Review of the EU bioenergy potential from a resource efficiency perspective

Background report to EEA study

Prepared by:
B.S. Elbersen
U. Fritsche
H. Eerens
K. Overmars
J.P. Lesschen
I. Staritsky
K.P. Zulka
L. Brodski
K. Hennenberg

Date:
July 2013

EEA Project Manager:
J.-E. Petersen

With input from:
A.-D. Barbu
D.O. Clubb

Universidad de Malaga
ETCSIA
PTA - Technological Park of Andalusia
c/ Marie Curie, 22 (Edificio Habitec)
Campanillas
29590 - Malaga
Spain

Telephone: +34 952 02 05 48
Fax: +34 952 02 05 59

Contact: etc-sia@uma.es

Report authors and contributors

Recommended citation:

ETC/SIA (2013). Review of the EU bioenergy potential from a resource efficiency perspective. Background report to EEA study. Alterra, Wageningen.

Contact:

Dr. Berien Elbersen
Alterra,
P.O. Box 47; NL-6700 AA Wageningen,
the Netherlands
Email: Berien.elbersen@wur.nl

ACKNOWLEDGEMENTS

This study was funded by the European Environment Agency. We thank all EEA member countries, DG-CLIMA, DG-JRC, DG-AGRI, DG-ENER and DG-ENV for their comments to the draft report which helped us a lot in elaborating the final version. We also thank Ignacio Perez and Maria Blanco Fonseca for providing the CAPRI input and their excellent support on how to interpret the data.

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Glossary

Bioenergy: renewable energy produced from material derived from biological sources.

Biofuel: transport fuel derived from biological sources - these include wood, wood waste, agricultural crops, straw, manure, sugarcane, organic waste and by-products from food and feed production.

Biomass: biological material derived from forestry and agriculture output and by-products as well as municipal and industrial waste streams. It includes: trees, arable crops, algae and other plants, agricultural and forest residues, effluents, sewage sludge, manure, industrial by-products and the organic fraction of municipal solid waste.

Bioenergy pathway: technical route for converting biomass to energy. These vary a lot depending on the type of primary biomass, the conversion technology used and the energy end use (for heating, power or transport).

Carbon stock: pools of carbon, i.e. the overall carbon content accumulated in ecosystems. These pools include carbon in living biomass (above and below ground), dead organic matter (e.g. deadwood and litter) and soil organic carbon.

Carbon debt: the GHG emission peak that can arise from the combustion of biomass when the replacement of the biomass through plant growth (which captures carbon) takes a long time. This is not relevant for plant material with a short life cycle but can reach 100 years and more if mature trees are harvested for energy production. During the period when the plant material regrows there will be a carbon debt arising from the original combustion of biomass.

Ecosystem resilience describes two aspects of ecosystem stability: 'engineering resilience' and 'ecological resilience'. Engineering resilience describes the time it takes for an ecosystem to recover to a quasi-equilibrium state following a disturbance. Ecological resilience denotes the capacity of ecosystems to absorb disturbance without collapsing into a qualitatively different state that is controlled by a different set of ecological processes.

ILUC: stands for indirect land use change – this term describes the displacement of (agricultural) land use to third countries that results when (agricultural) production capacity in one country is eliminated due to the diversion of original output to other uses (such as diverting wheat or oilseed rape area from food to energy production).

NREAP: national renewable energy action plans. Article 4 of EU Directive 2009/28/EC on Renewable Energy required EU Member States to submit national renewable energy action plans by 30 June 2010. These plans provide detailed roadmaps of how each Member State expects to reach its legally binding 2020 target for the share of renewable energy in their final energy consumption.

Energy crops: plants grown with the explicit purpose of producing biofuel or other forms of bioenergy. These can be traditional agricultural crops or special crops that are cultivated for energy production only.

Perennial crops: agricultural crops that have a multi-annual growth cycle, i.e. do not need to be planted every year. Their lifetime can be a few years (e.g. some energy grasses) to several hundred years (e.g. olive trees). Perennial cropping generally reduces topsoil losses due to erosion, increases biological carbon sequestration within the soil and reduces waterway pollution from leaching of nutrients.

Payback time: the time it takes to 'pay off' the carbon debt, i.e. the time it takes for biomass to grow and absorb CO_2 so that the initial burst of GHG emissions that resulted from the combustion of the biomass is fully absorbed again in plant biomass. Achieving this balance may take decades or even centuries in the case of forest biomass and greenhouse gases will therefore reside in the atmosphere for a long time.

SRC: stands for short rotation coppice which is plants grown under a coppicing regime – which means that they are harvested every few years rather than when they are fully grown. High yield varieties of poplar and willow, for example, are grown as an energy crop under a coppicing regime with a short-term (5-8 year) cycle.

Storyline: storylines are employed in forward-looking analysis to vary the factors that could influence the trends to be investigated. They allow the construction of alternative futures that help to understand how different combinations of external and internal factors change future trends.

Residues: these are by-products from the harvesting of agricultural crops (annual and perennial) and from forest operations (e.g. thinning of stands or felling trees). These are normally left in the field or forest but can be employed as biomass for energy generation.

Resource efficiency: this term stands for an approach that focuses on increasing the efficiency of using natural resources and while decreasing associated environmental impacts. The approach covers production processes over their entire life cycle and has been adopted as a key policy goal in the EU 'Roadmap to a Resource Efficient Europe'.

1. Context and approach for the analysis

1.1 Report background and aims

The European Union has been developing its policy on using biomass to generate energy, in particular via biofuels, for more than a decade. Ambitious EU bioenergy targets were set in December 2005 (EC, 2005) in response to the Kyoto Protocol's requirements on reducing greenhouse gas emissions (EC, 2002) and to help cut EU energy dependency.

In view of the potential environmental impacts of greatly increasing bioenergy output, the EEA decided to investigate the 'environmentally compatible' potential of bioenergy from agriculture, forest and waste sources in Europe. The term 'environmentally compatible' was defined by EEA as an approach to biomass production that does not lead to environmentally damaging intensification of agriculture and forest production and respects relevant EU environmental legislation. Follow up work investigated the most efficient use of the bioenergy estimated to be available in the different pathways. The findings were published in three reports (EEA, 2006; EEA, 2007 and EEA, 2008a).

The 2006–2008 reports represented a substantial analytical investment based on the methods considered appropriate at the time. The international dimension of EU bioenergy policy was not considered, as analytical methods appropriate for addressing that issue were just being developed.

Since 2008, scientific knowledge, public debate and the political landscape have all evolved, generating new insights and providing a context within which the environmentally compatible bioenergy potentials should be reassessed. In addition, the European Environment Agency's Scientific Committee reviewed the development of bioenergy output in the context of more recent knowledge about indirect land use effects, ecosystem carbon cycles and greenhouse gas accounting standards, and recommended careful consideration of which bioenergy pathways and production volumes ensure real greenhouse gas savings (EEA SC, 2009 and 2011).

In recent years the International Resource Panel (UNEP, 2009 and 2011), the European Environment Agency (EEA, 2010a and 2012) and many others have shown that European and global natural resources are limited and that humanity risks transgressing potentially irreversible ecosystem boundaries (Rockström *et al*., 2009). The EU's *Roadmap to a resource efficient Europe* (EC, 2011a) represents a response to these concerns and establishes resource efficiency as the guiding principle for EU policies on energy, transport, climate change, industry, commodities, agriculture, fisheries, biodiversity and regional development.

Enhancing resource efficiency essentially means findings ways to achieve more at lower costs to the environment. This obviously implies reducing the amount of resources used to meet our needs. But it also relates to the environmental impacts — on water, air, soil and biodiversity — that result from extracting resources from natural systems and emitting wastes and pollution. Energy is a key concern in this context. Our economies and societies require energy to function and this has enormous implications for our resource use and broader impacts on ecosystems. Energy sources vary hugely in character: some are non-renewable sub-soil sources, such as coal and oil; some, such as biomass, are renewables but depletable if natural systems are not managed properly.

Since 2009, therefore, the EEA has invested substantial resources via its European Topic Centres on Air and Climate Change and Spatial Integration and Analysis into updating its previous analysis. That work has pursued five main objectives:

- updating the estimate of the 'environmentally compatible' bioenergy potential from agricultural sources on the basis of recent data and technological insights;
- integrating current knowledge on indirect land use change effects into the analysis of likely greenhouse gas savings from different EU bioenergy pathways;
- reviewing recent scientific debates on the actual greenhouse gas benefits of using forest biomass to produce energy (i.e. the 'carbon debt' concept);

- exploring the resource efficiency concept with regard to an optimal design of EU and national bioenergy policies until 2020;
- comparing current bioenergy cropping trends and cropping projections to 2020 to scientific models of the environmental impact of agricultural land use.

It must be acknowledged that an analysis of the (economic and environmental) costs and benefits of bioenergy is very complex. There are multiple types and sources of biomass and many different conversion pathways for feeding energy into end uses such as heat, power and transport. In addition, consideration needs to be given to the land use dimension, which affects carbon, soil and water resources as well as biodiversity. Evidently, developing sound carbon balances for different bioenergy pathways is a challenging task, in particular where indirect land use effects have to be taken into account.

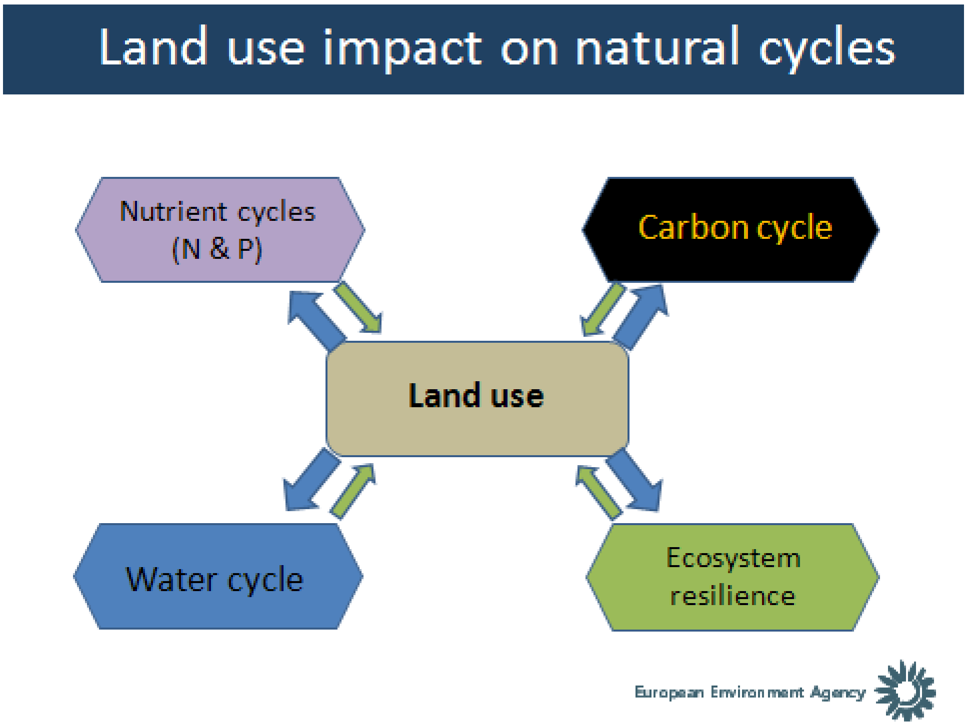
Despite the challenges, it is essential that we understand how much biomass can be produced sustainably in the EU, as well as what kinds and amounts of biomass or bioenergy carriers can be imported without negative consequences for the global environment and food security. There is also a need to maximise efficiency in terms of the resulting bioenergy output and life-cycle greenhouse gas savings.

This report aims to analyse these factors, with particular focus on agricultural land use change effects until 2020, and to contribute to policy debates about further development of bioenergy policies in the EU and elsewhere. The analytical emphasis is on the possible contribution of agricultural biomass to reaching the NREAP targets in 2020 and associated environmental effects, although wider discussions on GHG benefits from bioenergy and the use of forest and waste biomass for energy are also covered. The carbon debt issue related to the use of forest biomass is discussed but was not the subject of specific quantitative analysis in this study.

1.2 The role of renewable energy in managing our natural capital

The development of environmentally sustainable approaches to managing and exploiting natural resources – land, water, energy, ecosystems and materials – is a key challenge for societies in Europe and globally (EEA, 2010a). It has arisen due to the major impacts of human activities on the natural cycles that determine the global climate, the availability and quality of water resources, the productivity of soil resources and the resilience of ecosystem processes that underpin food production. Figure 1.1 illustrates the interactions between land use and major environmental cycles.

Figure 1.1 *Land use and ecosystem cycles*



Source: EEA, 2013b

The development of renewable energy sources is one key element of a sustainable approach to harnessing and managing the Earth's natural resources. If appropriately designed, they can help reduce greenhouse gas emissions, foster a resource-efficient use of materials, including bio-materials, and support diverse and low-input land uses. Using renewable energy can also reduce energy import dependency and provide additional employment and income opportunities in different sectors and regions of the EU. However, such positive contributions strongly depend on the way renewable energy systems are implemented and their overall economic, social and environmental sustainability.

All renewable energy sources can have positive and negative environmental impacts, depending on technology, scale, siting and operation. Solar photovoltaic systems, for example, generally have impacts linked to manufacturing and possibly recycling but raise few other issues. The impact of using wind to generate electricity is highly site specific, implying that spatial planning and operational safeguards can significantly mitigate potential negative effects. By contrast, bioenergy raises a wide variety of complex concerns relating to land and water use, the choice of cultivation systems and practices, downstream processing and final use of bioenergy carriers, which together influence overall sustainability.

1.3 Bioenergy policy objectives and the concept of resource efficiency

Bioenergy is a key energy source for short and medium term EU renewable energy supply. In 2010, renewables already made up 11 % of the EU's gross final energy consumption (EC, 2012b and 2012c). Bioenergy accounted for 68 % (EurObserv'ER, 2012) of that total and shows potential for substantial growth to 2030 and beyond (IC et al., 2012).

The Renewable Energy Directive (RED, EC, 2009) sets a general binding target for the European Union to derive 20% of its final energy from renewable sources by 2020. This includes a sub-target of 10% of EU transport energy to be derived from renewable sources. The RED also specifies that all biofuels and other bio-liquids counting towards the target must meet a set of mandatory sustainability criteria to achieve greenhouse gas reductions compared to fossil fuels and to mitigate risks related to areas of high biodiversity value and areas of high carbon stock. The mitigation criteria cover emissions related to direct land use changes. However, the European Parliament and Council asked the European Commission to examine the question of indirect land use change and possible measures to avoid it. This resulted in an impact assessment and a European Commission Communication (EC, 2010a) summarising the consultations and analytical work conducted on this topic since 2008. In this communication the European Commission acknowledges that indirect land use change can reduce the greenhouse gas emissions savings associated with biofuels and bioliquids. This resulted in the approval by the European Parliament of the Commission's proposal (EC, 2012a) for an amendment of the RED and the fuel quality Directive to (amongst other measures) limit the contribution of food-based biofuels within the overall 10% biofuel target to 5% in the future.

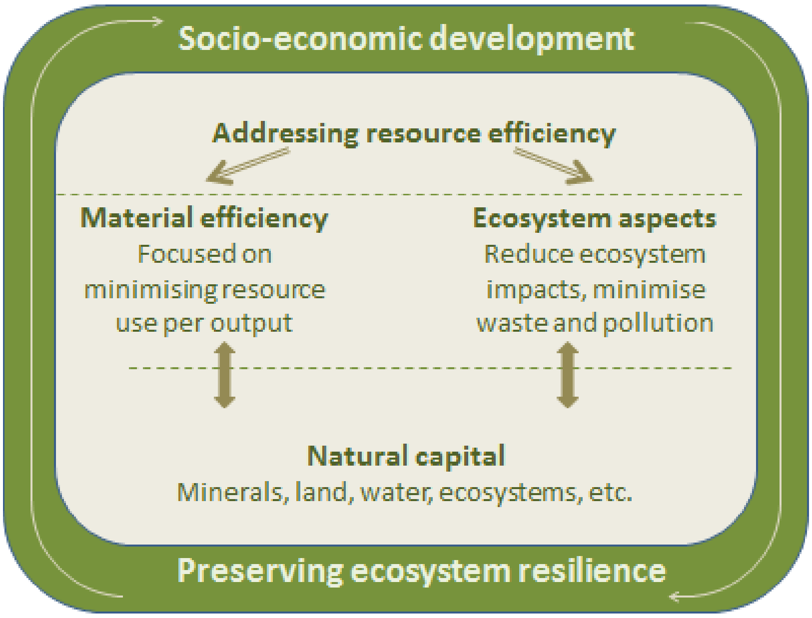
While the EU has been a bioenergy policy pioneer, many other major economies, including Canada, China, India, South Africa and the United States (US), have set ambitious targets for increasing the use of bioenergy, especially for liquid biofuels in the transport sector. National targets for renewable energy exist in at least 85 countries, including the EU-27 Member States, Australia, Canada, Israel, Japan, the Republic of Korea, New Zealand, Norway, Singapore, Switzerland, some US states and several developing countries and emerging economies including Brazil, China, Egypt, India, Indonesia, Malaysia, Mali, the Philippines, South Africa and Thailand (REN21, 2012) - see Annex 1 for more information.

The analysis in *The European environment – state and outlook 2010* (EEA, 2010a), the reports of the International Resource Panel (UNEP, 2009; UNEP, 2011) and other analyses including the Organisation for Economic Cooperation and Development's Environmental Outlook to 2050 (OECD, 2012) show that long-term environmental sustainability requires that environmental concerns are integrated in sectoral policies, including renewable energy policy.

This perspective has been adopted in EU environmental policy, most notably in the EU *Roadmap to a resource efficient Europe* (EC, 2011b) and the *Europe 2020 Strategy* (EC, 2011c)[1]. Figure 1.2 illustrates the key principles of the EU resource efficiency concept.

1 (European Commission, 2011c, pp.11–12)

Figure 1.2 *The two key aspects of resource efficiency*



Source: EEA, 2013b.

The Roadmap defines resource efficiency as 'using the Earth's limited resources in a sustainable manner' (EC, 2011b). Resource efficiency involves improving the efficiency and effectiveness with which resources are used — using less to do more, and reducing the impact from the resources that are used (EC, 2011d). Resource efficiency is therefore not simply about the amount of resources used to produce a given economic output, it also concerns humanity's impact on ecosystems and the services they provide. That includes impacts across the full life cycle, from resource extraction to end use and final disposal, and is concerned with water, air, soil quality and biodiversity.

Long-term plans for low-carbon energy supply are also included in the *EU Energy Roadmap to 2050* (EC, 2011a) and also foresee a central role for bioenergy. The Roadmap to 2050 foresees an 80–95% reduction of EU greenhouse gas emissions by 2050 and presents different routes towards a transition to a low-carbon energy system. It proposes ways to increase resource productivity and decouple economic growth from resource use and associated environmental impacts.

The commitment to resource efficiency has two important implications for the development of renewable energy, including bioenergy:

1. New energy sources should be as resource-efficient as possible, which implies that small relative reductions in greenhouse gas emissions compared to fossil-fuel based energy systems are not sufficient in a resource efficiency perspective;

2. Renewable energy sources should not lead to medium- or long-term depletion of non-renewable resources or cause negative impacts on the world's natural capital, such as forests, soil productivity, global ecosystems, or water resources.

All renewable energy sources offer potential environmental benefits and risks, and have a variable demand on natural resources, whether that is land, raw materials, ecosystems or water. However, the environmental trade-offs associated with bioenergy are particularly complex. This arises from the fact that the use of many biomass sources directly affects land use systems which influence water, nutrient and carbon cycles as well as biodiversity (see Figure 1.1). Agricultural land use in particular already exerts significant environmental pressures (EEA, 2010a; OECD-FAO,

2009) and is projected to increase its global environmental impact (FAO, 2010). An increase in the production of biomass as a source of energy is therefore likely to lead to the further intensification of existing land uses, both in agricultural and forest lands, as well as to the conversion of (semi-)natural ecosystems into cropped land or plantation forests.

A second question mark with regard to the GHG mitigation potential of bioenergy relates to the 'carbon debt' that can arise from the use of forest biomass for energy (see Section 2.6). As harvested wood or woody residues are combusted to provide energy, the carbon content of the wood is released as a one-time pulse of CO_2 whereas any forest re-growth takes place over a period of one to several decades, or even longer. This creates a 'carbon debt' that can be initially very large and then declines during the period of re-growth (for detailed discussions of the issue see Repo *et al.*, 2012 or Zanchi *et al.*, 2012).

The sections above show that there are many dimensions to take into account when evaluating the relative environmental performance of different types of bioenergy. These include the environmental issues to be evaluated, time and space as well as interactions with others sectors that are potential users of biomass. Current analytical tools and accounting systems may not always be suited to that challenge (e.g. EEA SC, 2011).

Nevertheless, while the development of bioenergy carries significant environmental risks, it needs to be acknowledged that the further development of well-designed bioenergy pathways in developing countries could help improve agricultural sustainability through a widening of crop rotations or better soil cover as well as providing additional sources of income.

A number of tropical energy crops and perennials have the characteristics to help to improve degraded soils if the right socio-political and environmental conditions are in place. In addition, access to modern bioenergy sources would support rural development objectives and could reduce pressures of deforestation and forest degradation (FAO, 2010; UNEP, 2009).

1.4 Past EEA analyses and the present report

1.4.1. Past EEA analysis

Building on limited earlier work, the EEA began in 2004 to investigate the environmentally compatible potential of biomass in Europe as well as the most efficient use of the available biomass in different bioenergy pathways. The findings were published in three reports (EEA, 2006; EEA, 2007b and EEA, 2008a).

The first two reports outlined environmental preconditions and appropriate energy crop mixes for alleviating land use pressures from energy cropping and forest harvesting on Europe's soil, water resources and biodiversity. In addition, they pointed out potential synergies between bioenergy production and the development of environmentally compatible land use in Europe if appropriate incentives and rules were introduced in bioenergy and related policies. Despite applying quite strict environmental constraints the reports identified a very substantial potential for the production of energy from European biomass, including organic residues and wastes. However, the analysis did not look explicitly into potential indirect land use effects outside Europe[2] and, with the benefit of hindsight, the technological assumptions employed appear somewhat over-optimistic.

The 2008 report utilised a scenario approach to analyse the influence of the share of different bioenergy pathways, for heat, power or transport fuels, on overall greenhouse gas savings from the available volume of biomass estimated by the preceding reports. This approach provided an insight into the relative greenhouse gas emission savings from using biomass feedstock in different bioenergy pathways,

[2] Implicitly, such effects were reflected in the approach towards agricultural land availability: using the agricultural market projections only those lands were considered as a potential which were "set free" from agricultural commodity supply (based on business-as-usual scenario of the CAPRI model for the EU-27).

explored air pollution consequences of different bioenergy technologies and estimated the relative costs of different types of bioenergy in relation to fossil energy sources. This report also worked only with an estimated European biomass potential and did not consider indirect effects in calculating the greenhouse gas balances of different pathways.

As set out in Section 1.1, scientific understanding of potential environmental benefits and costs of increasing bioenergy production has advanced substantially since 2008. In particular, better knowledge about indirect land use-change (ILUC) effects associated with EU renewable energy targets marked them as a crucial factor for the overall greenhouse gas balance of different bioenergy pathways using (agricultural) land as well as Europe's impact on global forests. In addition, new technological developments and analysis of forest carbon cycles in relation to their use for energy purposes have emerged. Together, these factors have inspired an update of the original work from the period 2006-8. Given limited resources, however, and the particular importance of ILUC effects for agricultural biomass, the analytical update has focused on the agricultural potential.

1.4.2. Analytical approach of the present study

This study builds on the previous work in terms of the analytical approaches applied but combines them in a novel way and integrates the potential consequences of global indirect land use change. It re-analyses the agricultural bioenergy potential but re-utilises the previously estimated biomass from forestry and waste resources as input to a new modelling approach on resource efficiency.

The combination of biomass estimates with knowledge on the respective efficiency of different bioenergy pathways allows an assessment of the potential development of bioenergy production in a resource efficiency perspective in three different storylines. The analysis was carried out in the context of EU bioenergy targets to 2020, in particular the targets set out in the NREAPs, which informs the technological assumptions for the different storylines.

Overall the most important differences to previous work lie in the integration of potential global indirect land use change effects in the analysis, an updated database for bioenergy pathways as well as the combination of various analytical tools to develop a resource-efficiency perspective in estimating the EU bioenergy potential.

Qualitative analysis also covers the scientific discussion on the net greenhouse gas balance (or carbon neutrality) of increased use of forest residues and stemwood for energy (e.g. Colnes *et al.,* 2012; Holtsmark, 2012; McKechnie, 2011; Schulze, *et al.* 2012). Due to restrictions in available resources, however, no targeted quantitative analysis is included in the current study. This is clearly an area where further work is required in the future.

An important methodological consideration is that the three storylines presented in this study should not be considered as an exercise in forecasting likely futures. Instead they explore plausible bioenergy development paths from a resource efficiency perspective under three specific sets of economic and political assumptions.

This means that they aim to identify how different bioenergy technologies may fare in different market and environmental contexts, and what the resulting environmental impact of EU bioenergy production and consumption might be. It should be noted that these storylines do not intend to evaluate specific policy instruments as the available analytical models and key input data do not suffice for targeted policy analysis. Nevertheless, reflecting on them can help inform EU debates on the appropriate design of EU bioenergy policies in a resource efficiency perspective. Table 1.1 below sets out the key characteristics of each of the storylines.

__Table 1.1__ Key characteristics of the three storylines

Storyline	Minimum GHG efficiency target	Consideration of ILUC effects	Technology and feedstock assumptions	Environmental constraints
Market First	None	None	Larger centralised installations Feedstock price up to 3€/GJ	No special constraints No 'no-go' areas
Climate focus	50% for biofuels only	Yes, for biofuels only	Smaller de-centralised installations; more technol. innovation; feedstock price up to 6€/GJ	No use of HNV farmland, peat land, permanent grassland or Natura 2000 areas; but for use of cuttings
Resource efficiency	50% for all bioenergy uses	Yes, for all bioenergy uses	Smaller de-centralised installations; more technol. innovation; feedstock price up to 6€/GJ	No use of HNV farmland, peat land, permanent grassland or Natura 2000 areas; but for use of cuttings; keep minimum 10% of fallow land; no irrigation of bioenergy crops

Additional information on the methodological approach adopted is provided in the analytical chapters for the respective methodological components they are building on. Furthermore, Annex 2 contains a complete overview of the differences between the present study and the EEA 2006–2008 studies.

