in the Panonnian zone. In this zone there is a wide choice of suitable biomass crops. The most environmentally sustainable arable crops would be hemp, mustard seed, clover-alfalfa, linseed, sunflower, sorghum (only in Pannonian) and cereal mixes (except wheat). But again, in a compromise between economy and environment the best options would be sunflower, sorghum, cereal mixes and rape. The double cropping practice would also be an option in the continental zone, but not in the Pannonian where water is relatively scarce especially during long hot summers. Perennial crops would be the best crop option from an environmental perspective and the choice of crops is quite extensive, ranging from permanent grass, miscanthus, switchgrass, Reed Canary grass and SRC willow and poplar.

The opportunities for the widespread introduction of biomass cropping are quite good in this zone since there is plenty of relatively well suited arable land available. However, this is certainly not without the increasing risk of environmental problems and loss of farmland biodiversity. Agricultural land use varies very strongly in intensity. Both intensification and land abandonment is a problem in this region, especially where natural constraints are strongest in relation to topography (steep slopes and higher altitudes), soil quality (e.g. shallow, wet, peaty, alkaline soils) and/or climate (very arid zones e.g. semi-steppes or mountain ranges with long cold winters) and where farm structures are still dominated by small family holdings HNV farmland is dominant.

With the introduction of biomass crops in these zones, it will also be important to accompany introduce measures that prevent further rotation tightening, monotonisation of the (arable) land use, higher input use and mechanisation. The introduction of innovative production systems such as mulch systems, double cropping, multiple cropping and row and strip intercropping (see Box 8.3) could be sustainable options for biomass production in this zone. They could even provide opportunities for extensification in the more intensive arable parts, e.g. in Germany, Czech republic, Poland, Hungary. In the more remote, mountainous parts or wetlands of this region, where HNV farming is still important, the introduction of perennials like SRC willow and poplar and perennial biomass grasses could be an option, but only if this does not lead to the ploughing of semi-natural grasslands or the draining of wetlands or other valuable habitats. Some SRC plantations may also be suited for multifunctional applications delivering ligno-cellulose material waste-water treatment (see Box 8.3). Since land abandonment is significant in these zones, opportunities for grassland cutting for biomass would certainly be an interesting option to investigate (see Box 8.2).

Atlantic Central and Lusitanian
Along with the Continental zone, these zones have the greatest potential for taking up Europe's biomass cropping needs. The most important regions covered by these zones are Ireland, central and southern England, the Netherlands, Belgium, the largest arable cropping areas of France, northern Spain and the northern half of Portugal. Agricultural land use is very important and covers around 70 % of the land use in both zones with arable land using almost 50 % of the UAA in the Atlantic part but less than 30 % in the Lusitanian part. The choice of most environmental biomass crops are the same as in the Continental and Pannonian zones, and this also applies to the mix that is the best compromise between economy and environment. The double cropping practice would also be an option in both zones. However, if water resources become scarce in the Lusitanian zone due to climate change, this could change. Perennial crops would be the best crop option from an environmental perspective and the best choice of crops would be permanent grass, miscanthus, switchgrass, SRC willow and poplar. Giant reed and SRC Eucalypthus would be possible but not advisable from an environmental perspective, as they would cause water abstraction problems in particular.

The opportunities for the widespead introduction of biomass cropping are good in this zone since there is plenty of relatively well suited arable land available. However, environmental problems in these zones are already large and especially relate to high intensity agricultural land use, causing problems with soil erosion and compaction, eutrophication, pesticide pollution and habitats fragmentation. Land abandonment is less of a problem, except in parts of the Lusitanian zone. The introduction of biomass crops may cause further intensification, but will also offer opportunities for extensification if accompanied with innovative biomass cropping systems, such as mulch systems, double cropping, multiple cropping and row and strip intercropping (see Box 8.3). Similar to the other zones, the introduction of biomass crops needs to be accompanied by measures that prevent further rotation tightening, monotonisation of the (arable) land use, higher input use and mechanisation. In the more remote, mountainous parts of the Lusitanian zone, where HNV farming is still important, the introduction of perennials like SRC willow and poplar (with or without water treatment applications) and perennial biomass grasses could be an option, but only if this does not lead to loss of extensive land use categories and other valuable habitats. Opportunities for grassland cutting for biomass also need to be investigated in this zone (see Box 8.2).