1.5 Limitations of the present study

Most, if not all, attempts at integrated analysis, of which the present study is one example, fall short in the eyes of users or specific expert communities in one way or the other. This can be due to the analytical boundaries employed but often also has origins in the limitations brought about by imperfect input data. This section briefly describes the shortcomings of this study (as perceived by its authors). In doing so it groups the listed limitations in two groups: those linked to the analytical framework adopted and those that derive from the limitations of the available modelling tools and input data sets.

1.5.1. Choices regarding the analytical framework

- **Utilisation of biomass in different end uses:** This study has only looked at the use of biomass for energy purposes. In this context it needs to be noted that the emerging discussion on a bio-economy — as part of the broader green economy paradigm (EEA, 2012; UNEP, 2012) — goes well beyond bioenergy. The bio-economy concept encompasses, inter alia, new biomaterials such as biopolymers, the use of biomass as construction materials and for fibres and textiles etc. Technological innovation should lead to bio-refineries which promise more resource-efficient, low-waste conversion of biomass for multiple uses (IEA BioT42, 2012). These uses of biomass generally also replace materials that are sourced from fossil fuel and hence provide alternative carbon saving options. Such a comparison is a very complex analytical task, however, and was therefore not tackled.
- **Other options for increasing resource efficiency:** an example of such options is the cascading-use concept which foresees biomass to be utilised for various functions throughout its lifecycle. These developments all require a broader view on biomass in a cross-sectoral way, requiring even more complex analysis of reference systems, trade implications, and the dynamic of market interactions as well as demand-side responses.
- **Reflections on changing consumption patterns:** In the context of an ever increasing demand of human society for energy and materials around the globe improving the efficiency of resource use alone will not bring total demand below sustainable levels of extraction or utilisation. Decreasing total demand via changing consumption and life style patterns therefore needs to be part of an integrated approach to resource management (EEA, 2012).
- **Indirect effects and carbon balances linked to forest biomass:** Various types of biomass, including from forest sources, are already traded widely across the world. This implies that indirect effects on intensity of forest utilisation globally can be expected from an increasing use of European forests for bioenergy production. Linked to that effect is also the question of potential 'carbon debts' due to the delayed carbon re-stocking in forests after utilisation of forest biomass for energy purposes. Both questions could not be tackled with quantitative analysis even though the carbon debt issue is reviewed in a qualitative manner.

1.5.2. Limitations of available modelling tools and input data

- **Time horizon:** The timeline used for the current study only extends to 2020 compared to 2030 in previous studies. This is due to the fact that key modelling approaches used in the current study only allow projections to 2020. This period also corresponds with the timeframe of the NREAPs.
- **Estimation of costs of available biomass:** The potentials estimated for forest and waste biomass for 2020 were derived from the EEA 2006-2007 studies. However, their deployment for reaching the NREAP bioenergy consumption targets depends on the maximum price they can be expected to command in 2020. Input data on the cost of current biomass volumes in different EU Member States are very difficult to obtain, hence the cost assumptions for 2020 carry substantial uncertainty.

- **Biomass transport logistics:** as biomass is generally a very bulky feedstock with low energy density the logistics for collecting and transporting biomass volumes are often resource-intensive. No resources were available for reviewing how associated technology and logistics chains are likely to develop by 2020. Consequently, the estimation of available biomass volumes from agriculture, forest and waste resources may be over-optimistic.
- **Progress in biomass conversion technology:** the industrial-scale development and roll-out of 2^{nd} generation conversion technologies (e.g. biomass-to-liquid or Fischer-Tropsch processes) is difficult to predict and actual deployment has regularly lagged behind announcements from the bioenergy industry. The estimated share of such technologies in this study probably lies on the optimistic side but any such predictions are prone to substantial potential error.
- Lastly, **new potential feed stocks**, such as land-based microalgae and marine macroalgae (EC, 2012a) and renewable methane from non-biomass sources (BNetzAg, 2011) were not included in this study due to their expected limited deployment by 2020 as well as lack of knowledge on operational details of their pathways. These sources will require careful evaluation in the future.

2 Direct and indirect land use change, GHG emissions and the carbon cycle

2.1 The need for GHG emission impact assessment for bioenergy demand

A crucial dimension for assessing the impact of different bioenergy pathways is their impact on agriculture and forest land use GHG emissions and the carbon cycle. Although the focus of this study is on the environmental implications of agriculture from agricultural sources, we also pay attention to the carbon debt issue in relation to the use of forest residues which are also deployed to arrive at a complete NREAP consumption target for 2020.

The issue of GHG in bioenergy requires looking at land used for biomass production as a natural resource. This includes the soils, minerals, water and biota that the land comprises (UNEP, 1993b). Land plays an essential role in underpinning the delivery of a range of ecosystem services, from enabling the production of biomass for food, energy and products, through regulating services including water filtration and carbon sequestration, to educational and cultural services. The ability of land to provide these services depends on its management for agriculture, forestry, transport, living, recreation all of which involve land‐cover conversions and/or land‐use intensification. From a physical and economic perspective, land is an inherently fixed or finite resource limited by its extent or suitability for a particular purpose.

Cultivating more energy crops implies an additional demand for land that can increase competition for usable land[3]. The increasing competition has two main dimensions: the conversion of natural ecosystems and the intensification of existing farm and forest land (WBGU, 2008) with related impacts on environmental quality of which GHG emissions and the wider carbon cycle are discussed in this chapter.

Global studies suggest that the shift from conventional energy production, with a negligible land demand, to low-carbon energy sources, including bioenergy, could become a major driver of land use change. According to FAO (2008) this is particularly true for biofuels which are seen as one of the largest sources of new demand for land for agricultural products, beside the existing and growing land uses.

Bioenergy demand for land comes on top of the already huge and increasing demands for land for that are expected to continue to rise to meet forthcoming needs for food production (Harvey and Pilgrim, 2011; Royal Society, 2009). It is expected that the global population will reach approximately 9 billion people by 2050 (UN, 2009). Projections of the future food requirements for this population in the most optimistic scenarios indicate a related requirement of additional food production of at least 50% by 2050 (Royal Society, 2009).

Estimating the exact amount of land required for future bioenergy production is difficult, especially identifying what land use changes will take place. However, several studies done to estimate future land use changes, especially to estimate the

3 If demand for additional bioenergy crop land is met by freeing land through more intensified cultivation of conventional agricultural products, the respective impacts on, for example, greenhouse gas emissions, nitrogen and phosporous balances, water use, and (agro)biodiversity must be considered.

greenhouse gas emissions related to bioenergy-demand-induced direct and indirect land use changes, do give a clear indication. These studies are extensively discussed in the next sections in this Chapter. They show that these changes are to be taken seriously and that large conversions of natural ecosystems may be involved which will have clear impacts for on GHG emissions and the GHG mitigation potential of bioenergy.

At the same time increasing demand for food and biomass has already caused changes in land use and will continue to do so both within and, increasingly, outside Europe. These involve conversions of natural and semi-natural ecosystems to productive, directly-managed agricultural systems as well as changes in land management to more intensive uses in most instances. Intensification, which generally leads to higher output per area of land brings with it higher production efficiency and thus reduces overall land demand, or at least reduces the need for expanding the agricultural land area, depending on whether total biomass demand remains stable or increases. However, intensification is usually accompanied by stronger farm mechanisation, higher fertiliser and pesticide use and irrigation, all of which increase the risk of higher greenhouse gas emissions as well as adverse impacts on soil carbon.

Land use change, in particular deforestation and land use practices are responsible for around 15% of global greenhouse gas emissions (IPCC, 2007a). In Europe the contribution of agriculture to total greenhouse gas emissions is lower but still amounts to about 10% (Berndes *et al.*, 2011).

2.2 Direct and indirect effects

The following definitions focus on differences that are specifically relevant in a policy context.

2.2.1 Direct effects

Direct effects are those that can be directly and exclusively linked to the life cycle of the bioenergy product. During the entire life cycle of a product, resources are used, emissions occur, services or goods are delivered and people work. The changes in these elements are all regarded as direct effects. For biofuels in transport the most common boundary of the life cycle is from the growth of the biomass to its application as fuel. This well-to-wheel method is applied to determine direct greenhouse gas emissions as well as other environmental impacts. The most important direct effects are:

- land use: changes in land cover, use and/or management;
- greenhouse gas emissions;
- water use (which will be discussed in next chapter);
- employment;
- economic development/activity

In the current policy context, direct effects can be directly linked to – and therefore controlled by – the actors in the production chain. This makes criteria and regulations for direct effects potentially effective. The present EU criteria in the RED (EC, 2009a) include direct greenhouse gas emissions and direct effects on land use.

Direct greenhouse gas emissions have been the subject of intense discussions and this is also why specific sustainability criteria have been defined in the RED regarding minimal emissions savings and the use of high carbon stock and/or high biodiversity land use types for feedstock production.

2.2.2 Indirect effects

Indirect effects are those that are caused by the introduction of a bio-energy product, but which are not a direct outcome of establishing a biomass-to-energy production chain.

The production chain of a bioenergy product is just one of many production–consumption chains. These chains interact with dynamic, often global, systems, such as economic and climatic systems, ecosystems and the agricultural system. The interaction between the bioenergy sub-system and the larger systems lead to all kinds of changes in global systems beyond the immediate production factors connected to the bioenergy production chain. These are called the indirect effects as they occur through wider second-order system changes. Examples are changes in supply and demand which may influence food, fodder and fibre prices, and hence the use of extra land for agriculture.

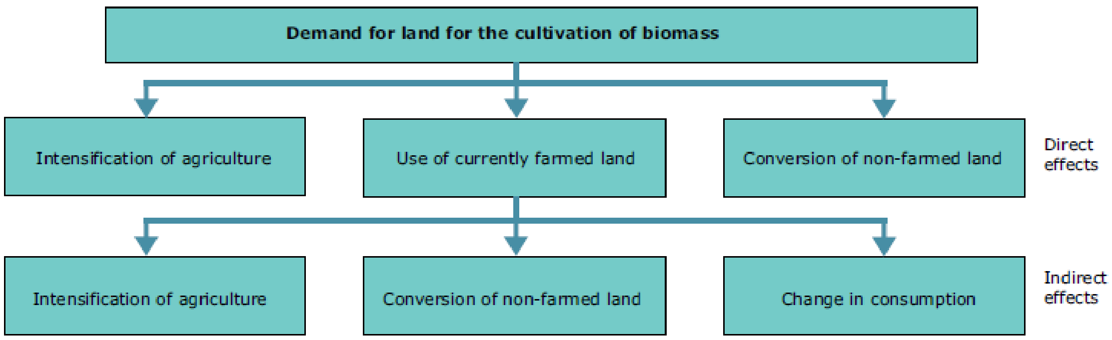
These land conversions may in turn affect fodder or land prices. The many chain reactions resulting from the production of a bioenergy product mean that every direct and indirect effect causes a new effect, although the impact becomes smaller the further the chain reaction moves from the first direct effect. However, a final equilibrium is often not reached, because these dynamic systems change continuously, as do the indirect effects.

Indirect land use change is the main indirect effect considered in this study. It results from all the system effects related to an increased demand for biomass. The next section explains the link between greenhouse gas emissions and the indirect land use change effect, and why it should be taken into account when calculating the greenhouse gas emissions avoided as a result of bioenergy pathways. Another indirect land use related effect is that the production of biofuels results in a significant amount of by-products/co-products. These enter the market and can reduce the demand for other fodder sources. Since this leads to a reduced demand for land for fodder production, this could cause a reduction in the net direct land use effect of biofuels and thus in the total greenhouse gas emissions and mitigation potential. There are several other indirect effects of bioenergy demand and the most important are discussed further in Annex 3.

2.3 Implications of agricultural land use on greenhouse gas emissions

The cultivation of energy crops requires land. The two options for growing bioenergy feedstock are the use of currently productive land, for example, agricultural or forest land formerly used for crop production for food, fodder and fibre, and the conversion of unproductive natural and semi-natural land-cover types – both result in direct land use effects. In the first option, the original crop or other productive land use, would have to be transferred elsewhere, or consumption must change (Figure 2.1). This is the starting point for the indirect effects.

Figure 2.1 *Direct and indirect effects of land use for bioenergy*



Source: Own elaboration

In the conversion of natural or semi-natural land cover, all the effects are direct, since there is a one-to-one relationship between feedstock production, land use change and related emissions. There is no indirect land use change elsewhere because there was no productive use that needs to shift to another place. However, the direct greenhouse gas emissions related to this direct land use change are usually large, especially if it involves forest lands with a very large carbon stock which is immediately lost after conversion to cropped land.

Indirect effects occur if existing agricultural land used for food and fodder production is converted to biomass for bioenergy production. This displacement leads directly or indirectly, through a number of other displacement steps, to conversion of natural lands such as tropical rainforests, savannah and wetlands, and semi-natural lands including extensively grazed grasslands into agricultural land. Secondly, part of the demand is absorbed through the intensification of existing land uses. The displacement of food and fodder production can result in three indirect effects (Figure 2.1):

1) food and fodder production is intensified in other places, leading to higher yields but no additional land use;
2) the conversion of additional natural land to agricultural use elsewhere, both inside and outside the EU;
3) a change in consumption, for example, reduced consumption due to higher land prices and higher food prices.

The mechanisms that determine the contributions from intensification, land conversion or changes in consumption to compensate for former crop production on lands used for bioenergy depend on many parameters, which vary between countries and regions. The parameters include:

• price elasticity;
• availability of suitable land;
• national policies favouring use of inputs or cultivation of land;
• the economic ability of farmers to buy inputs or invest in technologies;
• the availability of labour.

Both land use conversions and intensification can lead to additional greenhouse gas emissions. Land contains carbon, stored in vegetation and soil. The amount of carbon depends on the type of vegetation - forests and trees, for example, are high in carbon, and peat land is high in carbon. In general, agricultural land contains less carbon than natural land, even if compared to natural grassland areas.

The carbon in vegetation is released by combustion or through natural decomposition. In soil, the carbon content changes slowly to a new equilibrium which may be reached after several decades. Carbon is released into the air in the form of carbon dioxide. These emissions decrease over time. In many cases the indirect land use-change emissions are calculated as average yearly values over periods of 20–50 years – the RED applies a 20 year time horizon.

Typical total emissions for conversion to agricultural land over a 20 year period are, on average, 300–1 600 tonnes of carbon dioxide equivalent per hectare (t CO_2eq/ha) for conversion of forest, and 75–364 t CO_2eq/ha for conversion of grassland or savannah (Fargione *et al*. 2009, Searchinger *et al.* 2008; Van Minnen 2008). In Fritsche and Wiegman (2011), a global average value of 3.4 t CO_2eq/ha per year was presented assuming a 20-year time horizin, but for areas with higher conversion shares of forest this value will be significantly higher.

Indirect land use-change effects are not specific to biofuels or bioenergy, but are related to all incremental land related activities, particularly food and fodder production. Unfortunately these effects cannot be directly measured or monitored. Model calculations can provide estimates of the area and type of land needed to satisfy the demand for bioenergy production and also the related indirect land use-change effects. Several studies have recently been published showing results for estimates of indirect land use-change effects and related greenhouse gas emissions. These are discussed in Chapter 3.

Intensification is often mentioned as one way of preventing increasing demand for land. However, in the context of greenhouse gas-emission reductions this has limitations. Intensification by applying more fertilisers leads to an increase of emissions in greenhouse gases, because fertiliser-related nitrous oxide emissions increase. Generally, these are less than land expansion emissions; however in some cases they might be equal and therefore should not be ignored (PBL, 2010b).

There are also a number of additional greenhouse gas impacts which arise from indirect sources associated with bioenergy production. These are not explicitly covered by the modelling that was carried out for this report, but are discussed in Annex 3.

2.4 Analytical and modelling approaches connected to estimating indirect land use change

The previous chapters have shown that bioenergy is renewable, but not necessarily more sustainable than its fossil equivalents. This concern has led to the introduction of sustainability criteria for liquid bioenergy and biofuels in the RED, and in recent years many studies have assessed the environmental impact of biofuels, particularly in relation to greenhouse gas emissions. These are significantly influenced by potential indirect land use changes related to cultivating biomass feedstocks on previously used land. This is also why measures to avoid, reduce and compensate for possible greenhouse gas emissions are presently under discussion. Several studies on indirect land use change were conducted by the EC Directorate General – Joint Research Centre (JRC) and commissioned by the EC to third parties (EC, 2010a; EC, 2011f) to get a better understanding of the extent of indirect land use change and how it relates to the different bioenergy feedstock categories. The importance of analysing the potential direct and indirect effects of utilising biomass for energy production on global carbon cycles was also highlighted in a recent opinion of the EEA Scientific Committee (EEA SC, 2011).

Expanding the use of land for agricultural production, whether a result of demand for food, feed, biofuels or other non-food purposes, can lead to increased greenhouse gas emissions. The extent to which these effects can be related to an additional demand for biofuels or for other non-food products is difficult to determine and can only be modeled. What is known, however, is that at least 15% of global greenhouse gas emissions are related to land use changes (IPCC 2004, 2007a), principally those associated with deforestation and expansion of agricultural production for food, while less than 2% of global agricultural land is presently used for biofuel cropping (Bertzky *et al.*, 2011). Nevertheless, projected substantial global increases in the use of biofuels (IEA, 2011) in parallel with rising demands for other bioenergy (IEA, 2012) have led to critical discussions of the indirect land use change effects of additional bioenergy and biomaterials in both the scientific world and the policy domain, particularly in the EU and the United States. The reason for this is that a key argument for bioenergy production is the expected reduction of net greenhouse gas emissions, and related climate change, in the transport, energy and chemical sectors which still largely dependent on fossil feedstocks such as oil and natural gas. If, however, the greenhouse gas mitigation potential of bioenergy is diminished or even fully neutralized through indirect land use change effects, an important reason for promoting bioenergy loses validity.

This section, therefore, reviews a number of studies carried out in the last three years on the effects of indirect land use change on the greenhouse gas balances of bioenergy. As explained in Section 2.2, greenhouse gas emissions are linked to indirect land use change, which must be taken into account when calculating the overall net greenhouse gas emission reductions of bioenergy pathways and which place additional pressure from a resource efficiency perspective on scarce resources, particularly land and water.

Indirect land use change effects depend on many factors, such as the yield of the bioenergy feedstock grown, the yield of crops previously grown on the land, and the yield of the same crop in the new location to which it has been shifted because of the land use change to bioenergy feedstock cultivation. This will also vary strongly between different regions, and over time. The effect is likely to increase with growing demand for bioenergy, if no safeguard policies are employed. All biofuel targets affect the demand for agricultural commodities on the world market and this leads to a price-related production response and related land use changes, which can, through inter- and intra-national trade, occur in many different places.

This section provides an overview of indirect land use change-related greenhouse gas emissions for different biomass feedstock types in different regions of the world, based on a review of studies. The effects discussed are mostly based on targets for biofuels. However, indirect land use change effects related to wider renewable energy targets – for transport fuels and heat and electricity – are practically not discussed in current publications, because renewable heat and electricity pathways are expected, in the short- and medium-term, to be based mainly on agricultural by-products such as manure and straw, organic wastes, and wood residues – demolition wood, sawdust, forest residues etc. Nonetheless, future dedicated perennial cropping of woody or herbaceous biomass feedstocks could occur on land that is currently used for food and fodder production. The indirect land use change effects of dedicated bioenergy cropping – either annual or perennial – are, therefore, expected in the near future. The effects of perennial cropping may be comparable with those of the biofuels described in this section, though different land use per unit of useful energy output, and different by- and co-products must be considered.

It is also important to note that the inventory of studies presented in the next sub-section does not include the most recent modelling results on indirect land use change from the International Food Policy Research Institute (IFPRI)-MIRAGE-BioF model (Laborde, 2011) which was prepared as in input to the pending impact assessment on indirect land use change related to biofuels. This study will be discussed separately in Section 2.5. These most recent IFPRI results are taken as a starting point for the sensitivity assessment in Chapter 8. The results presented as the average indirect land use change factors discussed in Section 2.5 should be taken as an upper boundary of the results range of newer studies – conservative estimates of indirect land use change – while the results of the most recent IFPRI analysis (Laborde, 2011) represent the lower-end boundary in the overall analysis presented in this study in Chapters 5-7.

2.4.1 Estimates of ILUC effects of compilation of studies

A selection of studies was made for this review, which is not intended to be exhaustive, but to capture key work. The criteria for selection were that the studies should be original calculations of indirect land use change and published in the three years prior to 2012, irrespective of the methodology applied. Focus is on the main studies initiated by the EC before 2011, studies originating from several Member States, and the CARB study from the United States (California).

The studies covered in this section are:

1. IFPRI: *Global trade and environmental impact study of the EU biofuels mandate*. (Al-Riffai *et al.,* 2010).

2. Agence de l'Environnement et de la Maîtrise de l'Energie (ADEME): *Analyses de Cycle de Vie appliquées aux biocarburants de première génération consommés en France*. (ADEME, 2010).

3. E4tech: *A causal descriptive approach to modelling the GHG emissions associated with the indirect land use impacts of biofuels* (E4tech, 2010).

4. Netherlands Environmental Assessment Agency (PBL): *Identifying the indirect effects of bio-energy production.* (PBL, 2010a) and

a. *The contribution of by-products to the sustainability of biofuels.* (PBL, 2010b).

b. *Indirect land use change emissions related to biofuel consumption in the EU based on historical data.* (Overmars *et al.,* 2011).

5. California Environmental Protection Agency, Air Resources Board (CARB): *Proposed Regulation to Implement the Low Carbon Fuel Standard Volume I. Staff Report: Initial Statement of Reasons*, and *Volume II. Appendices* (CARB, 2009a; CARB, 2009b).

6. Joint Research Center – Institute for Energy (JRC-IE): *Indirect Land Use Change from increased biofuels demand* (Edwards et al., 2010).

7. Oeko-Institut - Institute for applied ecology: *The 'ILUC Factor' as a means to hedge risks of GHG emissions from indirect land use change* (OEKO, 2010).

These studies are described with regard to methods, the results, and how they can be compared and interpreted. The final results form the basis for the storyline assessments, which aim to identify the extent to which indirect land use change-related greenhouse gas emissions can best be avoided or compensated for in Europe.

2.4.2 Methods and data

Estimates of the indirect land use change effects are made not by tracing back the complex chain of effects but by identifying the net effects of total agricultural production in a situation with, and one without, additional biofuel demand. In this way marginal land use changes coming from the additional biofuel demand can be separated from changes coming from an additional demand for food and feed such as from increases in demand as a result of population growth, an increase in welfare and changes in diets.

For the calculation of land use-change effects, agro-economic models are used. In all these studies similar steps are followed:

1) the marginal land use changes are estimated in a future world with and without additional demand for biofuel;

2) an analysis is made of the differences between land uses and land use changes in situations with and without biofuel demand. From this comparison it can be determined where and how much land is displaced through biofuels and what land use changes are involved, for example, conversions of tropical rainforest, savannah or grassland. The analysis is done by country so that the displacements can be related to land use types and crops. The land use changes are estimated in hectares per year;

3) once the amount and type of land use change have been established in step 2, it can be estimated how many greenhouse gas emissions are related to those land use changes. These are expressed in greenhouse gas emissions (carbon-dioxide equivalents) per MegaJoule of biofuel and strongly depend on efficiency of land use (yield) and technology (conversion efficiency, by-product generation and utilisation).

The possible greenhouse gas implications of indirect land use change require an analysis of the quantitative relationships between:

a) additional biomass feedstock production and the displacement of previous land use(s);

b) the displaced production and its possible direct land use change effects elsewhere.

The first should be derived from economic analysis of agricultural production, for example by analysing the trade relations between countries, commodities, and markets. Land is considered an economic input factor for producing commodities so that any change in markets, trade or production can be related to changes in land use. The second needs biophysical analysis to derive the actual land use changes and the corresponding carbon dioxide emission balance.

These relationships should be reflected in the approach or model used by the studies. Also, all model features, whether the approach is a simple calculation or a complex computer model, influence the outcome of the indirect land use change calculations. Some of these result from the model structure, some from the model parameters, and the data used is also important. The general model structure is summarised in Table 2.1 in the Model/Methods column. In most cases these general model features are well described and are not part of the current discussion.

In short: partial equilibrium models take into account one or more sectors of particular interest, for example, agriculture, forestry and energy. General equilibrium models take into account all sectors of the economy. These models, therefore, calculate the effects of increasing production in one sector on production costs in other sectors. The economic modelling approaches include the price elasticity of demand for agricultural products. Life-cycle assessments focus on the product and its production, consumption and waste generated per unit of output or service. This approach is not as attached to the outside economic and biophysical world. The descriptive-causal approach consists of a tree structure with causal relationships describing the subsequent effects of the cultivation of first-generation biofuels. Part of the uncertainty and variability in the outcomes originates in the fact that these methods and models are built on different analytical approaches.

In the description of the methods and data (Table 2.1) the elements that are especially important for modelling biofuels are highlighted. Two features are essential for proper modelling of indirect land use change. First, the models should include the by-products of feedstock production, if any. Second, agricultural intensification is an essential component of the modelling approach, since the additional demand for agricultural products can be met by using more land for agriculture, but also by obtaining higher yields on current agricultural land. Both can lead to greenhouse gas emissions, although land conversion generates more of these, on average, than intensification. Third, logically, the approaches should be able to model/determine land conversion and the related emissions. Especially for calculating the latter many different assumptions can be made which have important consequences for the final greenhouse gas emissions and mitigation capacities of the biofuel/bioenergy pathway.

Table 2.1 *Main model features in relation to biofuel modelling*

Study	Model/method	Includes by-products	Intensification	Conversion emissions data
CARB	GTAP: General equilibrium model	yes	yes	Woods Hole[4]
E4tech	Causal-descriptive approach	yes	yes	Winrock[5]
ADEME	Life cycle assessment, with sensitivity analysis for indirect land use change	yes	yes	Guide for biofuels LCAt 2008, IPCC
IFPRI	MIRAGE: General equilibrium model	yes	yes	IPCC
PBL	Historic analysis of FAO data	yes	yes	IPCC
JRC	LEITAP: General equilibrium model	yes	yes	40 tC/ha for soil C emissions was used (Based on IPCC). The error bars represent the maximum range using 95 tC/ha (Searchinger *et al*, 2008), and the minimum derived from an emission factor of 10 tC/ha[6]
	FAPRI: Partial equilibrium model	yes	yes	
	AGLINK: Partial equilibrium model	yes	yes	
	GTAP: General equilibrium model	yes	yes	
	IMPACT: Partial equilibrium model	no	yes	
Oeko-Institut	LCA-approach based on trade patterns and land use change due to displacement	yes	yes[7]	IPCC

As the outcome is influenced by the data, as well as the models and parameters, an essential data component is the translation from land use change to greenhouse gas emissions, i.e. the conversion emissions (Table 2.1). The models use different sources. In some of the reports the variability of this factor is the only factor that determines the higher and lower estimates. Other models use a single value and other elements determine the high and low estimates of indirect land use change.

4 As used in Searchinger *et al.* (2008) Figures in http://www.arb.ca.gov/fuels/lcfs/ef_tables.xls
5 USEPA 2010a
6 used in FAPRI-CARD calculations with GREEN-AGSIM reported to the JRC
7 Expressed as a bandwidth of the "risk level" from 25% to 50%, see OEKO (2010) for details.

2.4.3 Differences in assumptions for greenhouse gas emission and mitigation calculation

The calculation of the greenhouse gas emissions of biofuel pathways are calculated using lifecycle analysis which involves the calculation of emissions during the whole value chain from feedstock production to final consumption of biofuels or other products. The EU RED criteria specify that for the calculation of the greenhouse gas emissions and mitigation potential of biofuels the following emissions need to be included:

$$\mathbf{E = e_{ec} + e_{l} + e_{p} + e_{td} + e_{u} - e_{sca} - e_{ccs} - e_{ccr} - e_{ee}}$$

E	=	total emissions from the use of the biofuel;
e_{ec}	=	emissions from the extraction or cultivation of raw materials;
e_{l}	=	annualised emissions from carbon stock changes caused by land use change;
e_{p}	=	emissions from processing;
e_{td}	=	emissions from transport and distribution;
e_{u}	=	emissions from the fuel in use;
e_{sca}	=	emission saving from soil carbon accumulation
e_{ccs}	=	emission saving from carbon capture and geological storage;
e_{ccr}	=	emission saving from carbon capture and replacement; and
e_{ee}	=	emission saving from excess electricity from cogeneration

In the direct emissions during cultivation and harvesting which are included in e_{ec}, e_{l}, e_{u} and e_{sca} categories, the main emissions involved are nitrous oxide emissions related to management of a crop originating from fertilizer and manure application and mechanisation and carbon dioxide emissions from loss in soil carbon stocks during cultivation – particularly important for use of organic soils. The greenhouse gas emissions from fertiliser production and mechanisation are also included. On the other hand they also include carbon accumulation in the soil, in the case of, for example, switching an arable crop to a perennial energy crop.

The downstream emissions and carbon capture after harvesting are included in e_{p}, e_{td}, e_{u}, e_{sca}, e_{ccs}, e_{ccr}, e_{ee}. They involve all emissions from the transportation of the feedstock, the pre-treatment and conversion of the crops, and also the greenhouse gas gains because of production of by-products. The latter are particularly relevant as in the biofuel chain they would include protein rich by-products such as dried distillers grains with solubles (DDGS) to be used as animal feed but also glycerine and non-fermentable residues which can be used in a thermal power plant to generate electricity and heat. The calculation of the gains in greenhouse gases from these by-products equals the emission of products they replace, such as soy-feed in the case of DDGS and fossil oil in the case of glycerine. The emission of the replaced products, emitted throughout their own life cycle, can be allocated in the greenhouse gas balance of biofuels as gains.

Table 2.2 *Factors determining the total GHG emissions and mitigation potential for biofuels*

Factor	Explanation	Uncertainty/range
Above and below ground biomass carbon stock (ABCS) emissions	This factor specifies the change in biomass carbon contained in the soil and in the vegetation above. The biomass carbon is highest in peatland and organic soils and lowest in sandy soils. The above ground biomass carbon stock is largest for a forest and lowest for areas with limited or no vegetation coverage.	From this perspective it is clear that the largest biomass carbon losses occur on peat soils with forest on them. The amount of land use change the models allocate to these type of land uses are very influential. On the other hand if arable lands or even non-forest natural and semi-natural lands are converted to perennial plantations, particularly oil-palm plantations, this leads to a mitigation of ABCS emissions. Since the IFPRI-MIRAGE-BioF predicts many arable lands to be converted to oil-palm plantations in Indonesia and Malaysia and also Sub-Saharan Africa, large mitigations are reached in these regions for ABCS.
Soil organic carbon (SOC) emissions	If a soil is disturbed through removal of vegetation, ploughing etc. the soil organic carbon is released in the form of carbon dioxide and nitrous oxide emissions.	Generally the largest releases of SOC occur on peatlands and other organic soils since they contain the highest amount of carbon. On the other hand if conversions take place with perennials, such permanent crops as oil-palm plantations, miscanthus or sugar cane, less SOC is released then when converted to arable (rotational crops) like soya, wheat. A conversion of tropical rainforest to soya leads to a larger loss of SOC then when converted to oil palm. This is, however, not general practice in Indonesia and Malaysia where it is more likely that tropical rainforests are converted to oil palm. Since this often involves rainforest on wet peatlands the SOC contents of the soil is very high and so are the releases. In Brasil it is more likely that a rainforest is converted to soya or sugar cane. If converted into sugar cane there could still be a net mitigation of greenhouse gases. This, however, depends on cultivation practice. If crop residues are burned, releases of SOC are high and no mitigation takes place. But if the assumption is made that crop residues are incorporated into the soil it leads to an improvement in SOC.
Amount of peatland conversions	Since peatlands have the largest biomass carbon and SOC they are also the main source of releases in GHG when converted to biofuel crops.	There are large uncertainties in the modelled estimates of the amount of peatland conversions and also the way they are converted. Furthermore, there are also different estimates provided in literature on the emissions factors related to peatland soils.
Blending assumptions	These refer to the amount of biodiesel and bioethanol blending assumptions made. If there is more biodiesel assumed to be blended and imported there will be a higher demand for oil crops and if lower, *vice versa*. Since the land use changes are strongly determined by the crop type demand the land use shifts will also be different.	Higher diesel shares lead to overall higher net biofuel emissions than higher shares of bioethanol.
Assumptions on management	Specific management practices lead to lower emissions. Practices which make a difference are burning of sugar cane, no-till, low input levels for fertilisers, mechanisation, yield levels and increases in yield, length of plantation etc.	Assumptions on management can range strongly between the different modelling practices.

As can be seen, the RED equation does not include indirect land use change emissions from displaced land uses, but this may change in the future. In the additional calculation of greenhouse gases from indirect land use change different sources are included which also have a different range in uncertainty as discussed in Marelli et al. (2011) and summarized in Table 2.2. It is evident that assumptions for all these different aspects differ per study, including in the studies analysed in this section.

2.4.4 Scenarios

Scenarios are an important external input to the models and strongly influence final results. The scenarios include general features, for example assumptions on world population, oil prices and gross domestic product, as well as specific biofuel scenario assumptions. The latter are of most interest to this study and are elaborated below. Yield developments and food consumption and its price elasticity are also important in this respect.

This section provides a comparative overview of the indirect-land use change-related greenhouse gas emissions resulting from the studies.

There are three main reasons for the large differences within and between studies: differences in methodology and assumptions, in scenarios and in model parameterisation and data.

Differences in methodology

An aspect that is of particular importance is the final land use allocation. The question is where land expansion, if any, takes place, because this determines the land-conversion emissions and the productivity of the land. In the modelling approaches this is mainly determined within the models, whereas in the other approaches this is based on expert-based assumptions that determine directly where the land use changes occur. Examples of modelling approaches are the JRC, IFPRI and CARB studies. They use general equilibrium and partial equilibrium models to calculate the full land use changes at global level. In the E4tech study and intermediate approach is followed. First the model FAPRI is used to determine the additional demand for biofuels, but market responses are then determined in a post-model assessment using historic data, expert consultation and assumptions. The ADEME study does not include economic analysis to determine land use change, but makes assumptions on land use directly. The PBL study is based on historic data and assumptions. So, part of the economic response to biofuels is captured by the data and additional assumptions are made on where changes in production have happened. The Oeko-Institut study uses trend projections based on historic trade and land use-change data.

The types of land use conversions assumed per study are very influential on the final indirect land use change emissions. The most critical is extension of cropland into peatland and other more natural areas, such as forests and savannah, mostly related to conversions to oil-palm and soya production respectively. Conversions of these types of lands show an enormous release in soil organic carbon, because the stock of above- and below-ground carbon is very high, most certainly for the peatlands and particularly for forests on peatlands (Table 2.2). The assumptions on how much of these natural areas are taken into use are, however, very uncertain, not least because of the allocation of specific land use conversions to specific crops remains a factor difficult to model.

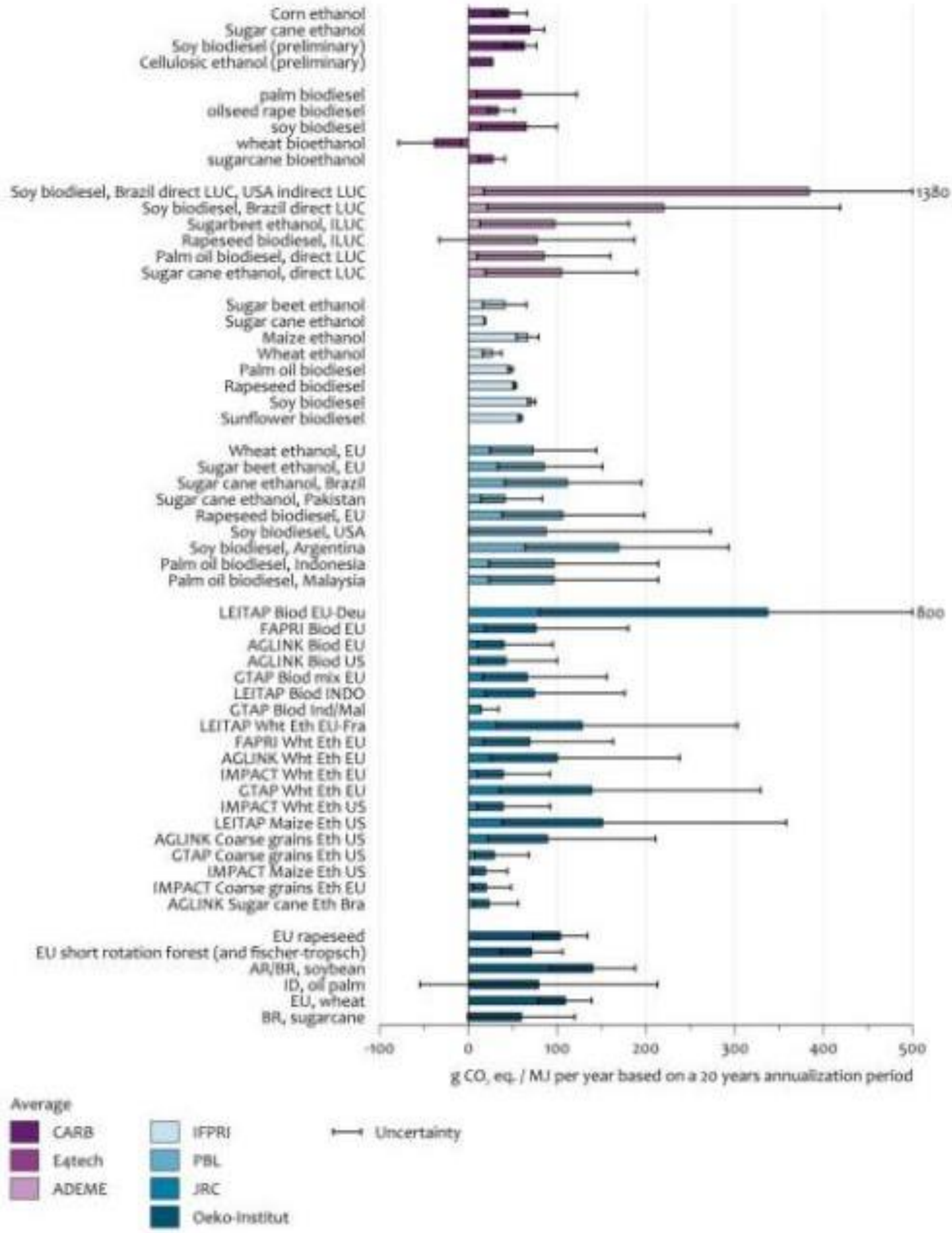
Differences in scenarios

The studies use some kind of baseline. For most of the studies this includes current and adopted policies. However, in many cases it is not explicit how exactly the baselines are constructed. For example base years can be different. Differences in baseline are a cause of variability.

To construct a biofuels-policy scenario most studies include a certain shock (i.e. a certain amount of extra demand linked to factors external to model) in the demand for biofuels and evaluate the effects of this shock. Some studies apply a shock of one biofuel at a time (CARB, JRC); other studies include a mix of biofuels (E4tech, IFPRI). The shocks also differ in amount. Some studies use a marginal shock in which a small but equal amount of biofuels is added in the contrasting scenario (JRC) where the others use larger but varying shocks.

Finally, the scenarios differ in the country targets included: CARB includes the US, JRC includes one country at a time by specifying the feedstock source (US, EU, Indonesia, and Brazil), E4tech, IFPRI and Oeko-Institut include global targets. The total amount of biofuels therefore varies between all the studies (except the studies in the JRC report). The PBL study does not apply a shock, but is based on historic data for the year 2007 on biofuels consumption; Oeko-Institut gives a bandwidth. The ADEME study does not use biofuel targets in their analysis. However, these differences in scenario set-up should be seen in perspective. The corn ethanol sensitivity analysis of the CARB study shows much higher sensitivity to model parameters than to volume changes. This suggests that other model parameters are more important than the quantity of the shock added to the system in the contracting biofuels scenarios or than the differences in the baselines.

Figure 2.2 *Indirect land use change emissions based on a 20 years annualisation period (see Annex 9 for detailed figures)*



Source: See Annex 14, table 1 for detailed sources

Differences in model calibration and data

Parameterisation of the models/methods is an essential element in the economic models as in the other approaches. Since the models are different, similar parameters cannot easily be compared in all cases. Many of the parameters are calibrated in some way.

The different studies use different data sources on a variety of land conversion emissions, which causes differences in the results. For the studies that use a range of data, this also causes variability within a study. Conversion factors in reality are a continuum. Ranges for the conversion factors for different land-cover types are therefore a logical way to present this. Moreover, the land-cover classifications of various studies and datasets are not often the same nor easily exchangeable. However, the determination of where and which land cover types are converted is more susceptible to error than conversion of emissions, which can theoretically be determined physically[8].

The annualisation period has large impact on the outcome of the indirect land use change factors. A period that is twice as large will reduce the indirect land use change factor by the same factor. For example, an indirect land use change factor of 30 g CO_2eq/MJ in 30 years is 45 g CO_2eq/MJ in 20 years. The choice of annualisation period has little to do with the physical aspects of the real-world effects, but is rather a policy-oriented/policy-determined factor[9]. If a policy has a target for the next 20 years, say to 2030, it would be logical to have an annualisation period of 20 years. In that case, in the calculations of the effects of biofuel production after the annualisation period, the indirect land use change effects will be substantially different from the first period. The question of what will happen to land use after this period is of course important for the final effects. Will it be used for biofuels, for food or for regeneration of forest? Many policy decisions however have a relatively short time span and make up the balance after this specific period. In this study all results were recalculated to an annualisation period of 20 years as this is used by the Intergovernmental Panel on Climate Change (IPCC) and is part of the RED methodology.

Explaining the extremes

Some of the results divert more from the average picture than others. The main reasons for this are as follows:

Wheat ethanol in the E4tech study, minimum of -79 g CO_2eq/MJ
This study assumes that wheat is produced on EU land that would otherwise have been abandoned. The DDGS that is produced as a by-product prevents the soya area from being expanded in Brazil. In this way the carbon dioxide emission balance can become negative.

Rapeseed biodiesel in the ADEME study, minimum of -33 g CO_2eq/MJ
In this calculation the by-products of rapeseed replace the expansion of soya plantations in Brazil, which have high carbon-dioxide emissions due to land conversion. This gives a negative total for this biofuel.

Soya biodiesel in the ADEME study, maximum of 1 380 g CO_2eq/MJ
In this calculation the land use change due to soya cultivation is projected to be at the highest level on land with the highest carbon stock. In this variant, biofuels cause direct land use conversion of primary forest. However there is compensation for the oil cakes that are a by-product.

LEITAP biodiesel
The JRC report suggests that the reason for high results for LEITAP (in general) stems from the fact that the version of LEITAP used had some problems in treating vegetable oils and meals. The level of disaggregation is questioned.

8 From this one can assume that agreement on what emission factors should be used, in combination with land-cover maps, would be a relatively easy step to reduce variability in studies aimed at policy makers.

9 The 20 years in Europe results from the IPCC work on land us, land use change and forestry (LULUCF), and approaches of the Clean Development Mechanism (CDM) Methodolgy Panel for calculating land use change effects.

This seems to result in underestimation of the effects of by-products to which part of the carbon-dioxide effects can be attributed.

In summary

A summary of extremes and median values is presented in Table 2.3 in order to summarise the model outcomes included in this overview. The median value was used to provide one generalised number for each biofuel type that can be used as the conservative indirect land use change factor in the storyline assessments (Chapters 5 and 6). As the reason for that choice lies in the fact that this indicator is less susceptible to outliers than the average value[10]. The observations consist of a series of model outputs derived from the studies selected.

Table 2.3 *Summary of review*

Type of biofuel	Minimum indirect land use change emission factor (g CO_2eq/MJ biofuel)	Maximum indirect land use change emission factor (g CO_2eq/MJ biofuel)	Median from average values (g CO_2eq/MJ biofuel)*
Biodiesel based on rapeseed from Europe	-113	80-800	77
Ethanol based on wheat from Europe	-158	337	73
Ethanol based on sugar beet from Europe	13-33	65-181	85
Biodiesel based on palm oil from South-East Asia	-100	34-214	77
Biodiesel based on soya from Latin America	13-67	75-1 380	140
Biodiesel based on soya from the United States	0-11	100-273	65
Ethanol based on sugar cane from Latin America	-49	19-95	60

* Where studies report only a minimum and maximum, the average between these was taken. Most studies report the average and a range.

[10] By using the median, all calculated values in the different studies, including the extreme results, are included, but the influence of extremes on the final result is not too large.

2.5 Most recent IFPRI study on indirect land use change

The most recent model results in a series of indirect land use change studies launched by the European Commission are from the study performed by the ATLASS consortium (Laborde, 2011). It is an up-date of the IFPRI (Al-Riffai *et al.,* 2010) study discussed above. It uses a further elaborated version of the global computable general equilibrium model (MIRAGE-Biof). The scenario as compared to the 2010 IFPRI study now involves the EU biofuel mandates as further implemented in the NREAPs of the EU-27 Member States. It also involves improvements in the assumptions on the factors used for computing the specific separate feedstock land use changes and greenhouse gas emission allocations, for example, for oil palm, cereals, sugar cane, rape seed etc. These improvements are based on new evidence and insights on land use changes and farming practices in biofuel cropping particularly in Africa, Brazil, Indonesia and Malaysia.

Table 2.4 indicates that the ATLASS study (Laborde, 2011) results in considerably lower indirect land use change emissions related to starch and sugar crops used for the production of bioethanol. However, for oil crop biodiesels, indirect land use change related greenhouse gas emissions are lower than the median value, but not much lower except for soya-based biodiesel.

Table 2.4 *Indirect land use change greenhouse gas emissions per crop (g CO2eq/MJbioenergy) from the ATLASS consortium study (Laborde, 2011)*

Type of biofuel feedstock	Average ILUC emissions from ATLASS (2011) in	% share of median values from Table 2.3
Rapeseed	55	71%
Wheat	14	19%
Sugar beet	7	8%
Palm oil	54	70%
Soybean (from Latin America)*	56	40%
Soya (from the United States)*	56	86%
Sugar cane	54	90%
Maize	10	17%
Ligno-cellulosic based land using second-generation ethanol**	15	29%
Ligno-cellulosic based land using second-generation biodiesel**	15	29%

*Laborde (2011) does not distinguish between the two

**In this study this refers only to the second-generation biofuels produced from dedicated crops. In the ATLASS this includes a much wider range of lingo-cellulosic feedstock, including waste, which is probably one of the reasons for this lower indirect land use change factor.

2.6 Carbon balances and carbon "debt" in relation to the use of forest biomass for energy

This report presents and discusses the GHG emission reduction potentials from bioenergy with specific regard to and update of data on agricultural cropping for bioenergy, and respective organic residues and wastes, taking into account potential emissions from both direct and indirect LUC associated with biomass feedstock cultivation on agricultural land.

However, the EU27 bioenergy potentials presented in Chapter 6 include also potentials from forestry which were taken from the earlier work on the environmentally-compatible bioenergy potential (EEA, 2006), and updated with other data (see Chapter 6 for details).

A Closer Look: Carbon Balances of Forest Bioenergy

The forest bioenergy potentials used in this report are not affected by land use **changes**, but the GHG mitigation potential of increasing use of forest biomass for energy depends on the land **use**, i.e. how the forest carbon (C) stocks are affected by changes in the management of existing forests and their harvest cycles and outputs that occur in response to increasing forest biomass supply for energy.

Specifically, changes in forest C stocks depend on soil and climate factors, forest management practices and harvest regime that are used (Hudiburg *et al.*, 2011; JRC, 2013): Certain forest management practices to promote growth (e.g., fertilization, and restocking to higher densities) can increase forest C stocks (Alam 2011; Sathre and Gustavson 2012; Routa 2011) while shortened forest rotation periods and increased removal of residues from thinnings and fellings decrease forest C stocks (Cherubini *et al.*, 2011; Repo *et al.*, 2012; Zanchi *et al.*, 2012). Modelling and assessment methodologies also influence results (Lippke *et al.*, 2011; Berndes *et al.*, 2012; Galik and Abt, 2012; JRC, 2013).

The key consideration to positive or negative results regarding GHG mitigation and respective radiative forcing impacts of forest bioenergy compared to fossil energy reference systems is that removed wood is combusted for energy provision. Thus the embodied C is instantaneously released as CO_2, rather than over a longer time period. The latter would be the case when wood is left in the forest to slowly decompose or would have been used for longer-living wood products or left in the forest longer to grow.

On the other hand, forest management can promote increases in net annual increment allowing increased forest biomass removal without reductions of forest C stocks over time (Routa 2011; Berndes *et al.*, 2012)[11].

However, the inertia of forest rotation makes this a longer-term option, as net annual growth in boreal and temperate forests is much slower than in

[11] Such options are under investigation especially in Sweden, but cannot (yet) be translated to other countries, nor to the EU27 scale. Given the time horizons needed to substantially change existing forest practices, relevant impacts of using such optimised forest regimes are outside of the scope of this report.

agricultural cultivation schemes which have annual cropping-harvest cycles, or short-rotation coppices or energy grasses which are rotated in less than 5 years.

The rotation periods of forests are far longer - from several decades to up to 200 years - and thus, a closer look to the carbon dynamics is required for extracting biomass from forests for bioenergy.

It must be noted, though, that CO_2 emissions of bioenergy from forest will - over a longer time horizon - be compensated through forest regrowth, and in that are different from fossil-fuel CO_2 emissions which represent a **permanent** burden to the atmosphere.

As global warming and respective mitigation are longer-term processes and achieving a global 2 °C warming limit allows for short-term emission increases if those are compensated by medium-to-longer-term net emission reductions, the short-term climate impacts of forest bioenergy need to be considered also in the overall framework of future global emission trajectories.

Carbon Pool and Global Warming Dynamics: Impacts of Forest C Stock Changes on Bioenergy GHG Emissions

As harvested wood or woody residues are combusted to provide energy, the C content of the wood is released as a one-time pulse of CO_2. If this biomass were left in the forest, its longer-term decomposition and subsequent CO_2 release would have still taken place but not to total conversion of the biomass to emissions and over a far longer period (up to several decades), depending on local climate conditions, size of harvested residues and intensity of residues removal (Repo *et al.*, 2012; Zanchi *et al.*, 2012)[12].

Thus, there will be a time lag between CO_2 released from forest bioenergy when biomass is burned and the full re-absorption of this CO_2 through tree growing, which can be expressed as a "carbon debt". On the other hand, the biomass replaces fossil fuels and thus avoids GHG emissions - but only in the longer-run the cumulative radiative forcing of the biogenic CO_2 emitted earlier becomes smaller than that from the avoided fossil CO_2: The "carbon debt" is a result of the longer atmospheric residence time of biogenic CO_2 which causes respective global warming which could reduce mitigation measures in the next couple of decades, depending on the forest types, management practices, and assumptions on the reference systems.

Recent analysis on GHG balances of forest bioenergy which include C stock changes use the payback time to compare fossil systems and bioenergy from

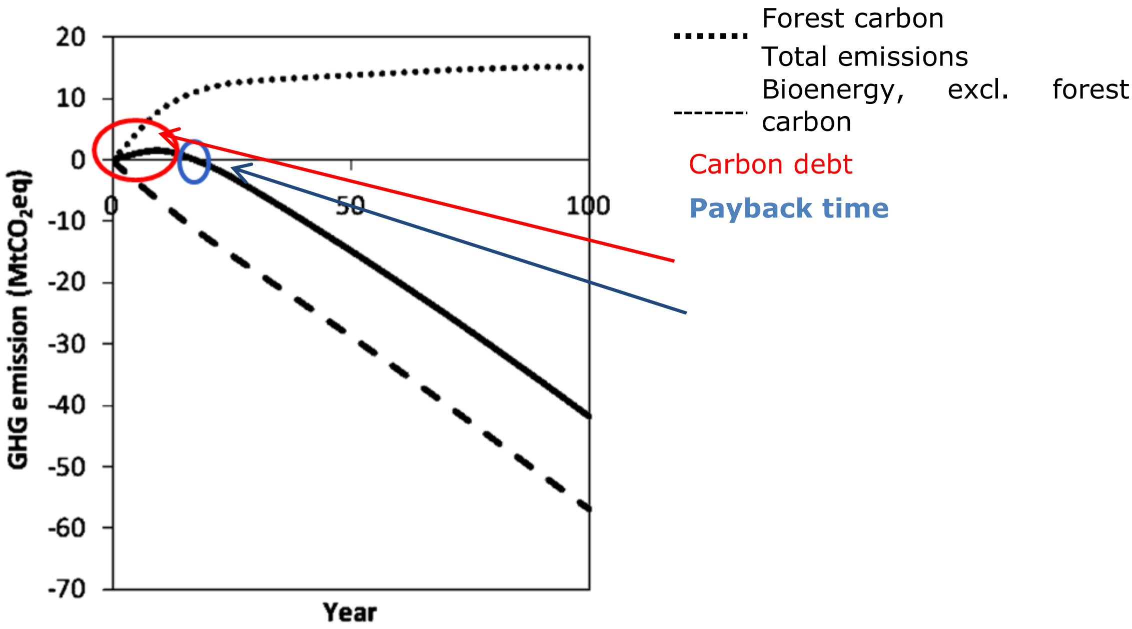
[12] A further potentially important aspect is that most carbon in forest ecosystems is stored in soils, except for tropical forests (Trømborg *et al.*, 2011). The extraction of residues could result in altering soil fertility and negatively affecting the overall forest C balance. Recent studies suggest that harvest residue removal could have implications for the long-term C storage (Jones *et al.*, 2011; Thiffault *et al.*, 2011; Strömgren, Egnell and Olsson, 2012). Meta-analysis conducted by Nave *et al.* (2010) found that (increased) forest harvesting resulted in an average 8% decrease in total soil C in temperate forest soils.

forest, defined as the time in which cumulative emissions from bioenergy are equal to replaced emissions of fossil energy systems[13].