Mediterranean mountains
This zone covers all non-alpine mountain areas of the Mediterranean. Natural constraints are strong in this zone in relation to topography (i.e. steep slopes and higher altitudes) and/or soil quality (e.g. shallow, wet and alkaline soils) and/or climate (e.g. short growing season in higher mountains but generally low precipitation). In spite of this more than 50 % of the land is still used for agriculture. However, less than 20 % of this UAA is arable. Similar to the Alpine zone, this zone is characterised by intensification in the areas least constrained by natural factors, while abandonment is a large problem in the rest of the zone. Consequently, there is not sufficient room in this zone for biomass cropping. If introduced, it would compete strongly with other agricultural and non-agricultural land uses.

The choice of arable biomass crops suited to this region is limited, but does allow for crops that could only be grown efficiently under irrigation in the rest of the Mediterranean. The most environmentally sustainable arable crop options are Clover-alfalfa, hemp, sunflower and cereal mixes. Cereals and sunflower are the best option in a compromise between economy (yield) and environment. Double cropping options are also possible in this zone. There are also some novel crops for the Mediterranean zones, which up to now have only been experimental, but might be a sustainable option in the near future, e.g. Jerusalem artichoke, Brassica carinata and Cynara cardunculus. The attractive characteristics of these crops are that they can provide relatively high biomass yields under arid circumstances. The perennials with the best environmental performance are permanent grass, miscanthus, switchgrass and SRC types of willow, poplar (in wetter conditions) and black locust and Iberian elm (in drier conditions) with or without water treatment applications.

Although intensification can cause environmental problems land abandonment poses a greater problem in this region. Large scale introduction of biomass cropping is not an option due to the limited amount of arable land available and the terrain. The terrain either does not lend itself to large scale biomass production and/or would make the transport of sufficient amounts of biomass to conversion installations financially unfeasible. If biomass crops are introduced in small quantities, it should be carried out in innovative production systems such as mulch systems, double cropping and multiple cropping (see Box 8.3 in Section 8.4). The harvesting of grass from abandoned grazing land could also be an interesting biomass option with multifunctional purposes (see Box 8.4 in Section 8.4). However, large scale practice cannot be expected, given the remote character of the region; high transport costs would make such applications economically unviable.

Mediterranean north and south
This region covers all central and southern regions of Spain, the rest of Italy and Greece, except for its mountainous regions. 80 % of the region's land is used for agriculture; of which almost 45 % is arable in the Mediterranean North and 27 % in the Mediterranean South. Environmental problems in these zones are extensive and include erosion, water abstraction, fire risk and land abandonment. Biomass options for this zone should not exacerbate these problems, but instead help to contain some of them. Therefore, biomass crop production should not lead to a further increase in agricultural water use.

The choice of present conventional arable crops for an environmentally sustainable biomass production is very limited and includes clover-alfalfa, sunflower and sorghum. The latter two give the best yields, yet add to the existing risk of adding to agricultural water demand in the region. Only with novel crops, giving relatively high biomass yields under arid conditions, can sustainable biomass crop production be realized in this zone. These types of crops, which could be castor bean, Jerusalem artichoke, *Brassica carinata, Cynara cardunculus*, and prickly pear, still need considerable research and field testing. A substantial amount of work would be needed to incorporate these crops into the present farming systems in these zones. The same applies to the perennial crops which include Miscanthus, Switchgrass and the novel crop *cynara cardunculus* as the most promising from an environmental perspective. Giant reed and SRC Eucalypthus would be possible but not advisable from an environmental perspective, especially due to water abstraction problems.

In addition to cropped biomass, it would also be useful to investigate the use of biomass residues from forests and abandoned shrub lands. The extraction of biomass in these types of land could be a significant help in preventing or reducing forest fires, which are a big problem in the Mediterranean. On the other hand, by-products have their problems especially in relation to quality, security of supply, regulations, inelastic markets and energy density (per ha) causing specific logistics problems. The best way forward for the Mediterranean seems to be to develop bioenergy chains using a combination of biomass sources (see JRC, 2006). Another niche for the Mediterranean might the introduction of cropping systems that combine perennial biomass crop production with erosion prevention, which is a major environmental issue in these zones. In the US, Switchgrass was especially developed for this purpose. In intensive arable agricultural regions of the Mediterranean, where monocultures dominate (e.g. cereals, cotton), the introduction of energy crops may help to increase crop diversity at regional level. Sustainable production system, which could be tested in such regions, include row or strip cropping and mulch systems.