For forest residues, current studies show typical payback times of 5-20 years if coal is the reference system, and 10-30 years for natural gas.

For bioenergy from additional fellings or intensified clearings, the payback time can be up to several hundred years (Repo *et al.*, 2012; Zanchi *et al.*, 2012).

Figure 2.3 *GHG emission quantification example for forest residues*



Source: own visualisation based on McKechnie et al. (2011)

Accounting for biogenic GHG emissions in the RED

The RED methodology for GHG balances defines CO_2 from fuel use as carbon-neutral (i.e. zero direct emission), and does not include the dynamic warming impacts of C stock changes due to wood harvest, or increased forest residue extraction.

The effect of this choice of system boundaries has been discussed with regard to GHG balances of bioenergy systems using LCA (JRC, 2012; Levasseur, *et al.*, 2012), indicating that although biogenic CO_2 release to the atmosphere is re-absorbed later through re-growth of forest biomass, bioenergy systems operated by forest biomass can cause higher GHG emissions than fossil systems, depending on the time horizons of the accounting, and the reference systems assumed.

Still, the long-term role of unharvested biomass in forests need consideration as well, as it is the key avenue of nutrient recycling from harvested biomass in managed forests, a key source of soil C, an important habitat for many

[13] The payback time can be defined as the time in which the cumulative CO_2 emissions of a bioenergy system are equal to the emissions of the replaced fossil energy system. At the payback time, the initial increase in emissions above the fossil alternative is compensated in absolute terms, but the extra radiative forcing caused by the increased initial emissions is not yet compensated. The break-even time in radiative forcing happens later, at a point where the atmospheric impact of the bioenergy and fossil energy systems is the same. After this time, the bioenergy system creates net reductions of radiative forcing, compared to the fossil reference system.

organisms and it protects the soil from erosion and excessive insolation after harvest. At the same time, natural fires, insect outbreaks, and other disturbances can quickly convert forest stands from a net sink to a net emitter of biogenic carbon (Berndes *et al.*, 2011). If this is prevented by harvest, this can offset the "carbon debt".

With regard to the spatial variation of circumstances influencing the C balance of biomass extraction from forests, and the respective uncertainties in C stock modelling and accounting as indicated in the literature on the one hand, and the potentially significant impacts on the GHG balance of forest-related bioenergy on the other hand, the scientific understanding of the "carbon debt" issue is that it needs further analysis and better data (Berndes *et al.*, 2011; EEA SC, 2011; JRC, 2012; Levasseur *et al.*, 2012).

Three examples from current research should illustrate the range of possible situations to underline the need for a disaggregated view:

- In the case of pellets imported from the Canadian province British Colombia, a significant source is "salvage wood" stemming from Mountain Pine Beetle outbreaks for which the carbon debt could, depending on the reference case assumptions, be comparatively small (Lamers *et al.* 2013).
- In Georgia in the US Southeast, a substantial source for pellets is roundwood harvested from forests which were planned to supply to pulp and paper and construction industries, but demand for these products decreased significantly due to economic recession, and closure of many paper mills in this region. Thus, the C debt associated with these pellets depends even more on the selection of the baseline (Junginger, 2012). Recent analysis indicated that pellet imports from the Southeast US to Europe have a comparatively low carbon debt (Lamers and Junginger, 2013), but there are also other views (Carr, 2013).
- Recent results of a country case study of a German project on the sustainability of solid bioenergy indicate that for pellet production in Northwest Russia, lower-quality roundwood is being used, although substantial residue potential from sawdust and harvest leftovers exist (Krismann, 2012).

In consequence, this report **does not** include forest bioenergy from additional fellings nor intensified silviculture practices in the quantification of bioenergy potentials for the EU27 but focuses on residues as the key bioenergy resource from forest operations. Similarly, it is assumed that the majority of solid bioenergy imports needed to meet the NREAP targets will come from forest residues, thinnings, and sawmill by-products (see Box 6.1 in Chapter 6).

Constraints on time and resources did not allow analysing more deeply how changes in "traditional" forest biomass harvest which might be implied by future demands for bioenergy - e.g. increased roundwood use for bioenergy - would influence the CO_2 balance.

Constraints on time and resources did not allow analysing more deeply how changes in "traditional" forest biomass harvest which might be implied by future demands for bioenergy - i.e. increased roundwood use for bioenergy - would influence the CO_2 balance.

It is recommended here that future work should take into account results from ongoing analyses and studies to quantitatively model the dynamic GHG emissions from C stock changes associated with both European forest residue extraction, and solid bioenergy products being imported into the EU which at least in part could come from roundwood harvests[14].

2.7 Conclusions and discussion

The results of the various ILUC studies are difficult to compare in detail because of differences in the types of models and approaches, and in scenario assumptions. However, it is considered that all studies are relevant in the context for which they were developed. All cover some of the possible outcomes of the effects of indirect land use change for a specific case.

For this study an indirect land use change factor was chosen that results from a comparison of studies assuming that the combined indirect land use change of biofuels with various feedstocks in various regions is most likely to be a composite of the different calculated values. The results show relatively high average and median indirect land use change factors in comparison with the most recent ATLASS study (Laborde, 2011).

Based on the reported average indirect land use change emissions, it can be concluded that indirect land use change related emissions are substantial and cannot be ignored in a policy which aims at climate change mitigation. The final choice for reference values for indirect land use change emissions should be justified by policy considerations. The median values presented in Table 2.3 are only indicative, and lower and higher values are also justifiable, for example, in a policy context of taking higher or lower risk (Ros *et al.,* 2010). At the same time the results in Table 2.3, and in Table 2.4 particularly for biodiesel crops, show that most indirect land use change factors are already of the same order of magnitude as the carbon dioxide emissions of fossil fuels – around 84 g CO_2/MJ. So, indirect land use change effects alone can often negate the positive contribution of biofuels to greenhouse gas emissions reduction. However, in addition to greenhouse gas mitigation, there are other policy goals that also support the involvement of indirect land use change in an environmental assessment of bioenergy pathways, one of which is biodiversity conservation. From this perspective any conversion of highly biodiverse land to agricultural production – either direct or indirect – should be avoided.

Given that indirect land use change effects vary strongly between different studies this report includes a sensitivity analysis of key results of the most greenhouse gas-efficient bioenergy pathways on the basis of two different indirect land use change factors. The first one is taken from Table 2.3 and is considered to represent an assumption of higher greenhouse gas emission risk related to indirect land use change effects. The second one builds on the results of the ATLASS study (see Table 2.4.) and is considered as representative of a world model where indirect land use change effects are generally low. Using these two indirect land use change factors allows testing the validity of the results arising from the original model run building on Table 2.3 results.

[14] This question will partly be addressed in two new EU studies (BiomassPolicies, and S2Biom), but first results of this work will become available only in 2014.

Finally, bioenergy feedstock production should be seen in relation to the production of other agricultural products. It is not desirable that biofuels the most efficient or high-yielding areas, leaving only the less productive sites for food production and other equally important uses. With growing world populations and changing diets, food is becoming increasingly scarce, and low indirect land use change effects that can result from using very productive land for biomass production should not be sought at the expense of food production.

This chapter does not cover dedicated cropping with perennial crops for electricity and heat. However, the mechanisms of indirect land use change discussed here for biofuels also apply to perennial crops. An important factor here that determines whether the emissions are lower than those of biofuels is energy production per hectare. This is determined by the biomass yields per hectare, which are generally much higher for perennial crops, but also for the conversion pathways.

As to the carbon debt, it is recommended that future work should take into account results from ongoing analyses and studies to quantitatively model the dynamic GHG emissions from C stock changes associated with both European forest residue and possible roundwood extraction, and solid bioenergy products being imported into the EU which at least in part could come from roundwood.

3 Other environmental implications of bioenergy production

3.1 The need for wider environmental impact assessment of bioenergy demand

In Chapter 2 the implications of bioenergy demand for GHG emissions and mitigation potential and the issue of carbon debt were discussed. In this chapter we focus on other environmental implications which also start from the direct and indirect land use changes related to biomass demand.

Cultivating more energy crops implies an additional demand for land that can also significantly increase the loss of biological diversity (UNEP, 2007). This has two main dimensions: the conversion of natural ecosystems, and the intensification of existing farm and forest land (WBGU, 2008) with related impacts on environmental quality and biodiversity.

Given the function of land as a natural resource, it is, therefore, clear that an analysis of the effects of increased biomass demand for energy cannot be limited to land impacts but should be assessed in a wider environmental context including effects on water, air, soil and biodiversity.

The increasing demand for food and biomass causes conversions of natural and semi-natural ecosystems to productive, directly-managed agricultural systems as well as changes in land management to more intensive uses in most instances. The intensification is usually accompanied by stronger farm mechanisation, higher fertiliser and pesticide use and irrigation. This does not only lead to higher greenhouse gas emissions but also has adverse impacts on soil, water and air quality, depletion of fresh water resources, and loss of biodiversity. The following sections briefly review key environmental impacts of agriculture.

Water pollution: agriculture is the major source of nitrogen pollution of European water bodies, including lakes, rivers, ground water and the European seas (EEA, 2010b).

Water quantity: the agricultural sector is the major user of water in Europe, with particularly in southern and eastern regions due to the importance of irrigation for agricultural production. In southern European countries the share of agriculture in total water abstraction reaches above 50% (EEA, 2010c).

Soils: farming, in particular cultivation practices, exposes soils to risks of water and wind erosion, and can lead to soil compaction and salinization if inappropriate farming practices are followed (JRC, 2010). All these factors contribute to soil loss, declines in soil organic carbon content and productivity as well as the resulting environmental impacts (JRC, 2010).

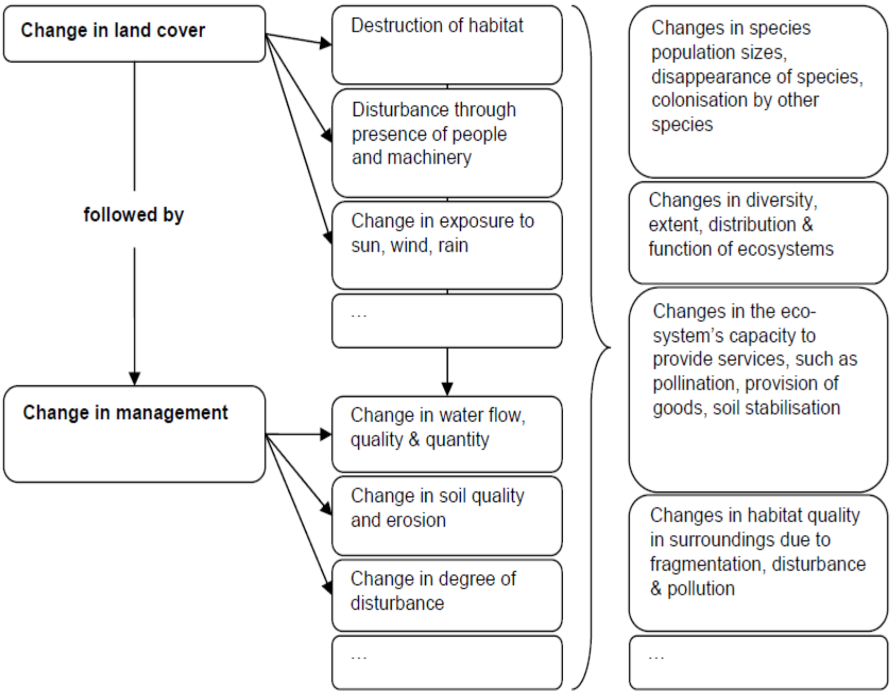
The effects of agricultural expansion and intensification on biodiversity are acknowledged all around the world (Donald 2004). In fact, farming is already the greatest extinction threat to birds, the taxon about which most is known, and its adverse impacts look set to increase, especially in developing countries (Green *et al.,* 2005). Increased demand for bioenergy, which puts additional pressure on land for agricultural production, is therefore likely to further add to the already high pressure on biodiversity. That biofuel demand may have negative impacts on biodiversity is now also widely recognised (Bertzky *et al.,* 2011; van Oorschot *et al.,* 2011; Fargione *et al.,* 2010; Fargione *et al.* 2009; Gallagher, 2008). At a global scale, for example the JRC (2011) took the changes in land use caused by increased bioenergy demand in the EU by 2020 as estimated by the International Food Production Institute (IFPRI) model (Laborde, 2011) and translated these further into biodiversity effects. The results indicated that the transition to cropland for bioenergy production would cause an 85% decrease in biodiversity, at least as measured by a change in the Mean Species Abundance (MSA) index, in the affected areas. These results are in line with the conclusions of the GLOBIO3 study (Alkemade *et al.,* 2009), which also showed that the increased demand for biofuels would increase the rate of loss of biodiversity.

In the study by Bertzky *et al.* (2011) the effects of bioenergy-related land use changes on biodiversity were analysed. The effects (Figure 2.1) lead to land-cover changes and changes in farmland management and these have implications for biodiversity.

Bertzky *et al.* (2011) makes a distinction between on- and off-site effects on biodiversity (Figure 3.1). The first occur at the location where the indirect land use change happens and the second occur in the surroundings as a consequence of the indirect land use change. The on-site effects include the loss of species incapable of using the new agricultural system as habitat. Off-site effects are contagious effects of management practices, such as irrigation leading to the depletion of water sources; drift and leaching of pesticides, herbicides and fertilizers and their effect on local biota; and structural changes to the landscape, which decrease the ability of species to disperse, disrupt foraging routes and isolate remnant populations. Such landscape disrupting effects could also be caused by development of roads, power lines and other infrastructure associated with the conversion of natural habitats to new agricultural lands for bioenergy production.

When focussing on the EU, it should be recognised that agriculture is the most extensive single land use type (163.7 million hectares of utilised agricultural area (UAA), covering more than 40% of the total area of EU-25; (EC, 2007b)). Although most of this is already intensively farmed and exerts significant environmental pressures (EEA, 2010b; EEA, 2005b; EEA, 2004), there is still a large share of farmland that can be categorised as being of high nature value (HNV) – 30% of the UAA (Paracchini *et al*., 2008; Cooper *at al*., 2007; Andersen *et al*., 2003) (see Annex 4). Thus a substantial proportion of total biodiversity can be expected to be associated with farming, which highlights the considerable importance that the effects of agricultural-land management might have on biodiversity (Oppermann *et al*., 2012, EEA 2005a, OECD 2001, Tucker and Evans, 1997). Given this, it is clear that changes in farmland management caused by increased demand for bioenergy may also have important implications for biodiversity in the EU.

***Figure 3.1** Schematic overview of how increased demand for agricultural lands leads to changes in biodiversity*



Source: Bertzky *et al.,* 2011

This is also shown in several studies of agricultural bioenergy production in the EU or individual Member States (Arblaster *et al*., 2007; EEA, 2007; Reijnders, 2005; Fritsche *et al*., 2004; Feehan and Petersen 2003,). It is also acknowledged in these studies that effects may be negative if they lead to further intensification and loss of semi-natural habitats. But they can also be positive if bioenergy cropping leads to extensification of existing agriculture through, for example, lower input use, or improved landscape structural diversity.

Agricultural bioenergy production is already well-developed in Germany, and recent analysis shows that potential impacts on water quality and biodiversity have become a real environmental concerns. This relates mainly to the conversion of grassland or fallow and set-aside land to arable biomass crops and general land use intensification on arable and grasslands (see Annex 9).

Meeting the 2020 renewable energy target without significant environmental impacts requires that appropriate land resources, which can be used for biomass production and/or harvesting, are identified. These land resources should not cause losses to biodiversity or increase competition for food and fodder.

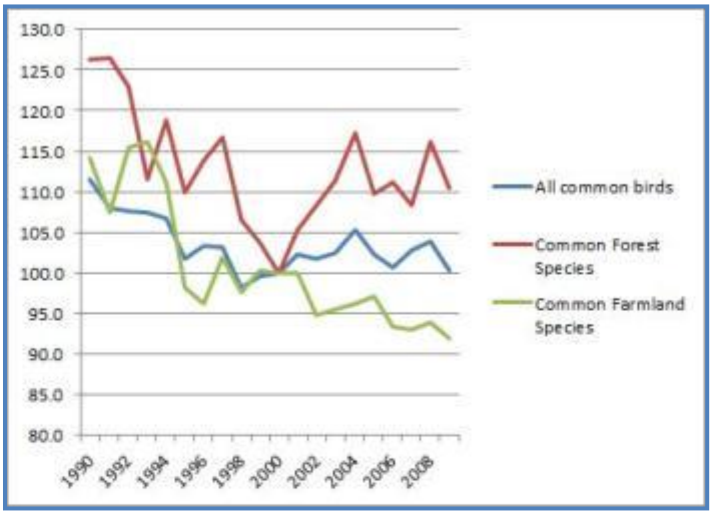
3.2 Implications of land use change for ecosystems

In principle, current agricultural production and management for food, fodder and biomass have comparable impacts on farmland biodiversity, certainly when first-generation biofuel crops are concerned. Farming has been identified as a major biodiversity-impacting sector already within the 5th Environmental Action Plan (EC, 1993). This is not surprising since agriculture is one of the most important land use activities in most European countries.

At the same time farmland hosts a large part of Europe's biodiversity including several valuable habitats, plants and animal species listed in the Annexes I and II of the EU's Habitats Directive (EC, 1992). It has been estimated that half of all species in Europe depend on agricultural habitats (EEA, 2005b; Cooper *et al.,* 2007). Therefore all environmental pressures from agriculture are in some way linked to biodiversity.

The trend in farmland birds is a good barometer of change in the biodiversity of European agricultural landscapes. EEA's IRENA indicator shows that farmland bird populations declined significantly between 1990 and 2009 (Figure 3.2). This was a larger decline than noted for forest and all common birds. Increased specialisation and intensification, as well as abandonment of farmland, have driven this decline.

***Figure 3.2** Common birds in Europe: population index (2000=100)*



Source: Eurostat, 2011

In general, cultivating biomass crops and large-scale removal of biomass can lead to further intensification of land use and a continuation in the conversion of habitats of high biodiversity value to productive lands, for example, arable land, deforestation. On the other hand there could also be positive effects on biodiversity from land use changes caused by the demand for bioenergy, if the area converted for agriculture were previously degraded land. If appropriate management were applied to these lands, this could lead to improved soil quality and vegetation structure, and therefore enhanced habitat quality (Tilman *et al.,* 2009).

It is relative profitability along with the productive capability of the land, which will determine which changes in land use occur first to meet the demand for biomass. The impacts on biodiversity of changing some extensive land uses to intensive arable or biomass production could be severe, but from an economic and technical point of view, these changes are not always very likely to occur particularly within the EU.

Changing wetlands to intensively used arable land, for example, is not likely because of the high cost of drainage and because of legislation to protect them. Growing short-rotation coppice on wetlands would be more economically viable but in many cases the sites are still protected by law, and the conversion of grassland is restricted by EU cross-compliance rules. However, outside the EU, circumstances may be different and incentives to convert natural and semi-natural areas to dedicated cropping for fodder, food and bioenergy stronger.

When examining the impacts on farmland biodiversity, a distinction should be made between extensively managed agricultural lands including such ancient agro-forestry systems as the Dehesas/Montados of Spain and Portugal, species-rich hay meadows, and the more common habitats including intensively managed agricultural categories – horticultural, arable, intensive fodder and grazing lands.

The first group is very sensitive to biodiversity loss, while the last could gain from a shift to bioenergy cropping which may increase environmental quality with positive direct and indirect impacts on some species. The first group can also be characterised as HNV farmland[15] and belongs to the 30% of farmland in the EU-27 which will suffer from large losses in farmland biodiversity if affected by intensification or abandonment. The direct and indirect pressures exerted by biomass production could further encourage intensification, but could also help to prevent land abandonment. Direct impacts are habitat fragmentation, habitat loss and diversification, changes in canopy structure and soil cover. Indirect impacts include all environmental effects both negative and positive, such as eutrophication, acidification, water depletion, and soil improvement or degradation. The last of these may lead to overall changes in habitat quality and have impacts on broader areas including adjacent land (e.g. off-side effects) (EEA, 2007 and Bertzky *et al*., 2011).

3.2.1. Biomass cropping

Land use changes within agricultural areas resulting from a shift towards biomass cropping can have positive or negative effects on farmland biodiversity. Until now Europe's agricultural biomass production for bioenergy has mainly been derived from conventional rotational food crops such as maize, wheat, barley, sugar beet and oil seeds including rape and sunflowers. The production requirements of these crops when used for bioenergy are similar to those when used for fodder and food and are related to existing environmental pressures. For example, managing oilseed rape for biodiesel, or cereals for bioethanol production, offers only little opportunity to reduce fertiliser and pesticide inputs compared to their management for food (Turley *et al*., 2004a).

[15] 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). Annex 4 provides more information on the concept and the role of HNV and the Rural Development Policy in Europe.

The introduction of new crops for biomass production may also increase the risk of biodiversity loss as a result of invasive alien species. Species are often selected for characteristics such as fast and productive growth and are known as invasive alien species in other parts of the world. Therefore, the likelihood of a species becoming invasive in Europe needs to be assessed before being cultivated in new areas. Perennial biomass cropping, such as miscanthus (*Miscanthus spp*.), poplar and reed canary grass (*Phalaris arundinacea)*, is currently only small-scale, as demand for ligno-cellulosic biomass is still limited by the present state of 1st generation conversion technologies. In spite of this, there are some countries with large-scale plantations of reed canary grass, such as Finland, and miscanthus, such as the UK, which are now only used as feedstocks for conversion into electricity and heat. The advantage of these perennial crops is that their input requirements are generally lower than those for annual crops, they are not used for food and fodder, and they can be grown on such lower-quality soils as abandoned land not suited for rotational arable crops. Their environmental footprint seems to be smaller and the competition effect on food and fodder markets is therefore limited. However, miscanthus has been assessed as invasive in Europe (GISP, 2008).

Despite this, these species still compete for land, especially if demand for biomass increases significantly. Last but not least, there is a large scientific-knowledge gap on the effects on biodiversity and such environmental issues as greenhouse gas or soil carbon balances of converting abandoned lands to large-scale perennial biomass plantations.

It is generally not possible to assign positive or negative impacts on biodiversity to individual crop species without a better understanding of current land use, and the proposed energy crop and management system. Annex 6 provides an overview of the possible positive and negative impacts of shifts to different types of bioenergy cropping.

In addition to the impacts on biodiversity that occur directly or indirectly due to land use changes, different bioenergy cropping systems can have varying impacts. The main variables are cropping patterns – mono-cropping or diverse rotations, management intensity, the scale of the energy plantation, crop choice and the use of genetically-modified organisms (GMOs). The choice of management options is crucial for the effects on biodiversity and the wider environmental impacts of bioenergy cropping. Annex 7 provides an overview of the main environmental and ecological risks and opportunities related to different energy-cropping systems.

3.2.2 Very intensive land uses

Land in this category includes horticulture and root-crop production. It does not have any overlap with HNV farmland and will not contain any EU Habitats Directive Annex I habitats (Annex 6). Changes from intensive agricultural production of winter cereals, maize, oil seed or root crops to other annual biomass crops are unlikely to have major impacts on biodiversity and might even improve the situation, since the current cropping has little or no biodiversity value. Switching to biomass crop production may have a positive indirect effect through improvement of water and soil, and therefore habitat quality, but also through an improvement of landscape structure.

Root crops are grown throughout the EU, but a high concentration of these crops is found in only such countries as Belgium, France, Germany, the Netherlands, Poland and Romania. Conversion of land from root crops to other arable crops will generally have a positive effect on the environment and biodiversity because inputs of fertilisers and pesticides are reduced, tillage is not as severe, erosion risks decrease and irrigation can be reduced in drier areas. This will have significant benefits for soil and water quality and subsequently biodiversity, particularly in the soil.

The conversion of current intensive arable land to short-rotation coppice or perennial energy grasses should, in most cases, bring positive benefits for soil resources and water quality. Where permanent energy crops improve the range and spatial distribution of different habitats in intensive agricultural landscapes, their impact on biodiversity is likely to be positive, although mainly for species that are already common (Dworak *et al*., 2007).

3.2.3 Land with intensive arable and permanent crops

Land in this category involves sugar, starch and oil crops, intensive fodder crops such as maize and intensive permanent crops including citrus and other fruit or nut orchards, olive groves and vineyards. Biodiversity on this type of farmland has been greatly diminished in the last couple of decades as a result of general intensification. In all parts of Europe, inputs to this group are very high and, particularly in central and southern Europe and these systems are also extensively irrigated. The effects of a shift towards production of bioenergy crops on habitat quality and specific species groups will depend on the type of bioenergy crop planted and the related changes in farming practice.

If the conversion to a biomass crop involves increased tillage, fertiliser and pesticide use, and irrigation, it will have adverse impacts on soil, water and air quality. If it involves a decrease in inputs, which is more likely in these already very intensive systems, it will have positive effects on habitat quality (Schlegel *et al.,* 2007). Conversion from rotational arable to perennial biomass crops will have positive benefits for biodiversity – both indirectly through positive effects on water and soil, and directly as soil organisms benefit from the lack of tillage. There is some evidence of improved landscape structure, which is beneficial for the birds and mammals that use the perennial biomass crops as shelter and breeding sites (Schlegel *et al.,* 2007). In general, short rotation coppice systems can introduce additional habitats and niches in landscapes. However, where perennial biomass crops are grown on a very large scale they may become dominant and are likely to decrease biodiversity in mixed agricultural landscapes (Eppler *et al.,* 2007). A shift of land use in this group to perennial crops is quite likely, especially when policy incentives encourage the most greenhouse gas-efficient bioenergy pathways.

Intensive winter cereals are grown throughout the EU-27, but are more prevalent in the EU-15 and especially the northern Member States. This land use is one of the least diverse in Europe, and this is likely to persist if a switch is made from food to rotational arable biomass crops.

Maize cultivation is also common on this type of farmland. Because maize grows in the summer and autumn, this tall plant, unlike other cereal crops, provides shelter to animals in the autumn. In other respects maize is similar to other intensively-farmed arable crops. When it is switched for rotational arable biomass crops the shelter function is lost. It would therefore be advisable from a biodiversity perspective to use perennial crops instead with similar shelter capacities such as perennial grasses and short-rotation coppice.

The major pressure from converting intensive permanent crops, strongly concentrated in the Mediterranean, to rotational arable biomass crop production will come from increased tillage. This will have major impacts on soil and water quality and subsequently soil organisms. However, if the conversion is to perennial biomass grasses or short-rotation coppice it is likely to have a negligible or positive effect on biodiversity at the local scale.

Finally there is a risk, particularly in the Mediterranean but also in central and eastern Europe, for further increases in water abstraction when biomass crops are introduced. Examples in this category are a shift from cereal cropping to irrigated maize, but also to perennials which are more able to deplete scarce water resources because of their deep rooting systems and fast growing capabilities. Effects of increased water abstraction include salinisation and contamination of water, loss of wetlands and disappearance of habitats by the creation of dams and reservoirs. On balance shifts to perennials tend to be a better alternative to arable crops from an environmental and biodiversity perspective, with exceptions in very arid regions of the EU where intensive cropping both for food, feed and biomass is problematic.

3.2.4 Shifts from medium- to low-intensity use and cropping trends

Intensive permanent grassland is mostly found in the northern states of the EU-15 and some parts of central and eastern Europe. The current levels of biodiversity associated with this land use are moderate to low and the inputs, especially of fertiliser, are still quite high but not as high as intensive arable agriculture (Nix, 2000). Ploughing permanent grassland will have negative impacts on biodiversity and especially on ground-nesting birds such as the lapwing.

Extensive fodder crops are often associated with short-term fallow systems in the Mediterranean and Steppic grasslands, compared with maize or beet grown for fodder for intensive livestock units across the rest of Europe. The major impact of the introduction of bioenergy crops into these systems would be to threatened bird species such as the great bustard (*Otis tarda*). The overall impact, however, depends on the extent to which the mixture of irrigated land and land managed traditionally, HNV farmland, for example, is changed, and the current presence or absence of rare bird species. However, it remains to be seen whether large-scale shifts can really be expected in these farming systems. In general this land is only marginally productive for rotational arable biomass crops, certainly in the more arid parts of Europe where irrigation is often essential for high yields. Future shifts in land use are dependent on government or EU subsidies to make them economically viable and on the future development of agricultural and energy markets. The land may be more economically suited to growing perennial biomass grasses and short-rotation coppice, which require less or no irrigation (Schlegel *et al.,* 2007).

3.2.5 Shifts from low intensity land use categories to bioenergy crops

Extensive land use types are high in farmland biodiversity, mostly coinciding with HNV farmland in Europe, and most of the agricultural Annex I habitats of the Habitats Directive (EC, 1992) are in these areas (see Annex 6). Any change in the use and management may put this high-level farmland biodiversity at risk. For example, agro-forestry systems in the Mediterranean including the Dehesas and Montados of Spain and Portugal, or extensively managed olive groves, make a substantial contribution to species richness, linked to their structural diversity which derives from low-density plantations and the combination of trees with open arable weed or grassland vegetation layers. If permanent energy crop plantations are not able to reproduce these habitat features, they are likely to lead to substantial biodiversity losses.

The same applies to the arable systems in this category. The biodiversity impacts of a shift toward bioenergy crops, certainly towards rotational arable biomass crops, are likely to be severe, as were the intensification shifts that took place in arable systems from the 1960s, and especially the 1980s, onwards. Both common and rare birds and cereal weeds such as corncockle (*Agrostemma githago*) declined and then became threatened or extinct. For example, more than 400 species of vascular plants in Germany have declined in recent decades because of habitat loss or fragmentation due to agricultural intensification. In the United Kingdom there has been a greater decrease in plant diversity in arable habitats than in any other habitat. Farmland invertebrates have also suffered, with reductions in the abundance of insects, including moths, butterflies, sawflies, spiders, parasitic wasps, and aphids.

Negative effects of shifts to bioenergy cropping in scrubland, moors, heathland, long-term fallow and wetlands are also possible as these types of land belong to the extensive farming systems category. Scrubland has often resulted from the abandonment of agricultural land. It occurs mostly on low hills and occasionally on plains. Moors and heathlands are extensively grazed in many parts of Europe, but abandoned in many others. Long-term fallow land is found in dry areas in the southern Mediterranean and is occasionally grazed or cultivated and has very limited crop potential. Wetlands in low-lying areas are locally concentrated and extensively grazed in summer, and are associated with high and threatened biodiversity throughout the EU. The economics of farming on these poor lands are generally poor and the chances of them being used for biomass production are low. Threats come from intensification, and also simultaneous intensification of some land and abandonment of other. If the land were used, the impacts on biodiversity would be disastrous.

A land category particularly at risk of conversion in the EU is extensive permanent grassland. This land use is very variable and mostly associated with the semi-uplands and uplands of northern Europe, high-mountain areas, low-lying wet and peat areas across the EU-27, and dry grazing areas such as the more open Dehesa of central Spain and southern Portugal. In biodiversity terms this is the most important land use as extensively managed permanent grassland provides habitats for many specialised plant and animal species (Brak *et al*., 2004; Beaufoy *et al.,* 1994, Annex 6). For example, 92% of all butterfly species of special conservation concern in Europe depend on agricultural habitats, particularly extensively managed grasslands (EEA, 2009a). Large parts of HNV farmland are used in this way, along with many important Habitats Directive Annex I habitats (see Annex 6).

An interesting aspect of extensive grassland use is the conservation or enhancement of biological diversity. Results from the Jena Experiment, a large biodiversity experiment in Germany, show convincingly that grasslands with greater biological diversity can achieve more ecosystem services – productivity, carbon sequestration, nutrient use etc. – than species-poor systems (Oelmann *et al*., 2007; Weigelt *et al*., 2008). Even forage quality and calorific values increase with increasing biological diversity (WBGU, 2008). Results for the North American prairie are similar, prairie with high biological diversity produced even more bioenergy per unit of land than a maize cultivation system for ethanol or a soya cultivation system for biodiesel, with fewer greenhouse gas emissions and less soil contamination from agricultural chemicals (Tilman *et al*., 2006).

Extensive grazing and hay meadows are already threatened. Although the current legislative system included in the Cross Compliance package of the Common Agricultural Policy set limits to the overall change in extent of permanent grasslands, it has been declining gradually for several decades[16]. Several factors, including afforestation, the intensification of livestock farming and development of sites for housing, have played an important role in this process. With regard to bioenergy cropping, conversion of permanent grassland by ploughing would pose significant water protection problems. Initially, there is a massive release of nutrients and soil carbon following the decomposition of the considerable quantity of organic matter in the upper layers of the soil. Turning grassland into arable land can also drastically increase soil erosion rates, depending on the cropping patterns and management, leading to higher surface run-off of nutrients to surface waters.

In some areas, including the Mediterranean and Germany, these grasslands could be converted to arable or biomass production, and conversion could occur in large areas of the new Member States. Conversion in the Mediterranean would be totally dependent on government and EU subsidies for land improvement or irrigation systems. If this land use change is allowed to take place the impacts on biodiversity will be disastrous. Evidence of loss of permanent grassland as a result of an increased demand for bioenergy is already being seen in Germany (see Annex 9).

[16] The current cross Compliance compulsory GAEC standard of the protection of permanent pasture (IEEP, 2011) allows a loss of 10% of permanent pastures at national or regional levels (which can mean almost complete loss in the most vulnerable areas), and also allows for the offset of semi-natural biodiversity and carbon-rich grasslands by a similar area of artificial grass cover on arable land.

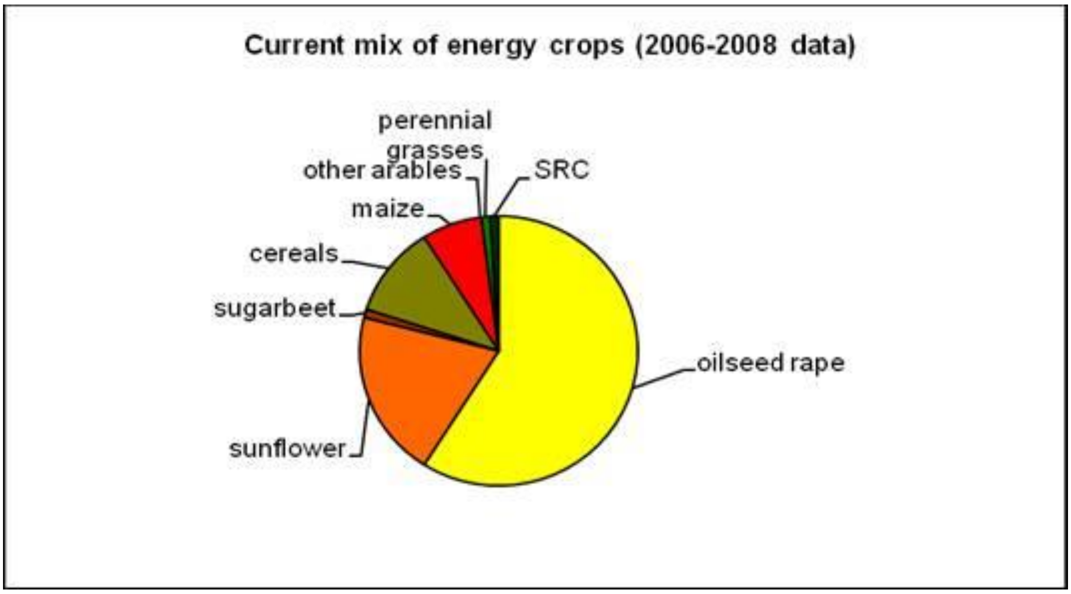
3.3 Current bioenergy land use and cropping trends

Statistical data on energy cropping trends in the EU-27 are difficult to obtain and are often outdated. Data available at EU-level at the time of writing lead to an estimate that dedicated energy cropping for biofuels as well as electricity and heat generation covers approximately 5.5 million hectares of agricultural land in 2008 (see Annex 8). This amounts to 3.2% of the total cropping area (not the utilised agricultural area) in the EU-27. Practically all of this land is used for dedicated biofuel cropping, mostly oil crops (82% of the land used for biomass production). These are processed into biodiesel; the remainder is used for the production of ethanol crops (11%), biogas (7%), with perennials going mostly into electricity and heat generation (1%).

An overview of present dedicated bioenergy cropping is given in Annex 8, with the regional distribution of energy cropping areas illustrated by Figure 3.6[17]. The area with fodder maize used as feedstock for biogas takes a large share of the biomass cropping area in Germany. This should be kept in mind when interpreting the map as in other countries this feedstock crop is not important at all. At present dedicated cropping is only important in a selection of EU countries of which France and Germany are the most important. Significant areas of oil crops for biodiesel are also found in the UK, Poland and Romania.

The most recent energy cropping data show a clear dominance of annual arable crops in the energy crop mix, with perennial grasses and short rotation coppice (SRC) occupying ca. 2% of the total (see also Figure 3.3 and 3.4).

***Figure 3.3** Current mix of energy crops (2006-2008 data)*

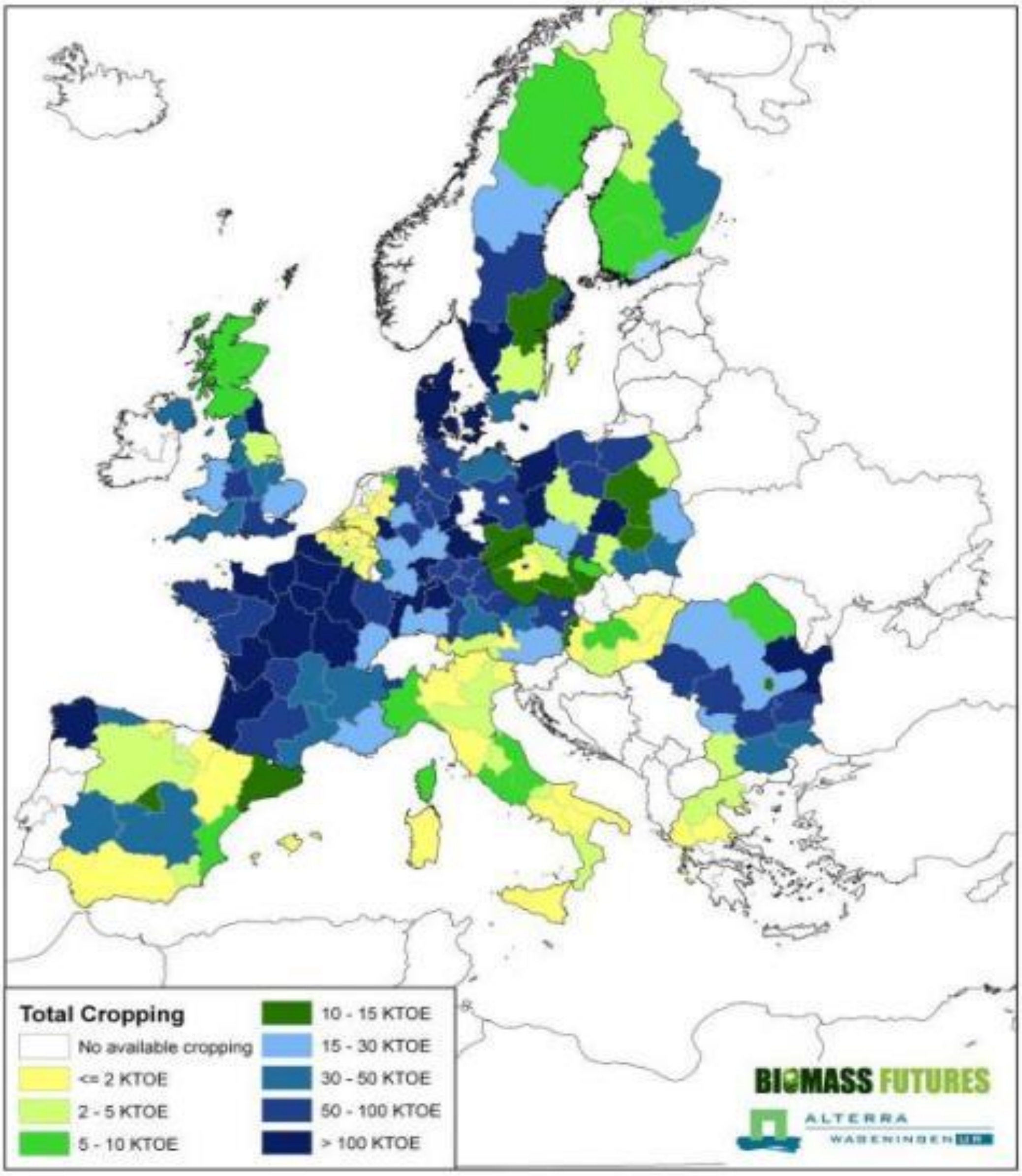


Dedicated cropping with perennials so only takes place at a very small scale. The countries that have the largest areas are Finland, Sweden, United Kingdom and Poland. As a general rule perennial crops, such as short rotation willow and poplar and also perennial energy grasses like miscanthus, switchgrass and reed

17 The regional distribution of dedicated cropping patterns is based on the assumption that the bioenergy crops are distributed over regions in the same proportion as similar crops which are used for fodder and food purposes. The statistical figures on crop types and areas have therefore been used as a weighting for the distribution of biomass crops.

canary grass, require lower input use than annual arable crops such as oilseed rape, cereals or maize. However, since their area share is still very small any potential positive impacts on natural resources or biodiversity will currently be minor. In some countries larger areas are reported, but it is not clear on which type of lands these have been planted, so the land use conversions are not known and would require further analysis.

Figure 3.4 *Energy potential from dedicated biomass cropping*



Sources: see Annex 8.

3.3.1. Environmental effects of energy cropping

Information on the environmental consequences of current dedicated cropping for bioenergy production is limited. Such effects can be expected in countries like Germany and France where their production and area share has increased tremendously in the last 10 years. That biofuel demand has led to tremendous increases in oilseed rape cropping area is beyond all doubt; Eurostat figures show that between 2000 and 2009 the EU production of rape almost doubled (93 % increase) and the cropping area increased by almost 50%. Countries that especially contributed to this increase were Germany, Romania, Hungary, all Baltic States, Poland, Slovakia, Ireland and Sweden.

At present there are no specific energy varieties among the annual crops grown for bioenergy production. Amongst conventional annual crops, cereals (rye and barley) and sunflowers usually have a better environmental profile (EEA, 2006), whereas wheat, grain maize, potatoes, sugar beet and oilseed rape have a relatively higher negative impact on the environment. It is especially the crops in the latter group that have shown to be grown for biofuels in the majority of regions, which must have gone together with increases in their surface and in their relative share. Nutrient input is generally high for these crops but varies strongly between countries and farming practices (EEA, 2006).

Most energy cropping in the EU-27 takes place on already intensively used farmland, which includes oilseed rape and cereals. The environmental impacts in such cases are limited even though negative impacts on farmland bird communities are expected where energy crops have replaced previous set-aside or fallow land. There are reports of the planting of other energy crops on previous grassland (e.g. NABU, 2009, regarding maize for biogas in Germany, or Eppler et. al., 2007, concerning the planting of SRC plantations in Poland). As far as energy cropping lead to a more intensive exploitation of available land for mechanised cropping, this can involve the destruction of areas (which may in themselves be small) of high conservation value (e.g. field borders and structural elements of the agricultural landscape, protected area buffer zones and natural ecosystems). However, reliable field observations of such effects are generally not available, even though the case studies quoted in Annex 9 provide some evidence.

One of the main causes of permanent grassland decline in Germany is the increased production of silage maize for biogas production. This case study is provided in Annex 9. Clear correlations exist between increases in (energy) maize production and losses in permanent grassland area in many German Länder which have implications for species living of these habitats and loss of HNV farmland (Osterburg *et al.*, 2008). There are also are also indications of increased competition between energy maize and fodder maize production. Beside conversion of grasslands into arable land this also leads to increases in land use intensity, especially grasslands, which need to provide larger amounts of fodder for livestock holdings. It also increases fodder imports from outside the EU (e.g. soya from Brazil) leading to increases of land demand outside Europe.

3.3.2 Effects of present biomass demand for land and irrigation water use outside EU

The EU is not the only region that set biofuel and renewable energy targets. Ambitious targets were also set in other countries (see Annex 1). The demand for biomass for energy is therefore rising globally. An overview of the present land and irrigation water use for biofuel production in a selection of countries is given in Table 3.1.

The EU does not produce all its feedstock domestically. According to the latest Eurostat figures for 2008, 15% of EU biofuels consumed were imported (2932 ktOE). The EU also exported biofuels in the same year (1131 ktOE). Net imports were thus relatively small, but since there is still a large way to go to reach the 2020 targets it can be expected that imports will further increase.

Table 3.1 demonstrates that dedicated cropping for biofuel production is very large in the EU and that in total area use it is already above that of the most important exporter of biofuel, Brazil. However since the EU has not even reached half of its 2020 target, land use globally will still continue to increase significantly.

Irrigation water use is also large for this sector. Given the expected growth in biofuel demand this may become a growing problem in regions where water resources are scarce.

Table 3.1 *European and global land use and irrigation water use shares for biofuel and biogas cropping*

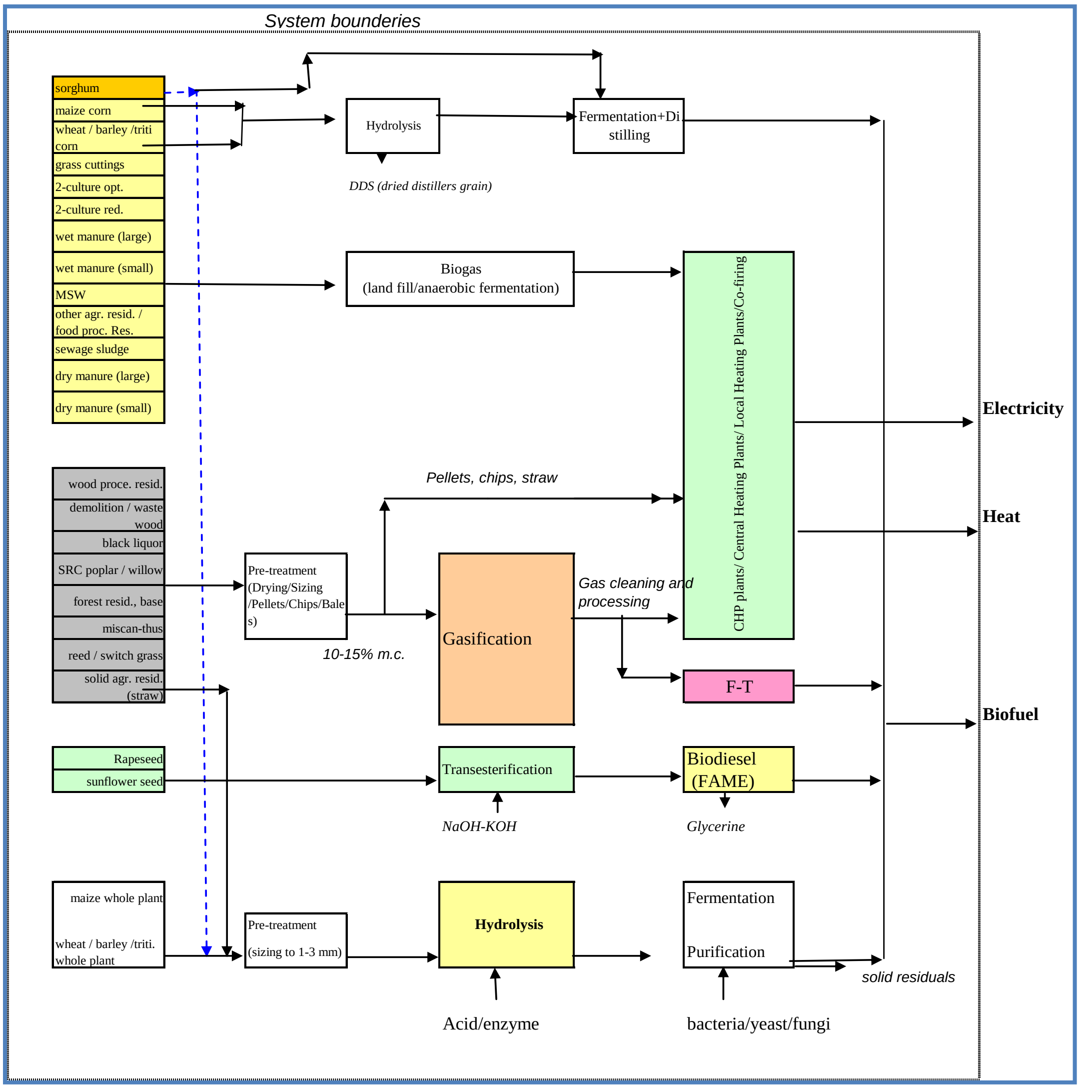
Situation 2005 to 2008	**Main feedstock**	**Area biofuel crop (mln ha)**	**% total cropped area**	**% total irrigation withdrawals**
Brazil	Sugarcane	2.4	5	3.5
USA	Maize	3.8	4	2.7
Canada	Wheat	0.3	1	1.4
Germany	Wheat, OSR & Maize	1.6	10	10.8
France	Sugar beet & OSR	1.5	8	1.6
Italy	Wheat	0.0	1	0.5
Spain	Wheat	0.2	2	2.0
Sweden	Wheat	0.1	1	0
UK	OSR	0.4	2	0.4
EU	OSR, wheat	4.8	3	2.3
China	Maize	1.9	1	2.2
India	Sugarcane	0.3	0	1.2
Thailand	Sugarcane	0	0	1.9
Indonesia	Sugarcane	0	0	1.2
S. Afrika	Sugarcane	0.1	1	9.8
World total		**12.4**	**1**	**1.1**
Source: De Fraiture et al., 2007, Eurostat crop statistics and Dworak et al., 2009b				

4 Current and future pathways to bioenergy production

4.1 Introduction

There is a broad portfolio of current and future technological options for the conversion of biomass feedstock into bioenergy. Currently, the three different types of energy end-uses for which biomass can be used – transport fuel, electricity generation and heating – use different but overlapping types of biomass. However, in the future it is expected that these markets will become more integrated, as advanced conversion technologies, bio-refineries and cascading use of biomass become more prominent. Figure 4.1 shows the most common biomass categories derived from agriculture, forests and wastes, and the conversion routes that are expected to become economic by 2020.

Figure 4.1 *Conversion routes for biomass to bioenergy*



Source: GEMIS 4.8 (2012) and own elaboration

The efficiency of the energy conversion pathways is the principal guiding factor that determines the make-up of the storylines in this study (see Chapter 5) – depending on it, the different technologies are assumed to be deployed in future markets. A summary of reasons for the inclusion of each conversion technology in the storylines is provided in Table 4.1.