Annex XII Final results: potentials by Member State in MtOE

Table XII-1 Potential by Member State, *high* energy prices and *high* yields

	MtOE			PJ		
	Year 2010	**Year 2020**	**Year 2030**	**Year 2010**	**Year 2020**	**Year 2030**
Country	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**
AT	0.6	1.4	2.1	25.5	60.1	86.4
BE	0.1	0.1	0.1	4.4	3.8	3.0
DE	5.0	13.7	23.4	211.3	573.8	977.8
DK	0.4	0.1	0.1	15.7	2.5	3.0
ES	7.8	12.9	16.0	324.7	539.6	670.8
FI	1.9	1.8	1.3	78.4	75.4	54.0
FR	2.6	7.8	17.0	106.8	327.9	712.2
GR	0.0	1.7	2.2	0.0	71.4	91.0
IE	0.0	0.1	0.1	0.0	4.8	5.9
IT	4.1	8.9	15.2	170.4	371.9	636.5
NL	0.2	0.5	0.7	6.9	20.3	29.1
PT	0.7	0.8	0.8	30.0	35.3	34.0
SE	0.6	1.1	1.4	24.1	46.8	58.3
UK	3.4	8.8	14.7	141.6	369.8	616.5
EU-15 (EU-14)	**27.2**	**59.8**	**95.0**	**1 139**	**2 503.4**	**3 978.5**
CZ	0.8	1.3	1.6	32.0	54.5	68.8
EE	0.4	1.1	1.3	15.4	45.0	56.3
HU	1.2	2.2	3.1	51.1	92.0	130.5
LT	2.0	5.6	7.9	84.8	233.8	332.1
LV	0.4	1.0	1.5	16.4	42.9	64.6
PL	14.5	24.1	30.4	608.2	1 011.0	1271.4
SI	0.0	0.1	0.2	0.9	2.8	9.2
SK	0.2	0.6	1.2	9.2	24.4	49.4
EU-10 (EU-8)	**19.5**	**36.0**	**47.3**	**817.9**	**1 506.4**	**1 982.5**
EU-25	**46.8**	**95.8**	**142.4**	**1 957.8**	**4 009.8**	**5 960.9**

Table XII-2 Potential by Member State, *low* energy prices and *high* yields in PJ

	MtOE			PJ		
	Year 2010	**Year 2020**	**Year 2030**	**Year 2010**	**Year 2020**	**Year 2030**
Country	**Country**	**Total**	**Total**	**Total**	**Total**	**Total**
AT	0.6	1.4	2.1	25.5	60.1	86.4
BE	0.1	0.1	0.1	**4.4**	**3.8**	**3.0**
DE	**1.8**	**1.0**	**1.3**	76.4	42.6	56.1
DK	0.4	0.1	0.1	15.7	2.5	3.0
ES	7.8	12.9	16.0	324.7	539.6	670.8
FI	1.9	1.8	1.3	78.4	75.4	54.0
FR	2.7	3.0	1.6	112.9	126.0	65.7
GR	0.0	1.7	2.2	0.0	71.4	91.0
IE	0.0	0.1	0.1	0.0	4.8	5.9
IT	4.1	8.9	15.2	170.4	371.9	636.5
NL	0.2	0.5	0.7	6.9	20.3	29.1
PT	0.7	0.8	0.8	30.0	35.3	34.0
SE	0.6	1.1	1.4	24.1	46.8	58.3
UK	3.4	8.8	14.7	141.6	369.8	616.5
EU-15 (EU-14)	**24.2**	**42.3**	**57.6**	**1 011.1**	**1 770.3**	**2 410.3**
CZ	0.8	1.3	1.6	32.0	54.5	68.8
EE	0.4	1.1	1.3	15.4	45.0	56.3
HU	1.2	2.2	3.1	51.1	92.0	130.5
LT	2.0	5.6	7.9	84.8	233.8	332.1
LV	0.4	1.0	1.5	16.4	42.9	64.6
PL	14.5	24.1	30.4	608.2	1011.0	1271.4
SI	0.0	0.1	0.2	0.9	2.8	9.2
SK	0.2	0.6	1.2	9.2	24.4	49.4
EU-10 (EU-8)	**19.5**	**36.0**	**47.3**	**817.9**	**1 506.4**	**1 982.5**
EU-25	**43.7**	**78.3**	**104.9**	**1 829.0**	**3 276.7**	**4 392.8**

European Environment Agency

Estimating the environmentally compatible bioenergy potential from agriculture

2007 — 134 pp. — 21 x 29.7 cm

ISBN 978-92-9167-969-0
DOI 10.2800/13734

TH-AK-07-015-EN-N

European Environment Agency
Kongens Nytorv 6
1050 Copenhagen K
Denmark

Tel.: +45 33 36 71 00
Fax: +45 33 36 71 99

Web: eea.europa.eu
Enquiries: eea.europa.eu/enquiries

ISBN 978-92-9167-969-0
9 789291 679690

Publications Office

European Environment Agency