***Table 4.1** Efficiency of output from biomass use, and implications for storylines*

Type of energy generation	Efficiency (%)	Implication for storylines
Co-firing with coal (electricity)	40–45 (IEA 2012, IRENA 2012)	Bridging technology, but still used in 2020 in Storylines `Market first` and `Climate focus` (Storylines 1 and 2) and only to a more limited extent in the `Resource efficiency` storyline (Storyline 3).
Dedicated biomass combustion (electricity)	30–35 (Eurelectric 2011)	No specific implications
Biogas/biomethane	50–85 (DBFZ 2012, IEA 2012)	Used for electricity and heat production, the latter only in co-generation not on its own due to low efficiency. This technology can also deliver transport fuels through the biogas-to-liquid route. This happens to a limited extent in Storylines 2 and 3 in order to reach the NREAP transport fuel targets.
Solid biomass cogeneration (electricity and heat)	65-85	No specific implications
Combustion to produce heat only	>85	Used in all storylines – woodchip boilers for larger buildings, otherwise pellets
First generation biofuel	25–70	Only produced in the EU in Storyline 1, in other storylines mitigation targets are not reached because of the impact of indirect land-use change on greenhouse gas mitigation.
Second generation biofuel	50–60	Considered to be economically viable by 2020, although penetration will increase in Storylines 2 and 3, in which more incentives are given to technological development and deployment of novel bioenergy products.

Source: based on GEMIS 4.8 data; biofuel efficiency data include by-products, allocated by energy content.

To select relevant technologies for the three storylines (see Section 1.4.2 and extensive details in Section 5.1), the options were screened with respect to their efficiency, life-cycle greenhouse gas emissions and production costs. Uptake of bioenergy technologies with high emissions or costs is projected to be small, while the share of improved and better performing technologies will increase, particularly in Storylines 2 (Climate focus) and 3 (Resource efficiency) in which more stimulation measures are expected to be taken to enhance technological developments towards the most greenhouse gas and resource efficient pathways.

Shifts towards lower costs and higher efficiency are expected to be gradual in the more resource-efficient storylines, since intervention effects and market shifts take time – after all, 2020 is only seven years from now.

This screening was done using data from several comprehensive studies on the life cycle and environmental profile of bioenergy[18], and used data from the JRC work on updating the RED default data[19], as well as data from IEA (2010-2012).

Almost all biomass resources – from agricultural and forest residues to dedicated energy crops and wastes – can be used for electricity generation. The conversion process can take several forms, including combustion of raw material, combustion of a gasified product and combustion as a co-product. The standard efficiency data are given in Table 4.1, indicating ranges which depend on the type and size of plant, and reference year. The detailed values used to calculate the storyline outputs are provided in Table 5.5.

18 Bioenergy data were taken from the GEMIS model version 4.8 that is freely available, see www.gemis.de for details. The bioenergy data in GEMIS (see Annex 4) were compiled in the research projects www.biomassfutures.eu (IC et al., 2012), GEF Biofuel Guidance (IFEU, CI, OEKO 2012), IRENA (2012), and based on earlier work for EEA (OEKO, 2009), and WBGU (2009).

19 JRC-IE (Joint Research Centre – Institute for Energy) 2011: Expert Consultation on "Assessing GHG default emissions from biofuels in the EU legislation" 22-23 Nov, 2011, Ispra.

The following sections provide further detail on each of the main energy sectors, namely electricity, heat and transport.

4.2 Electricity

Energy use is typically divided into three main sectors; electricity, heating and transport. Electricity is a versatile energy vector, which can in principle also be used for heating and transport. Partly because of this versatility, there is likely to be an increase in its share of energy consumption by 2050, almost doubling its share to 37% from current levels (EC, 2011b).

According to the principles of resource efficiency, society is best served by using forms of electricity generation which produce the greatest output for the least resource input, all other things being equal.

Most forms of renewable energy have a relatively high capital cost, but zero fuel cost, because once constructed, they require nearly no resource input. Electricity produced from biomass is different as it uses feedstocks cultivated on land which could be used productively for other purposes. Electricity generated from other renewable sources such as geothermal, hydropower, solar and wind also use land, but to a much lesser extent per unit of electricity, as shown in Table 4.2.

Table 4.2 *Land use of fossil, nuclear and renewable electricity systems in 2030**

Electricity from	**Land use m^2/GJ_{el}**	**Notes**
Total EU-27 Electricity mix	0.29	Excluding transmission and distribution
Coal	0.06	Imported coal (surface mining), new steam-turbine powerplant
Lignite	0.10	Lignite in Germany, new steam-turbine powerplant
Natural gas	0.02	EU supply mix including imports and a new combined-cycle powerplant
Nuclear	0.04	German supply mix, steam-turbine powerplant
Hydro (run of river)	0.03	100 MW run-of-river plant
Wind onshore	0.26	10 x 2 MW onshore wind park
Solar-PV-poly	2.7	1 kW_{el} (peak) system, full land use
Solar-CSP	1.9	80 MW_{el} system in southern Spain
Geothermal	1.2	1 MW_{el} ORC** system
Biogas-maize ICE	106	Biogas from maize in internal combustion engine cogeneration plant (energy allocation)
SRC cogen	112	Woodchips from short-rotation coppice in steam-turbine cogeneration plant (energy allocation)
Bio-SNG SRC cogen	164	Biomethane from short-rotation coppice in gas-turbine cogeneration plant (energy allocation)
Bio-SNG SRC CC	128	Biomethane from short-rotation coppice in gas combined-cycle powerplant

Source: Fritsche (2012) based on GEMIS 4.8 data
* The 2030 time horizon was chosen to include advanced bioenergy technologies such as bio-SNG, and solar CSP
** Organic rankine cycle

This means that the use of biomass in electricity generation has both direct and indirect impacts in other sectors that use biomass or land, and that these impacts can become potentially significant in relation to energy output if low efficiency pathways are chosen.

Nonetheless, electricity is a versatile energy carrier, efficient in providing a variety of energy services such as air conditioning, communication, lighting, and mechanical power including for rail and road transport. Thus, its value to society, as well as economically, is far higher than that of low-temperature heat.

Existing thermal processes to convert biomass into electricity follow the same thermodynamics as those using fossil or nuclear fuels: the electric efficiency of solid fuels in steam-turbine power plants increases with unit size, and combined-cycle power plants using gaseous or liquid fuels achieve the highest efficiency in terms of electricity output to fuel input[20].

4.2.1 Co-firing

A current low-cost option is co-firing of solid biomass – wood chips, pellets, straw, dry manure – in conventional coal-fired power plants, or biogas/biomethane in fossil-fired gas turbines or combined-cycle plants (electricity-only or cogeneration), in which biomass is added to fossil fuel, < 10% for straw; up to 100% for terrified biomass and biomethane. Comparatively little investment is needed for this, and the conversion efficiency of biomass into electricity is practically the same as for the fossil fuel (IRENA, 2012).

Implication for storylines
According to most longer-term roadmaps and scenarios for the EU energy system in the 2050 time horizon, coal-fired power plant capacity needs to be reduced significantly to achieve the 2 °C climate target. Co-firing solid biomass is therefore only considered a bridging option and only included in Storyline 1 (Martket first). Depending on the development of biogas and biomethane, co-firing in gas-fired generation or co-generation could become an interesting option for Europe in the longer-run.

4.2.2 Co-generation/Combined heat and power

Combined heat and power (CHP), also known as co-generation, is an efficient option to convert biomass into electricity while extracting some of the waste heat to provide supply for district heating, or industrial-process heat, or even a combination of heating and cooling (trigeneration). Biomass co-generation plants vary in technology and size, ranging from 0.01 MW_{el} to > 300 MW_{el}, and can use biogas or biomethane, wood and many waste products including straw and pellets. Combined heat and power co-firing also includes gas-based CHP operating on a mix of natural gas and biogas including biomethane which could be based on small-scale internal combustion engines (ICE), small-to-medium-sized gas turbines (GT), and larger-scale combined-cycle (CC) plants.

[20] An alternative to steam and gas turbine cycles, or their combination, are fuel cells (FC) which use chemical conversion of fuels to electricity: high-temperature molten-carbonate (MC) or solid-oxide (SO) fuel cells offers more than 60% electric efficiency even at small unit sizes (0.1-1 MW_{el}) and can use biogas or biomethane without prior conversion to hydrogen (H_2). The high operating temperature makes it possible to use the remaining waste heat again for additional electricity generation by small steam turbines, or to extract heat for industrial processes, or even cooling. In electricity-only mode, solid-oxide fuel cells (SOFCs) have a potential conversion efficiency of 70%, while in cogeneration mode, up to 60% is possible for electricity, plus 15% for heat. Due to the early state of development, though, neither molten-carbonate fuel cells (MCFCs) nor SOFCs are assumed to be commercially available before the late 2020s (IEA, 2012), and are thus excluded from the storylines.

Solid biomass for cogeneration can either be based on co-firing in coal CHP plants, or on dedicated biomass-only CHP systems which – due to logistical constraints – are typically medium-sized, 1–50 MW_{el}. The CHP technologies for solid bioenergy are typically less efficient than those operating on biogas/biomethane, and have higher investment and operating costs, but fuel costs are lower.

Future CHP systems such as solid-oxide fuel cells (SOFCs) might use biomethane from gasified solid biomass (bio-SNG) which offers high conversion efficiencies, but investment costs for medium-scale gasifiers and fuel cells are still high[21].

An interesting option is to use straw as a co-feed with liquid manure in biogas fermenters to enhance conversion (DBFZ, 2012). This hybrid system is under development, but could extend available biogas especially in regions with large manure and straw surpluses.

Land use changes are not considered relevant when residual or waste biomass is used, but environmental safeguards need to be observed with regard to maintaining soil organic-carbon levels, erosion risks, and nutrient depletion for forest residues as well as biodiversity restrictions such as deadwood levels in forests[22].

Land use change can be significant, though, when dedicated bioenergy crops are used for co-generation, with effects similar to electricity-only, heat-only or biofuels for transport conversion (Chapter 5).

In this study it has been assumed that co-feeding with straw still requires much technological development and investment through Rural Development Programmes (RDP) and is assumed to become economic by 2020 in Storylines 2 (Climate focus) and 3 (Resource efficiency), while in Storyline 1 (Market first), the traditional solid biomass CHP systems and co-firing dominate.

4.2.3. Biogas and Biomethane

The production and use of biogas as well as its upgrade to biomethane and the conversion of solid biomass to biomethane (bio-SNG) have great potential, as gaseous bioenergy can be used both for electricity generation or co-generation as well as for injection into the gas grid as a direct substitution for natural gas.

However, overall efficiencies need to be improved and methane leakage requires reduction to create more sustainable supply chains and respective products. There are many uncertainties about leakage of methane from biogas plants, but it is clear that these may influence the final efficiency significantly. According to Mistry and Misselbrook (2005) the methane leakage for on-farm anaerobic digestion is 3% and for centralised anaerobic digestion 1%. However, according to Vogt *et al*. (2008) methane leakage might be 2.5–15% of biogas produced for existing facilities (including CH_4 emissions from gas

[21] See footnote 20

[22] Note that these considerations not only apply to bioenergy used in cogeneration, but for all bioenergy uses. For a recent set of criteria and indicators proposed for all bioenergy, see Fritsche (2012).

engines buring the biogas). More recent data indicate a significant reduction of methane losses for new facilities using encased residue storage, and confirm that larger-scale plants often have lower emissions (DBFZ, 2011+2012). As an average for new medium-sized biogas plants (including gas engine emissions), CH_4 losses of 0.5% are seen as representative, while for existing plants, emissions of 2% are seen as realistic for Germany (Fritsche & Rausch, 2012). However, the methane losses from biogas fermenters – both of manure and bioenergy crops – can be reduced further through improving biogas combustion in gas-motors equipped with catalytic converters, or by using biogas in gas turbines, and, in the future, solid-oxide fuel cells.

A detailed look at the feedstocks and conversion processes for biogas and bio-SNG production based on straw is included in Annex 5.

While the use of biogas and biomethane are quite efficient and low-polluting, the production of biogas from dedicated energy crops such as maize, sugar beet or wheat require careful analysis. The emissions of these systems – both in terms of greenhouse and acidifying gases such as ammonia – are much higher and most of these are related to the cultivation of energy crops. Where manure is used, the greenhouse gas performance is far better (Annex 5). Furthermore, costs for co-substrates are relatively high, making the economic viability of biogas production less attractive. This was, however, compensated for in Austria and Germany. In Germany, this was done through favourable feed-in tariffs for biogas-based electricity. It was shown, however, that large-scale biogas cropping had negative impacts on agricultural diversity, though these effects were mostly on the regional and local levels[23] (see Annex 9).

Implication for storylines

Because both the lack of greenhouse gas efficiency in biogas systems based on crops and the high cost imply that for 2020, it has been assumed that all biogas installations either use booster residues such as blood, grease, fish oils and processed carcasses from the food processing industries, or straw. In case of the manure straw biogas pathway, this is only applied in Storylines 2 (Climate focus) and 3 (Resource efficiency) in which these technologies are assumed to be feasible because of higher support to technological innovation and carbon credit prices. This pathway is assumed to be economically feasible and to deliver a 10% higher efficiency than a manure-based pathway in Storylines 2 (Climate focus) and 3 (Resource efficiency), but is not included in Storyline 1 (Market first).

Furthermore, the inclusion of indirect land use change related greenhouse gas emissions into the life-cycle emissions of biogas from annual crops restricts the use of these options drastically in Storylines 2 and 3 (Chapter 5). The conversion of perennial crops, cultivated on marginal land not in competition to food crops, into bio-SNG offers favourable greenhouse gas balances, but has comparatively high costs.

Finally, biogas can also be diverted from electricity generation to the transport sector through biogas-to-liquid pathways. This only happens in Storylines 2 (Climate focus) and 3 (Resource efficiency)where biogas used in the public

[23] It is beyond the scope of this report to fully discuss the environmental implications of crop-based biogas, but recent analyses in Germany indicate significant impacts on land use, biodiversity, and greenhouse gas emissions which need to be addressed when expanding those uses (DBFZ, 2012).

transport sector is allowed to count double to the NREAP targets. In Storyline 1, these incentives are absent and biogas is only employed in the electricity and heat sectors.

4.3 Heating

4.3.1 Decentralised heating

Apparently, the current best option for generating heat from biomass in smaller-scale units is to burn wood pellets or logs in specialised heating systems, although this requires high capital investment compared with fossil fuel heating. Even traditional log stoves can reach a high efficiency (> 80%) if operated properly, but show negative air emission trade-offs, especially regarding fine particles (PM_{10}), and black carbon emissions, the latter having comparatively high short-term global warming implications (UNEP and WMO, 2011).

The overall heat demand of Europe needs to be reduced though energy efficient retrofits of buildings and zero-heat constructions – required from 2020 onwards for new residential buildings through the Energy Performance of Buildings Directive (EC, 2002). Furthermore, options such as geothermal and solar heating are available in some EU regions, and will become more competitive over time. This will reduce the potential market for bioenergy-based heat in the longer run.

For the perspectives beyond 2020, the limited availability of biomass and the resource-efficiency paradigm require the use of this resource with the highest overall efficiency– and this is not in direct heating, but in cogeneration (CE, OEKO, 2010; EEA, 2008a; IEA, 2012).

Furthermore, small-scale combustion of solid bioenergy – even if based on residues from forests and pellets from wood-industry wastes – emits comparatively high levels of air pollutants[24], requires sound storage systems, and is costly if run as automatic central heating systems.

Implication for Storylines
In general, bioenergy used for heat alone is far more efficient than bioenergy used to generate electricity (Table 4.1) so this would be a preferred option particularly in Storylines 2 (Climate focus) and 3 (Resource efficiency). As to the type of biomass and conversion routes, the storylines are based on the premise of using woodchips based on forest residues and on perennial crops only in boilers for larger heating systems such as multi-family houses, with adequate emission controls to reduce local nitrogen oxide and PM_{10} loads.

Small-scale decentralised biomass heating is valid in all storylines only for advanced automated pellet systems, based on all woody biomass from forests and from dedicated cropping with perennials. In Storylines 2 (Climate focus) and 3 (Resource efficiency)it is assumed that a share of small scale decentralised heating systems is larger because of higher support levels and stimulation policies to also use the bioheat locally. Biogas/biomethane is not

[24] This is especially true for wood-log combustion in small stoves. For woodchips and especially pellets in larger heating systems (50-1000 kW_{th}), emissions of CO and hydrocarbons as well as PM_{10} can be reduced to levels comparable of oil heating.

used for heating in Storylines 2 (Climate focus) and 3 (Resource efficiency)due to low overall resource efficiency, but indirectly provides heat from cogeneration.

4.3.2 District heating

As discussed, using waste heat from power generation or industrial processes is the most resource-efficient way to use biomass in the heating sector.

District heating can supply both large areas of densely-populated buildings, and smaller-scale neighbourhoods or larger building complexes using packaged co-generation.

Depending on the supply systems, district heat is an attractive option in all storylines. Nevertheless, high-efficient and low greenhouse gas emission systems operated on residues and wastes dominate in Storylines 2 (Climate focus) and 3 (Resource efficiency).

4.4 Transport

4.4.1 First-generation biofuels

First-generation (1G) biofuels in Europe use dedicated feed stocks such as sugar beet, oilseeds, and starch crops to convert the oils into biodiesel, and sugar/starch into ethanol. Both are then generally mixed with fossil-based liquid fuels.

The biofuels technologies include fermentation, the production of ethanol from the sugars extracted from crops (EEA, 2008a; OEKO, 2009; IEA, 2011), and trans-esterification to fatty acid methyl ester (FAME), the conversion of oil from oil-seed crops into biodiesel

Sugar extracted from sugar crops is easily fermented into ethanol. Starch crops such as wheat and corn are hydrolysed into sugar, which is then fermented into ethanol. Co-products such as distiller's dried grains with solubles (DDGS) are allocated on the basis of their energy value, based on RED methodology. These by-products are included in estimates of the total greenhouse gas-mitigation potential of this pathway in the rest of this study.

In addition, compressed biomethane, green CNG, from biogas or ligno-cellulosic-based bio-SNG could be used in gas-fuelled cars, buses etc. An advantage of this could be to bridge the transition period from first to second generation biofuels. Introduction of this may also stimulate the development of a learning curve on technology for biogas production.

4.4.2 Second-generation (2G) biofuels

Advanced – so-called second-generation (2G) – biofuels use other, mainly ligno-cellulosic feedstocks, including the whole plants – stems, stalks etc., short-rotation coppices (SRC), perennial grasses and forest residues as well as straw, all of which are referred to as cellulosic biomass. Cellulosic means that this biomass is composed of cellulose, hemicellulose and lignin, with smaller amounts of proteins, lipids (fats, waxes and oils) and ash. Cellulosic biomass is naturally resistant to being broken down, so requires advanced technologies to convert it into liquid fuels. Examples of these technologies include (IEA, 2010; IEA, 2011):

• Thermo-chemical conversion: biomass is gasified to syngas at 600–1 100 °C, and then converted to biodiesel using Fischer-Tropsch synthesis. This is called biomass-to-liquid (BtL) and can be applied to woody or grass-derived biomass as well as cellulosic or ligno-cellulosic dry residues and wastes. Currently, there are no commercial plants producing BtL, but several pre-commercial plants exist in Germany, Japan, and the United States. Cellulosic biomass can also be converted to liquid fuels called bio-oil or pyrolysis oil, by heating it to around 475 °C. However, pyrolysis oils consist of a mix of a different hydrocarbons and are not currently used as transport fuels.

• Bio-chemical conversion: this involves pre-treatment of cellulosic biomass and enzymatically enhanced hydrolysis and subsequent fermentation to convert hemicellulose and sugar into ethanol. There are demonstration plants in the EU (Denmark, Spain and Sweden), and Canada. Other countries such as Brazil, China, Germany, Japan and the United States are also developing 2G ethanol technologies.

• A third route uses land-based microalgae or marine macro-algae to either extract oils, or derive ethanol, biogas, or both from fermenting algal biomass. Due to limitations in yields, purity, and relatively high auxiliary energy demands and costs, these often called third-generation technologies are expected to need at least one decade to reach an early commercial demonstration stage.

2nd generation (2G) technologies are expected to be economically feasible by 2020 in all three storylines. However, their market implementation will be restricted in that timeframe, as even in optimistic scenarios, commercialisation will not start before 2015 so that actual deployment will be limited in absolute terms. Thus, the potential production of 2G biofuels will certainly not exceed 1.5 percentage points of the EU renewable transport fuel target (to which 2G fuels double-count) by 2020 (IEA, 2011).

Looking at the likelihood of the technical assumptions adopted the influence of underachieving the penetration rates estimated for 2G biofuels on final results is not considered to be high. This means that the overall results of the scenarios are not significantly changed if 2G biofuels would not be commercially available (given the feedstock costs and policy instruments assumed) by 2020. However, for the longer-term developments after 2020 aiming at the overall 2 °C global climate target for 2050 and respective decarbonisation requirements from 2020 onwards, 2G technologies play a critical role. This is because they will be key to reducing GHG emissions from aviation, and long-transport freight haulage by trucks as well as international marine freight transport for which only very few and costly alternatives to (resource-efficient) biofuels exist.

Table 5.5 in Chapter 5 summarises the main conversion technologies and feedstock combinations assumed to be economically feasible by 2020 in the three storylines, and shows the greenhouse gas emissions and the energy efficiency for each pathway. Emissions include land-based ones[25] and those from the downstream path including transport to plant, pre-treatment, and the conversion processes.

For cultivated crops, maximum and minimum values are calculated taking into account the extremes of land-based emissions under the wide diversity of agro-climatic and agronomic circumstances in the EU-27. Section 5.3 explains how the greenhouse gas emissions and energy efficiencies are calculated using the GEMIS model and the agro-environmental model Miterra (Veldhof *et al.,* 2009).

25 The direct emissions related to the production of a crop include greenhouse gas emissions from fertiliser production, carbon dioxide emissions from fuel use (mechanisation) and greenhouse gas emissions from cultivation (soil nitrous-oxide emission + carbon dioxide from peat soils).

5 Approach to estimating bioenergy potential

5.1 Introduction

This chapter outlines the approach used to estimate the potential for land and agricultural by-products to provide the feedstock needed to reach the EU renewable transport fuel and overall renewable energy targets for 2020. It takes account of different environmental criteria in relation to biodiversity and the wider environment, greenhouse gas mitigation and the prevention of indirect land use changes (ILUC) when reaching the NREAP targets in 2020.

The approach to finding the most optimal ways for reaching the 2020 renewable energy targets starts from the following rationale:

1) Resource efficiency is not simply about the amount of resources that are used to produce a given economic output, but is also about the impacts on ecosystems and the services that they provide. That includes impacts across the full life cycle, from resource extraction to assimilation of waste including emissions and impacts on water, air, soil quality and biodiversity, as well as use ratios of non-renewable primary energy, and raw materials.

2) Market prices can provide a distorted representation of true costs and benefits of resource use and economic choices. Fossil fuels dominance also build on the fact that market prices do not reflect the full costs of use – extraction, pollution etc.

3) Energy is essential for economies and societies to function and is a key determinant of resource use. Clearly energy sources vary hugely in character: some are non-renewable sub-soil sources, such as coal and oil; some are renewables but depletable, such as biomass, if natural systems are not managed properly; others are renewable and non-depletable thus in more or less infinite, though restricted, supply such as solar and wind.

4) All forms of energy supply have ecosystem impacts, including non-depletable: wind power, for example, demands resources for turbines and the grid while it impacts birds and cultural and amenity values of landscapes. Determining how best to meet society's energy needs, therefore, requires careful analysis of all costs and benefits – which are likely to vary by location.

5) Analysis of the costs and benefits of bioenergy is very complex. Land use changes lead to changes in biodiversity, soil, water and air quality. The assessment of a carbon balance in very complicated and needs to take account of existing approaches and the most recent studies. There are also multiple types of biomass and multiple ways of converting these into different types of bioenergy. Yet it is essential that we understand how much biomass can be produced sustainably in the EU and how efficiency can be maximised in terms of the resulting bioenergy output.

The search towards the optimal way of reaching the 2020 renewable energy targets based on the rationale described above is done by implementing three storylines for which the following criteria are specified:

- In **Market First (Storyline 1)** there is strong market influence and limited policy intervention. The only policy intervention is the setting of the EU renewable energy targets for 2020 (EC, 2009a). Reaching these targets is left to market forces and domestic quotas but is assumed to be achieved nevertheless.

- In **Climate Focus (Storyline 2)** there is less market influence and more policy intervention, especially regarding greenhouse gas mitigation. Only highly efficient cropping and conversion systems from the perspective of greenhouse gas mitigation are adopted, and highly biodiverse areas and/or areas with high carbon stocks are not used for bioenergy cropping.

- In **Resource Efficiency (Storyline 3)** there is also little market influence, but stronger policy interference than in Storyline 2. All the assumptions of Storyline 2 apply, but stricter requirements are imposed regarding use of most efficient renewable energy conversion technologies, and access to land for bioenergy cropping and types of cropping systems in order to ensure that no negative impacts are imposed on natural resources and biodiversity.

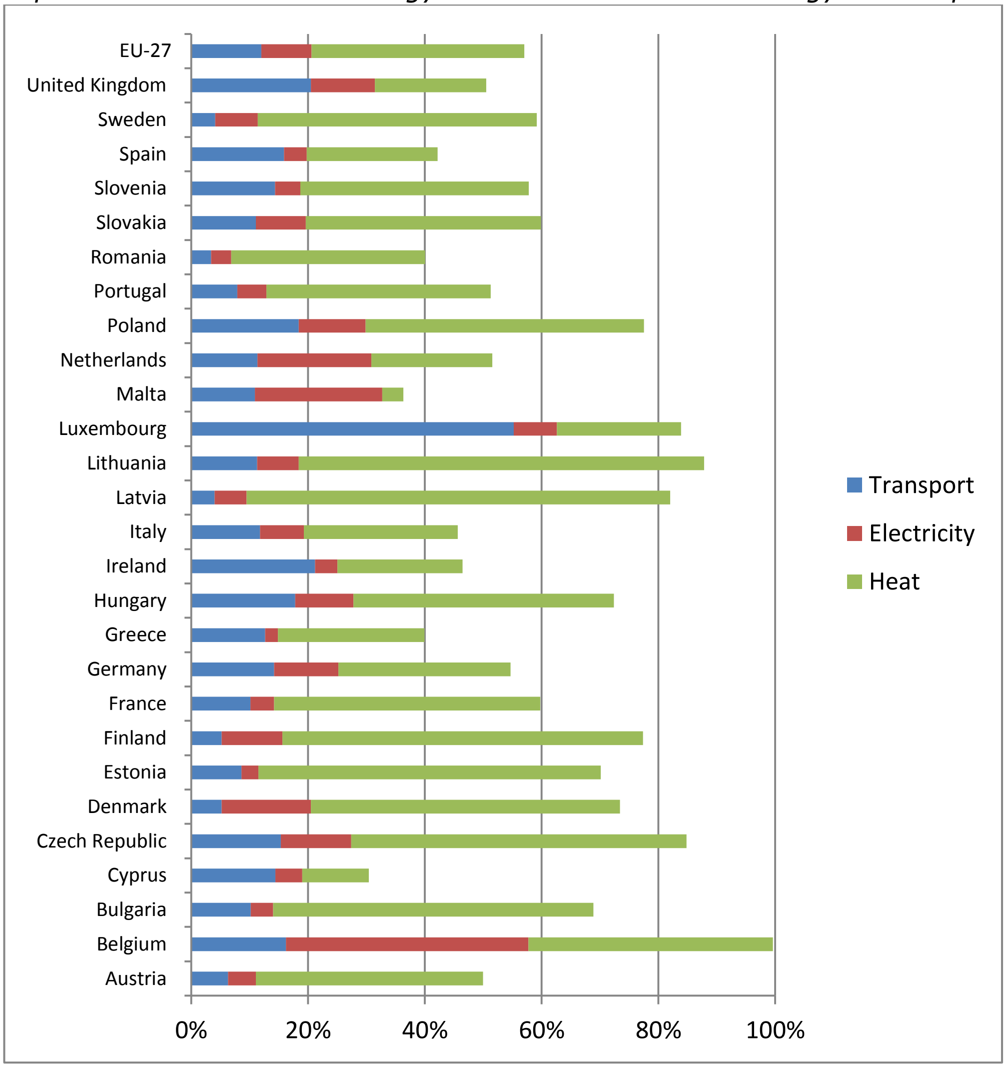
The next section describes the technological pathways for producing bioenergy for transport, electricity and heat by 2020. A distinction is made according to efficiency of the pathways in terms of energy and greenhouse gas emissions. The selection of the pathways is based on the technological development expectations by 2020 as described in Chapter 4 with further complementary information on technological development expectations within this chapter and Annex 5. How the technological pathways are fitted to the three storylines is described in Chapter 4 per energy sector. Overall in Storyline 1 the cheapest pathways are chosen first as there are less policy safeguards that stimulate the taking up of the most energy and greenhouse gas efficient pathways while in Storylines 2 and 3 more resource efficiency and environmental constraints are guiding principles.

Section 5.2 discusses the NREAP targets in relation to projected biomass demand in 2020, the starting point for all storylines. It partly dictates the mix of renewable-energy pathways with which the targets can be met. Section 5.3 describes the three storylines in detail, and Section 5.4 discusses the implications of the environmental and technological framework in each storyline for land availability and land use change. How the three storylines work out in reaching the final NREAP targets and related mitigation potential is presented in Chapter 6. Finally, Chapter 7 analyses the implications of the land use changes estimated for each storyline in relation to impacts on soil, water, air and biodiversity.

5.2 Future biofuel, heat and power pathways

All countries in the EU have NREAPs to meet the 2020 targets for greenhouse gas emissions and renewable energy, in which bioenergy plays a substantial role. Figure 5.1 shows the share of bioenergy in total renewable energy and the biomass demand within these plans.

Figure 5.1 *Expected primary biomass use in the EU in 2020 based on the NREAPs expressed as share of bioenergy in the final renewable energy consumption target*



Source: Beurskens et al., 2011

Most of the 2020 target is currently projected to be met from biomass feedstock. Biomass is the biggest component of the proposed heat targets – 35% for EU-27. The choice of most NREAPs to direct such a large share of their bioenergy to the heat sector is not surprising given the high conversion efficiency to heat as compared to conversion to electricity. However, this compilation does not account for the conversion efficiency of the downstream part, nor of efficiency in terms of greenhouse gas emissions and particularly the mitigation potential for the full life cycle of the product as compared to the fossil alternative. From this perspective, the choice of heat is not the best use, as will become clear from the final mix of biomass-conversion combinations that result from implementation of the three storyline situations and the related total greenhouse gas mitigation potential.

When taking account of conversion efficiency, it is estimated by Beurskens *et al.* (2011) that around 44% of the available biomass is to be used for electricity, 38% for heat and 18% for the transport sector in 2020 on average taken the combined EU-27 targets. The average demand for biomass in 2020 is about 15 GJ/person, but this ranges from 6 GJ/person in Romania to 75 GJ/person in Finland.

Table 5.1 *Summary of NREAP 2020 targets and bioenergy shares*

	Final energy consumption from biomass 2020 (PJ)	Final energy consumption 2020 (PJ)		Biomass in (%)		Renewables in total energy consumption 2020 (%)
		From renewables	Total	Total renewables production	Final energy consumption	
Austria	194	388	1 282	50	15	30
Belgium/ Luxembourg	216	220	2 710	98	8	8
Bulgaria	56	82	548	69	10	15
Cyprus	3	11	100	30	3	11
Czech Republic	156	183	1 429	85	11	13
Denmark	153	209	753	73	20	28
Estonia	30	43	225	70	14	19
Finland	347	448	1 179	77	29	38
France	904	1 512	8 194	60	11	19
Germany	882	1 614	8 858	55	10	18
Greece	82	204	1 057	40	8	19
Hungary	87	121	1 263	72	7	9
Ireland	44	95	643	46	7	15
Italy	411	900	6 093	46	7	15
Latvia	66	80	227	82	29	35
Lithuania	54	62	264	88	21	23
Malta	1	2	26	36	3	8
Netherlands	158	307	2 180	52	7	9
Poland	348	449	4 598	78	8	14
Portugal	130	253	1 029	51	13	10
Romania	122	304	1 439	40	8	25
Slovakia	43	72	521	60	8	21
Slovenia	33	56	223	58	15	14
Spain	390	923	4 711	42	8	25
Sweden	489	825	1 860	59	26	20
United Kingdom	434	859	6 237	51	7	44
Total	5 834	10 222	57 649	57	10	18

Source: Based on Beurskens et al., 2011
Note: Totals may not sum due to rounding.

Some countries significantly exceed the average consumption of biomass within their final energy consumption. They generally have limited alternative renewable-energy production options such as wind or hydro, and large biomass resources. Examples of such countries are Belgium, Czech Republic, Finland, Hungary, Latvia, Lithuania, Luxembourg, and Poland.

Table 5.2 *Final energy demand per country in 2020 according to NREAPs distributed over sectors*

	Final energy demand (PJ)				**Final energy demand (%/total)**		
Country	NREAP demand	heating	electricity	transport	heating	electricity	transport
Austria	194.0	151.0	18.5	24.4	78	10	13
Bulgaria	56.4	44.9	3.1	8.4	80	6	15
Belgium/Luxembourg	202.8	85.1	84.6	33.0	42	42	16
Cyprus	3.3	1.3	0.5	1.6	38	15	48
Czech Republic	163.0	105.4	29.5	28.1	65	18	17
Germany	884.3	475.3	178.0	230.9	54	20	26
Denmark	153.4	110.6	31.9	10.9	72	21	7
Estonia	30.4	25.4	1.3	3.7	84	4	12
Greece	81.5	51.2	4.5	25.8	63	6	32
Spain	389.9	207.2	36.0	146.7	53	9	38
Finland	346.6	276.7	46.5	23.4	80	13	7
France	903.8	688.8	61.8	153.2	76	7	17
Hungary	86.8	53.5	12.0	21.4	62	14	25
Ireland	44.2	20.3	3.6	20.2	46	8	46
Italy	410.9	237.3	67.6	105.9	58	16	26
Lithuania	54.2	42.8	4.4	7.0	79	8	13
Latvia	65.9	58.3	4.4	3.2	88	7	5
Malta	0.6	0.1	0.5	0.0	14	86	0
Netherlands	158.4	63.6	59.9	34.9	40	38	22
Poland	346.6	213.0	51.2	82.4	61	15	24
Portugal	129.8	97.2	12.6	20.0	75	10	15
Romania	121.3	100.5	10.4	10.4	83	9	9
Sweden	488.5	394.6	60.1	33.9	81	12	7
Slovenia	32.4	22.0	2.4	8.0	68	7	25
Slovakia	43.0	28.9	6.2	8.0	67	14	19
United Kingdom	434.0	163.8	94.1	176.0	38	22	41
Total	5 834	3 719	886	1 222	64	15	21

Source: Based on Beurskenset al., 2011.
Note: Totals may not sum due to rounding

In the majority of the countries heat takes the lion's share of the final energy demand. At an EU level, the final energy demand for transport comes second (one fifth of total), after heat, but this is not necessarily the case in all countries (Table 5.2).

In the transport sector, biofuels are not the only pathway to meet the target. The main policy-relevant distinction is between biofuels based on waste, residues, non-food cellulosic and ligno-cellulosic materials and other biofuels, mainly based on energy crops delivering vegetable oils, sugars or starch. The first category counts double toward the RED renewable transport target, mainly because they are considered as the environmentally preferable biofuels as there is no extra land use needed to produce them, while biofuels from 1st generation energy crops are responsible for the largest land demand.

For most of the countries the share of these preferred biofuels in their NREAP targets is zero. Exceptions are however Bulgaria, Cyprus, Denmark and Malta who expect all or most of their biofuels to count double. Finland, Italy, the Netherlands and Sweden expect to have a substantial share of those biofuels.

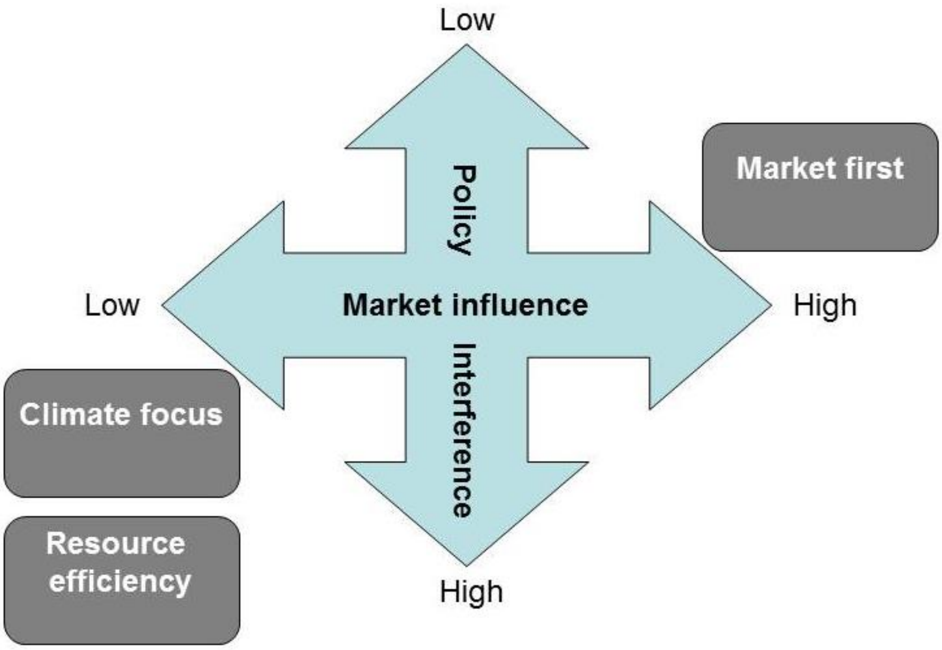
Not all of the double-counting biofuels are based on new and advanced technology. Biogas based on the digestion of waste and biodiesel based on waste oils and fats are produced with well-known technologies. Their long-term contribution is restricted because of the availability of suitable biomass. Advanced technology to use cellulosic material provides more potential in the long term. The NREAPs project that the share of these advanced technologies in 2020 will be low.

5.3 Environmental, technical and economic considerations

The three storylines capture information on the main environmental, technical and economic factors and constraints that will influence bioenergy potential in 2020 and the way market and policy interference may have to vary to reach the 2020 NREAP targets. Assessments of the storylines in terms of potential, land use change and related environmental impacts are presented in the following sections and chapters. The assumptions made in each storyline have an important impact on the greenhouse gas emissions, emissions to water, air, soil and biodiversity and imports. The analysis should provide a better understanding of which suite of stimulation measures and constraints will lead to the most resource efficient realisation of the NREAP targets while at the same time avoiding additional pressure on the environment.

The Storylines are developed along 2 axes – see Figure 5.2:

Figure 5.2 *Overview of character of storylines*



Market First (Storyline 1) is characterised by large market influence and limited policy intervention. The only such intervention is the setting of the RES-targets 2020 specified in the EU Directive on the promotion of the use of energy from renewable sources (EC, 2009a) and further specified as national targets in the NREAPs. The attainment of these targets is left to market forces and domestic quotas (Box 5.1) as no specific stimulation measures are assumed and no consideration is given to carbon-dioxide emission reductions or prevention of ILUC effects. Overall this means that the price level at which feedstock can be considered to be competitive will remain around current levels, estimated at around €3/GJ.

This storyline is most in line with the 2020 outlook for EU agriculture elaborated by the European Commission using the CAPRI model (Box 5.1). The agricultural outlook is based on a set of assumptions judged as the most plausible by a wide range of experts involved in the study. It assumes a continuation of the Common Agricultural Policy following the health check decisions (EC, 2008), and reaching the biofuel targets specified in the individual NREAPs taking account of quotas specifying how much biofuel should come from domestic sources. Targets for electricity and heat were not included in this 2020 outlook run, but were added in a post-model exercise in the study and translated into additional land use change and total domestic energy potential (Storyline 2).

Climate Focus (Storyline 2) assumes less market influence and more policy intervention, especially regarding greenhouse gas mitigation measures. The starting point is that only highly efficient cropping and conversion systems for biofuels are adopted, having a mitigation capacity of at least 50% compared with fossil alternatives, and that highly biodiverse areas and/or areas with high carbon stocks are not to be used for dedicated biofuel cropping. The policies also leave more freedom to regions to contribute to the biofuel target.

In addition to setting the renewable energy sources (RES) 2020 targets specified in the EU RES Directive (EC, 2009) and the national targets in the NREAPs, this storyline also assumes many stimulation measures, including a wide range of support measures at different levels in the chain, and intensive stimulation of technological developments in the field of renewable energy production. The combined support measures provide a floor price for biomass feedstock of up to €6/GJ at the factory/conversion installation gate. This is either paid directly to the farmer by the energy company, or indirectly. Direct payments from an energy company become effectively higher due to tax allowances, feed-in tariffs and carbon dioxide credit payments. Indirect income means that the farmer will earn back part of his investment and production costs through investment support, tax allowances, feed-in tariffs and/or area payments for perennial cropping. Since greenhouse gas efficiency is the starting point in this scenario, the most efficient pathways based on by-products and waste are mostly stimulated through double counting[26] and other stimulation measures.

Pathways based on second-generation technologies and dedicated perennial biomass cropping with no or very limited indirect land use change effect will also be preferred to biofuel cropping with no or practically no greenhouse gas mitigation effects if indirect land

26 This implies that certain biofuels, because they are more sustainable as they do not put extra pressure on land resources, count double for reaching the 10% biofuel target under the RES Directive (EC 2009a). This double counting applies to biofuels produced from wastes and residues.

use change is taken into account. The life-cycle analysis of biogas pathways is also expected to become much better than currently because of technological developments in increased co-feeding of straw as a feedstock (Annex 5). Overall this means that perennial crops become even more preferable then biofuel crops, but by-products and waste are used first.

Resource Efficiency (Storyline 3) assumes less market influence but stronger policy interference than Storyline 2. It implies that all the assumptions of Storyline 2 apply to biofuel but also to heat and electricity pathways, and that stricter requirements are imposed regarding access to land for dedicated cropping, the type of crop mixes and cropping systems to be used and the respective energy conversion technologies. These requirements are more in line with the environmental constraints already applied in the EEA study (2006) regarding crop mixes. However, the assumption of a 30% environmentally-orientated farming share and a 3% set-aside (EEA, 2006) is not used again as these assumptions can be applied to an agri-environmental policy scenario but cannot be directly linked to a renewable energy production storyline. In addition to Storyline 2 in this storyline the overall bioenergy targets set in the NREAPs are the guiding principle, but strict sectoral NREAP targets are not necessarily to be followed if it is, for example, more efficient to produce more of heat rather than electricity.

Box 5.1 *Agricultural outlook 2020 based on CAPRI baseline run*

In December 2010 the EC published *Prospects for agricultural markets and income in the EU 2010-2020.* This takes account of the most recent Health Check reform, the 2020 EU Targets and the most recent OECD-FAO projections for agricultural prices, population and welfare developments (EC, 2010b). The extended version of the CAPRI model was used for the projections of agricultural markets and income. The CAPRI model can now endogenously determine changes in supply and demand for fodder, food, and processing for biofuel feedstocks. As the market part of CAPRI includes behavioural functions for oilseed, and sugar and starch processing, the demand for bio-diesel and bioethanol processing can be covered either by domestically or by imported processed vegetable oils, and the domestic processing may be sourced from EU-produced feedstocks or imported ones. The following technology pathways are covered:

- For total domestic ethanol production, five technology pathways are covered, distinguished by usable feedstock groups:
1) Cereals, differentiated as wheat, barley, rye, oats, maize, and other;
2) sugar;
3) table wine;
4) second-generation ethanol; and
5) non-agricultural ethanol.

- For biodiesel, three technology pathways are covered, distinguished by usable feedstock groups:
1) vegetable oils - differentiated as rape oil, sunflower oil, soya oil, and palm oil;
2) 2nd generation biodiesel; and
3) non-agricultural biodiesel.

- There are also biofuel quantities produced from agricultural residues, like cereals straw or sugar beet leaves, or new energy crops i.e. perennials.

In order to incorporate domestic use and supply of biofuels in the assessment, domestic ethanol and biodiesel production are defined using a profit-maximisation approach as a function depending on processing margins. For biodiesel, the margins for individual vegetable oils are covered by using an average margin, depending on weighted individual margins for all usable vegetable oils. An exception is second-generation and non-agricultural ethanol and biodiesel, for which production quantities are given exogenously and thus depend on baseline assumptions. The baseline assumptions leading to 2020 projections are mainly based on expert knowledge, building on different sources that provide projections of domestic use and supply of biofuels for the individual EU-27 countries (PRIMES) and non-European countries (AGLINK-COSIMO simulation results, see Blanco *et al.*, 2010).
An important assumption is the share of domestic biofuel demand in 2020 results from the implementation of quota obligations. These were estimated by taking the information on implemented quotas up to 2009 (EC, 2009a) and it was assumed that all existing quota obligations, which are defined for a year before 2015, would be increased in the respective EU Member State in 2020 by 1.5%. In addition all existing quotas, which are already defined for a year beyond 2015, would only exceed the existing level by 1.1%. For all EU Member States where no quota exists it is assumed that a minimum quota of

6% will be introduced in 2020. For final quota levels see Table above.

Quota levels for biofuel consumption in 2020 by Member State

	BL	DK	DE	AT	NL	FR	PT	ES	EL	IT	IR	FI	SE
Biodiesel	6.0	6.0	9.0	7.5	6.7	8.0	5.5	7.6	5.2	8.2	6.0	5.9	6.0
Bioethanol	6.0	6.0	8.7	6.4	2.9	5.2	2.8	7.5	3.5	4.1	2.9	4.5	6.0
	UK	CZ	EE	HU	LT	LV	PL	SI	SK	CY	MT	BG	RO
Biodiesel	6.4	6.0	4.1	6.0	5.1	5.7	6.0	8.0	5.9	2.9	1.1	2.4	2.3
Bioethanol	6.4	4.1	2.8	2.4	4.2	2.0	3.4	2.6	3.0	0.8	0.6	1.7	1.6

Source: CAPRI model, calculated based on AGLINK-COSIMO representation and EC (2009a) national biofuel targets and quota (see Blanco Fonseca et al., 2010,).

The use of the CAPRI results is very logical within the context of this project as it is the only study available which models EU markets and production responses at the regional level (approx. NUTS 2) for the whole EU-27. It is therefore the only source of information available that gives a plausible overview of what land use changes can be expected by 2020 and the extent to which they can be related to dedicated bioenergy cropping and other renewable energy activities on farms. It also provides predictions of new 2020 market and income parameters for agricultural products, for example prices, demand, supply and farm income. The emphasis in the CAPRI run (Fonseca *et al.,* 2010) is on predicting biofuel cropping response. However, in addition to this specific information, it also provides detailed information on agricultural land use cropping and livestock patterns. This implies that in a post-model process the CAPRI model output serves as an excellent basis for:

- estimating the land use implications and total domestic biofuel feedstock production in Storyline 1;
- estimating the potential for agricultural by-products in 2020 – straw, manure and cuttings from permanent crops. These can be derived from the detailed land use patterns and livestock types and numbers in 2020 combined with additional information on production levels and competing uses;
- estimating the unused/released land potential in 2020, compared with 2004, that may be used for dedicated biomass cropping with perennial crops, taking account of the additional storyline assumptions developed in this study.

Further information on the agricultural outlook 2020 as modelled by CAPRI:
http://ec.europa.eu/agriculture/publi/caprep/prospects2010/index_en.htm
http://ageconsearch.umn.edu/handle/91395
http://www.ilr1.uni-bonn.de/agpo/publ/techpap/techpap10-01.pdf

5.3.1 Detailed storyline assumptions

An overview of the detailed assumptions for the storylines is given in Table 5.3. The assumptions specify the different stimulation policies, market influence and sustainability criteria that determine where and how land use would change in order to reach bioenergy targets by 2020. The assumptions are used to translate the land use and livestock patterns predicted in the CAPRI baseline (Box 5.1) into further agro-biomass feedstock, energy potentials and related greenhouse gas emissions.

Cost thresholds for feedstock
Storyline 1 assumes that reaching these targets is left completely to market forces with no specific stimulation measures except the introduction of quota levels for domestically produced biofuels (Box 5.1). The cheapest biomass will be used first for conversion into bioenergy and there is no demand for non-competitive feedstock at, for example, above market price. For this study the current market price level at which feedstock is competitive was taken as the reference level. For this purpose estimates were made of price levels of different feedstock types in 2020 by taking account of national and regional specific circumstances (large or small amounts available/large or low competition with other uses) and by extrapolating price levels of 2010 to 2020 and applying a correction for inflation. An overview of current at gate prices found in 2 main studies are given in Table 5.4. Further details on price estimates and results are provided in Annex 10. The maximum price paid for biomass feedstock for heat is level is estimated to be €3/GJ at the grower's gate for solid biomass and substrates for biogas; up to €6/GJ is assumed for Storylines 2 and 3. In all storylines, land for dedicated biomass production for heat and power are only be used if this is available, and was not used for fodder, food and fuel production according to the CAPRI 2020, baseline, and the feedstock costs are not higher than the €3 and €6/GJ thresholds for Storyline 1 and Storylines 2 and 3 respectively.

Table 5.3 *Overview of main storyline assumptions*

Cost thresholds feedstock	**Energy conversion routes and economies of scale**	**No-go areas**	**Greenhouse gas mitigation efficiency and indirect land use change compensation**	**Double counting for renewable energy target**	**Other environmental considerations**
1. Market First					
€3/GJ feedstock costs for heat & electricity	Mostly large and medium scale installations	NO	NO	NO	NO
Biofuels; CAPRI baseline scenario run in Agricultural Outlook 2020	Minimal thresholds in feedstock availability for 2nd generation conversion plants (minimal >500 Kton straw and >20 Kton DM perennials per region for bioethanol conversion/ minimal >10 Kton DM of prunings per region to use it for energy)				NO stimulation of use of abandoned lands
2. Climate Focus					
€6/GJ feedstock costs for heat and electricity	Large, medium and small scale >250 Kton straw for conversion to ligno-EtOH & no minimum on prunnings availability to convert to energy)	HNV farmland/Natura 2000/permanent grassland areas, except for use of cuttings	Prioritise most efficient greenhouse gas pathway	All waste categories and 2nd generation technologies, based on woody materials	Use of (part of) grassland cuttings of abandoned grasslands
If Biofuel land from CAPRI baseline run does not comply with mitigation requirement it may be used for other dedicated cropping pathways provided mitigation target of 50% (including ILUC compensation) are met.	More decentral plants (particularly for heat)	Peatlands (histosoils) & forests (but overlap with HNV farmland)	Compensate for indirect land use change from biofuel production	Green gas used in public transport (swapping)	Stimulation of use of abandoned farmlands provided greenhouse gas target is met and appropriate management is used
	More technology research support for bioenergy leading to faster introduction of 2nd generation and more efficient bioenergy		Minimal 50% greenhouse gas compensation as compared to fossil for biofuels only.		

Cost thresholds feedstock	Energy conversion routes and economies of scale	No-go areas	Greenhouse gas mitigation efficiency and indirect land use change compensation	Double counting for renewable energy target	Other environmental considerations
3. Resource Efficiency					
Similar to storyline 2	Same as in storyline 2	Same as in storyline 2	Same as in storyline 2	Same as in storyline 2	Same as in storyline 2
Similar to storyline 2	Same as in storyline 2	Same as in storyline 2	Compensate for indirect land use change of all bioenergy production	Similar to storyline 2	Same as in storyline 2
	Same as in storyline 2	Not allowed to reduce fallow to less than 10% of arable land No stemwood potential to be removed from protected forest areas.	Minimal 50% greenhouse gas reduction as compared to fossil for all bioenergy (biofuels, liquids, solids and gaseous)		No irrigation for bioenergy crops

Table 5.4 *Overview of gate biomass feedstock prices*

Feedstock/fuel	**€$_{2010}$/GJ (LHV)**
Wood chips, 40% moisture (forest residues)	3.9
Demolition wood	1.7
Woody landscape residues	2.7
Straw	2.0
Wood pellets	6.3
Wood pellets (DIN plus)	10.0
Rapeseed oil	25.1
Palm oil	17.5
Maize silage	4.7
Wheat (seeds)	9.0
Grass silage	5.2
Sunflower seeds (unprocessed)	1.1
Sugar beet	12.1
Animal fat	12.2
Recycled fat	10.3
Co-substrate (e.g. maize, grassland cuttings)	5.8
Manure	7.2

Sources: Thrän et al., 2010 and Tilburg et al., 2010.

Biofuel feedstock is assumed to use higher maximum feedstock prices than solid and biogas feedstock. In Storyline 1 the prices are as calculated by CAPRI in the baseline 2020 scenario (Box 5.1). An EU average of these prices is given in table 5.4 although regional price differences are large. For the other two storylines the same maximum biofuel feedstock prices are taken from CAPRI, but since the greenhouse gas efficiency and prevention of indirect land use change is the main requirement of these two storylines, the use of these crops for biofuel purposes can only occur when yields are sufficient to result in high enough mitigation.

In order to match the maximum cost levels of €3 and €6/GJ to national and, potentially, regional 2020 feedstock cost-level estimates, an inventory was made of the feedstock cost levels of as many possible biomass feedstocks. The description of how the individual feedstock costs were estimated and which sources were used is provided in Annex 10.

Feedstock costs are a crucial factor for 1G biofuels, as they dominate the total cost of their production (> 85%). For 2G biofuels, feedstock costs are less relevant (typically 50% of total cost), as these options have significantly higher investment (BtL) or operating (2G EtOH) cost. Thus, 2G technologies are less sensitive to feedstock cost changes, but their market introduction faces two key problems:

- The higher investment costs – and resulting higher total cost – imply a risk to investors, as they will need to recover their investment over a longer time than those investing in 1G options. Under current market conditions, 2G investments would need massive support.
- The better GHG balance of 2G technologies (if using sustainably produced feedstocks) is not translated into an economic asset, as the RED does not award over-achievement of its GHG threshold to count under the RED renewable transport target, and the Fuel Quality Directive (which gives a dynamic accounting towards the 7% GHG reduction target by 2020) allows for many

more GHG reduction options than 2G biofuels so that there is no clear market signal encouraging investors to shift towards 2G options.

The market introduction of 2G technologies thus highly depends on adequate market support schemes which allow investors to recover their cost (and additional revenue).

Energy conversion routes

The order of introduction of bioenergy pathways in each region will be determined by a combination of local biomass feedstock availability, efficiency of the local pathways, competing uses and land availability. The type of supply of domestic agricultural biomass feedstock will consist of a mixture of:

• by-products, for example, straw or prunings from permanent crops;

manure, straw, grass and/or maize for biogas conversion into either electricity, or co-heat and power;

• dedicated perennial cropping on surplus land, provided it is competitive with other uses and economic as a bioenergy feedstock;

• biofuel crops if predicted to be produced in a country by the 2020 CAPRI baseline run, in the case of Storyline 1 (see Box 5.1), and if mitigating enough greenhouse gas to also compensate for the indirect land use change-related emissions in Storylines 2 and 3 (see also next).

Unlike most other renewable energy generators, bioenergy installations use significant quantities of (biomass) resources to generate heat, electricity or transport fuels. Without the sufficient biomass input there is no energy output, and as the quantities at stake are large the importance of resource efficient approaches is very high.

In general, bioenergy used for heat alone is far more efficient than bioenergy used to generate electricity (Table 5.5). The general assumption in the approach taken for this study is that bioenergy should be used in the most efficient manner, which implies a strong shift in Storylines 2 and 3 away from electricity-only generation, or co-firing with coal, towards cogeneration or heat-only production.

This approach is reflected in the development of the storylines, which demonstrates that imports of energy-generating fuels would be far lower in a future that prioritises the efficient use of biomass for bioenergy. All pathways described in Chapter 4 and selected in Table 5.5 are assumed to be feasible by 2020. However, in Storylines 2 and 3 stimulation measures in the field of technology research, economic incentives and policy constraints are assumed to direct the technology mix towards more efficient and new pathways. An example is the biogas pathway based on manure with straw. This is assumed to be economically feasible and delivering 10% higher efficiency than a manure-based pathway in Storylines 2 and 3, but is non-existent in Storyline 1.

Table 5.5 *Conversion technologies included in 2020 storylines, related direct greenhouse gas emissions, excluding indirect land use change emissions, and energy efficiencies**

Type of biomass	**Technology**	**CO_2eq g/MJ (includes by-product allocation based on energy value)**			**Energy efficiency (MJ_{bio}/MJ_{out})**	**Implicit efficiency (%)**
		Average	Max	Min	Average	
Electricity						
Straw	Large co-firing ST	8.1	8.1	8.1	2.1	47
Straw	Medium ST	24.4	24.4	24.4	1.9	54
Miscanthus	Large co-firing ST	51.1	193.3	24.5	2.1	47
Miscanthus	Medium ST	62.6	187.1	39.3	1.9	54
RCG	Large co-firing ST	93.7	247.8	46.0	2.1	47
RCG	Medium ST	99.2	234.1	57.4	1.9	54
Switchgrass	Large co-firing ST	54.6	175.0	27.8	2.1	47
Switchgrass	Medium ST	67.5	172.9	44.0	1.9	54
Chips, forest	Large co-firing ST	9.9			2.1	47
Chips, forest	Medium ST	33.4			1.9	53
Chips, SRC	Large co-firing ST	63.2	570.9	25.4	2.1	47
Chips, SRC	Medium ST	80.0	524.4	46.9	1.9	53
Pellets, wood residues	Large co-firing ST	12.2			2.1	47
	Medium ST	34.7			1.9	53
Maize	Biogas ICE	40.1	183.2	18.6	2.7	37
OSR (SVO)	ICE	47.9	204.1	8.8	1.3	76
sunflower (SVO	ICE	45.0	162.5	15.8	1.3	76
Manure, liquid	Biogas ICE (CHP)	5.2			2.7	37
Manure, dry	Biogas ICE (CHP)	5.2				37
Straw co-feed/ manure	Biogas ICE (CHP)	4.7			2.4	41
Heat						
Chips, forest	Boiler district heat	4.9			1.2	86
Chips, SRC	Boiler district heat	33.8	308.6	13.3	1.2	86
Chips, miscanthus	Boiler district heat	30.9	149.2	15.4	1.2	82
Chips, switchgrass	Boiler district heat	32.1	156.1	18.3	1.3	78
Chips RCG	Boiler district heat	52.1	211.1	28.6	1.4	69
Pellets, wood residues	Boiler district heat	6.5			1.2	85
Pellets, wood residues	Stove	5.6			1.1	89
Transport fuels						
Wood chips, residues	BTL	6.0			1.8	56
Wood chips, SRC – willow/poplar	BTL	50.5	474.3	18.9	1.8	56
Chips, miscanthus	BTL	48.7	323.2	31.7	1.9	53
Chips, switchgrass	BTL	50.8	338.4	23.6	2.0	50
Chips, RCG	BTL	72.9	410.0	34.2	2.1	45
Straw	Ligno-EtOH	5.2	5.2	5.2	2.0	50
Wood chips, residues	Ligno-EtOH	6.0			1.8	56
wood chips, SRC – willow/poplar	Ligno-EtOH	50.5	474.3	18.9	1.8	56
Barley	EtOH	42.4	167.7	25.3	1.0	98
Wheat	EtOH	46.8	261.1	26.7	1.0	98
Sugar beet	EtOH	55.4	146.6	41.0	0.8	119
OSR	Biodiesel	38.6	147.6	11.4	0.9	109
Sunflower	Biodiesel	36.6	118.6	16.3	0.9	109

Source: GEMIS version 4.8, 2012.

* For further explanation of how average, min and maximum GHG emission and energy efficiency values were calculated please consult the sub-section in this Section on Greenhouse gas mitigation efficiency and indirect land use change compensation.

The differences in distribution of feedstock between pathways and storylines are because of specific efficiencies in terms of greenhouse gas emissions, scale of installation and concentration of feedstock mix per region, rather than because of differences in technology mix. In Storylines 2 and 3 the feedstock is first directed to the pathways with highest greenhouse gas mitigation potential, while in Storyline 1 preference is given to use in large and medium-scale central installations combined with large-scale concentrations of feedstock types. If the concentration of straw or feedstock from dedicated perennial crops in Storyline 1 is too small, 500,000 and 20,000 tonnes respectively, all feedstock is diverted towards alternative conversions such as co-heat and power installations, but if it is large it goes into ligno-ethanol and biomass-to-liquid (BTL) production respectively. In Storylines 2 and 3 less attention is paid to economies of scale, making the production of ligno-ethanol, BTL and heat from straw and woodchips from perennials more frequent. Also in Storyline 1, residues from fruit, olive trees and wine production are only used if there is a potential of more than 10,000 tonnes DM available to reach economy-of-scale thresholds. Cuttings from abandoned grasslands are not used at all in this storyline, as there are no stimulation measures to make it attractive while the opposite applies in Storylines 2 and 3.

Storylines 2 and 3 assume strong support for technological developments which increase the number of electric vehicles and the numbers of cars using bio-methanol. This implies that a larger share of the biofuel targets in these storylines are met by bioelectricity and gas – liquid-to-gas – than is possible in Storyline 1. The demand for dedicated biofuel cropping can therefore also be smaller in Storylines 2 and 3 and it is more likely that pathways with higher greenhouse gas mitigation potential and no or very limited indirect land use change effects are included in the technology mix.

Furthermore, if the NREAP biofuel demands cannot be covered by domestic supply in Storylines 2 and 3, biogas is assumed to be diverted from electricity generation to the transport sector through biogas-to-liquid pathways. An important incentive is that biogas used in the public-transport sector is allowed to count double for the NREAP targets in Storylines 2 and 3. In Storyline 1 these incentives are absent and biogas is only employed in the electricity and heat sectors.

No-go areas

In Storyline 1 no consideration needs to be given to the prevention of the loss of highly biodiverse areas or areas with high carbon stocks. This means that permanent grasslands, Natura 2000 areas and HNV farmland could be used for dedicated biomass cropping. The opposite applies in Storylines 2 and 3 in which highly biodiverse areas and areas with high carbon stocks are not used for biomass cropping. It is difficult to capture precisely all of these areas in Europe because of lack of spatially-detailed information and clear definitions. In this study both the Natura 2000 and HNV farmland areas were regarded as good proxies for highly biodiverse areas and agricultural areas with high carbon stocks. Annex 11 provides a further description of the characteristics of these areas and their spatial distribution.

Since land availability in Storyline 1 is not reduced by no-go areas, there is a larger potential available for dedicated cropping than in Storylines 2 and 3. Whether this will actually be used depends on the costs of dedicated cropping, which cannot be higher than €3/GJ in Storyline 1. This possibility of cheap dedicated cropping potential depends on local circumstances, climate, soil, input costs, which together determine at-gate costs and these will therefore differ considerably between EU regions.

A very important additional assumption regarding the use of land for dedicated cropping is related to fallow land use and only applies to Storyline 3. It assumes that demand for dedicated cropping cannot lead to a reduction of fallow of more than 10% of the present utilised agricultural area. The reason for this assumption is that fallow land is a very important agricultural habitat for biodiversity. As already discussed by the EEA (2006), farmland biodiversity is higher in landscapes with larger temporal and spatial variations in agricultural use. In other words, the presence of fallow land pockets in agricultural landscapes ensures that farming practices and use are not the same everywhere in terms of intensity of use.

One advantage of creating these fallow land pockets of unsprayed habitat is that they help support the biological control of pests. These pockets provide a habitat for species that are enemies of pest species (Östman *et al.;* 2001a, b; Thies and Tscharntke, 1999; Tscharntke *et al.,* 2005). Another advantage of fallow land pockets in intensively managed agricultural landscapes is their function as stepping stones which support connections between habitats and establish migration corridors for species. The presence of fallow land pockets also increases the survival rates of species that have adapted to arable farming systems, such as the hare and the great partridge (Boatman *et al*., 1999).

Greenhouse gas mitigation efficiency and indirect land use change compensation

While Storyline 1 includes no greenhouse gas-mitigation requirements, important requirements of Storylines 2 and 3 are the inclusion of very efficient conversion systems with high enough greenhouse gas-mitigation potential, and the prevention of indirect land use change. This implies that in all regions the maximum potential from residues such as manure for biogas, straw, cuttings and prunings will be the first to be used. If land is available, dedicated biomass cropping becomes an option provided the mitigation target is reached, taking account of compensation for indirect land use change related greenhouse gas emissions, if land use change occurs with displacing previous use (see also Chapter 2).

In both Storylines 2 and 3, the adopted greenhouse gas-mitigation requirement implies that dedicated cropping for biofuel production can only be done if it leads to a 50% mitigation of greenhouse gas emissions compared with the use of fossil fuel (Table 5.6). If biofuel cropping takes place on arable land in competition with food and fodder crops, leading to an indirect land use change most likely outside Europe, the emissions related to this indirect land use change effect should also be compensated for.

In Storyline 3 this is implemented even more strictly than in Storyline 2 as all pathways, for biofuel, heat or electricity, need to achieve 50% mitigation of greenhouse gas emissions. In Storyline 2 the 50% requirement applies only if land is used for biofuel cropping – if it is used for production of feedstock for heat and power the mitigation potential only needs to be positive.

Table 5.6 *Greenhouse gas emission of fossil based fuel comparator in the EU*

EU-27 mix, [kg CO_2eq/GJ_{fuel}]	**2010**	**2020**	**2030**
diesel	87.5	87.5	87.5
gasoline	90.2	89.4	89.4

Source: GEMIS 4.8 (2012); data are for 100% combustion efficiency, including upstream effects

An estimate of greenhouse gas payback and mitigation ability is made for all pathways using feedstock, including the indirect land use change effect and taking into account the type of feedstock and related bioenergy delivery pathway. A 20-year payback time is assumed. This is implemented by estimating the greenhouse gas mitigation efficiency factor linked to a yield level per location in the EU. This implies that the indirect land use change factor is determined as a share of greenhouse gas mitigation needed per biomass feedstock type and conversion pathway. Scientific consensus on the size of indirect land use change greenhouse gas emission factors does not exist, as is discussed in the Chapter 2. The major available studies regarding this issue have therefore been considered, and an average indirect land use change greenhouse gas factor is calculated to estimate the greenhouse gas payback and mitigation ability for each bioenergy pathway.

Which average factor for indirect land use change related greenhouse gas emission is used here and how it is derived is discussed in Chapter 2. The most recent modelling results on indirect land use change with the IFPRI-MIRAGE-BioF model (Laborde, 2011) which feed into the forthcoming European Commission *Impact assessment on indirect land use change related to biofuels* have not been taken into account in this overview. However, the results of that study are taken as a starting point for the sensitivity assessment in Chapter 8 in which the effect of lower greenhouse gas indirect land use change factors is assessed in terms of domestic potential and final greenhouse gas emissions[27].

To determine the final mitigation level for each pathway and region, the greenhouse gas emission of the whole bioenergy pathway is calculated, including the indirect land use change-related greenhouse gas-emission factors if land is used in competition with food and fodder, to compare with the greenhouse gas emissions of the fossil-based comparator[28]. Table 5.5 gives an overview of the average, minimum and maximum emissions of all technology pathways. The land use-change-based emissions were calculated by the MITERRA system (Velthof *et al.,* 2009) for every bioenergy crop grown in every EU-27 (NUTS 2) region (Annex 18). There are large differences between regions in soil-related climatic conditions and management and these determine the large differences between the average, minimum and maximum emissions in the pathways based on cropped biomass (in Table 5.5).

The emissions of the downstream part of the bioenergy pathways and of the fossil comparators are based on GEMIS, which refers to full life-cycle emissions. GEMIS is a life-cycle analysis programme and database for energy, material and transport systems. The GEMIS database offers information on:

1) fossil fuels, renewables, nuclear, biomass and hydrogen;
2) processes for electricity and heat;
3) materials; and
4) transport[29].

The fossil fuel mix for calculating the average emission of the 2020 fossil comparators for both electricity and heat are based on the PRIMES reference scenario for 2020 (Capros *et al.,* 2009). The emissions as presented in Table 5.7 are based on fossil fuels only (coal, lignite, oil and natural gas), since the assumption is that renewable

[27] For a critical review of this study, see Marelli (2011b and 2012).
[28] To calculate the final mitigation potential the difference in greenhouse gas emission between the renewable energy pathway and the greenhouse gas emission of the fossil comparator is taken and expressed as a proportion of the total emission of the fossil comparator.
[29] GEMIS includes the total life-cycle in its calculation of impacts - ifuel delivery, materials used for construction, waste treatment, transports/auxiliaries and includes by-product allocation, based on energy value. A further description of GEMIS and the calculated GHG emissions is given in Annexes 2 and 3 of EEA (2008a), and on the GEMIS website (www.gemis.de).

energy pathways will replace fossil fuels and not other renewable-energy sources or nuclear energy.

Table 5.7 *Average greenhouse gas emissions of fossil comparators 2020*

	Greenhouse gas emissions (CO_2eq g/MJ_{out})	
Country	**Electricity**	**Heat**
Austria	158.1	94
Belgium	145.9	91.5
Bulgaria	249.5	169.7
Cyprus	100.7	106.7
Czech Republic	261.5	100.2
Denmark	170.4	84.7
Estonia	267.2	87.4
Finland	187.1	90.4
France	140.2	87.9
Germany	200	84.5
Greece	214.6	105.5
Hungary	167.1	94.2
Ireland	160.5	109.3
Italy	141.4	86.1
Latvia	173.4	98.3
Lithuania	110.6	105
Luxembourg	111.3	91.8
Malta	99.4	101.4
Netherlands	158.1	73.3
Poland	249.2	153.8
Portugal	168.4	92.1
Romania	179.9	85.8
Slovakia	183.6	103.2
Slovenia	259.6	110.7
Spain	166.3	91.6
Sweden	119.4	93.2
United Kingdom	153	76.1

Source: GEMIS 4.8 (2012) and PRIMES reference scenario

The emissions from the land-based part of the chain, if cropping is involved, are calculated using the MITERRA-Europe model. This assesses the impact of measures, policies and land use changes on environmental indicators at the NUTS-2 and Member-State level in the EU-27. MITERRA-Europe partly takes the input of the CAPRI and GAINS models, supplemented with an nitrogen-leaching module and a measures module. MITERRA-Europe calculates all relevant greenhouse gas emissions from agriculture (methane from enteric fermentation and manure management, nitrous oxide from manure management and direct and indirect soil emissions, and carbon-dioxide from changes in soil carbon stocks and cultivation of organic soils), according to the IPCC 2006 guidelines. Greenhouse gas emissions from fertiliser production and mechanisation are also included. The emission and mitigation levels for crops depend very much on the yield at different locations. For biofuel crops, the yield potential is taken from the 2020 CAPRI baseline scenario. For perennial crops, the yield potentials are derived using the GWSI crop growth model which takes soil and climate characteristics into account (see Annex 12). The yield and emission levels for the perennial crops were produced at three levels per NUTS region: low-, medium- and high-yielding systems.

The minimum mitigation level of 50% against fossil comparators applied to biofuels in Storylines 2 and 3 also applies to heat and power pathways in Storyline 3. In Storyline 2 the minimum mitigation requirement for these pathways is set at zero. This implies that on land with no indirect land use change effects, for example, released land or fallow land, only the direct emissions need to be taken into account and these need to be 50% below the emissions of the fossil alternative. On land where competition with food or fodder is possible such as arable land, the indirect land use change-related greenhouse gas emissions also need to be compensated for.

In Storylines 2 and 3 land that was predicted to be used for biofuel cropping in Storyline 1, as based on the CAPRI 2020 baseline run, has now become available for dedicated perennial cropping. Whether such land is converted to perennials depends on the resulting mitigation potential, which needs to be more than 50% above the fossil alternative in Storylines 2 and 3.

Double counting for RED targets
Different assumptions apply to each storyline on whether certain renewable energy pathways deliver energy potentials that count double for reaching the 2020 targets. In Storyline 1 no double counting is applied. In Storylines 2 and 3 double counting applies to all waste-based and woody biomass-based biofuel pathways. The pathways in Table 5.5 to which this applies are those for ligno-ethanol pathways based on straw, wood chips made from residues, and woody crops and Fischer-Tropsch biodiesel made of ligno-cellulosic material.

Finally, in Storylines 2 and 3 the use of biogas in public transport, through converting green biogas to liquid transport fuel is also double counted. In the climate storyline incentives are absent and biogas is only employed to reach the heat and electricity targets.

Other environmental consideration
In Storylines 2 and 3 the use of certain lower productivity areas such as fallow, released lands in vineyards and olive orchards, and recently abandoned lands, is permitted under certain environmental constraints. As these lands have a relatively high carbon stock, one constraint is that plantations of perennial crops can only be established using no-till practice. This implies that carbon stocks are maintained but involves higher costs for the establishment of perennial plantations. These can however be compensated for by higher support levels. In both storylines 5% of the abandoned land area can also be used for dedicated cropping. The likelihood of using this land is much higher in these storylines because of higher support levels, making it economically more attractive.

As well as stricter rules on dedicated cropping, similar rules also apply to biomass from grassland, which, under a higher stimulation policy, is also more likely to become used. Cuttings from permanent grassland areas can be used, but these grasslands, although no longer used for grazing or hay production, cannot be used for dedicated cropping.

In addition to the requirements regarding targets, greenhouse gas emission efficiency, no-go areas, and the dropping of the 10% biofuel target, Storyline 3 also assumes stricter policies regarding overall environmental quality. This means that all assumptions of Storyline 2 apply, but that further requirements are also imposed:

• the demand for dedicated cropping cannot lead to a reduction in fallow of more than 10% of current utilised agricultural area (UAA);
• the selection of energy crops and their management at farm level has to follow environmental guidance – adaptation to bio-physical constraints and ecological values of a region, appropriate crop mixes and rotation, low use of inputs, double cropping etc.;
• irrigation is not allowed for dedicated bioenergy cropping, even in the establishment phase.

Finally, it needs to be explained that for the distribution of bioenergy production over pathways and related biomass feedstock categories by country and region (NUTS 2), storyline specifications, local circumstances and baseline situations are mainly relied upon. However, a match also needs to be made with the demand side for renewable electricity and heat. This is based on an extrapolation of the current situation, based on a detailed data inventory, to the situation in 2020. The extrapolation is done by using the targets for each country set in the NREAPs.

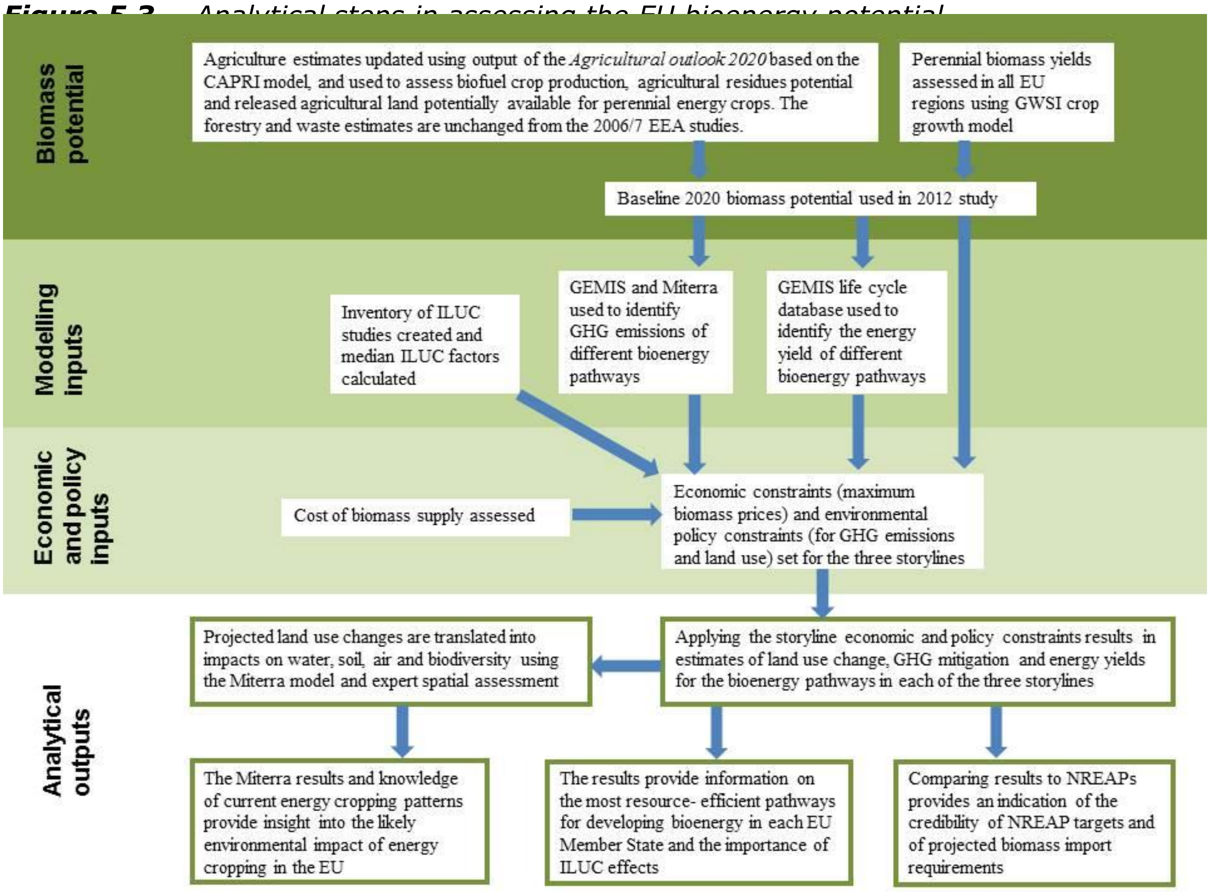
5.3.1 Analytical integration of all considerations

The different consideration and analytical tools used are applied in a certain order to come to the final calculation of the storyline land use change impacts, the bioenergy potential and the GHG mitigation impacts. The way this is done and the overview of the application of input data, models and analysis tools is summarized in Figure 5.3.

The analysis of the EU bioenergy potential can be broken up into four steps. The first involves estimating a baseline projection of biomass potential in 2020. Until now we have only discussed the estimation of the potential from agriculture, but to come to a total realisation of the NREAP targets account also need to be taken of the contribution of the potential from forest, waste and imports.

The forestry and waste potential estimates were taken from the 2006/7 EEA reports and were based on the EFISCEN forest model and national waste statistics (see EEA, 2006). In contrast, the agricultural potential was updated using agricultural land use projections from the agro-economic CAPRI model (*Prospects for Agricultural Markets in the EU 2010–2020* (EC, 2010b)) as already described above.

Figure 5.3 *Analytical steps in assessing the EU bioenergy potential*



The second step involves generating estimates of the greenhouse gas and energy implications of developing bioenergy. The GEMIS life cycle data base and the Miterra model were used together with baseline biomass potential to quantify direct emissions and energy yield from different pathways. The inventory of ILUC studies described in Chapter 2 provided a basis for calculating emissions due to ILUC effects.

The third step comprises the development and application of simplified economic and policy assumptions that serve as input to the three storylines and discussed extensively in the former. Each of the storylines assumes that Member States pursue and realise their NREAP targets but they differ in terms of the constraints and support provided to maximise greenhouse gas efficiency and minimise ecosystem impacts.

The last step involves the generation of analytical outputs. Applying the storyline assumptions enabled the different input data to be transformed into projections of land use change (see Section 5.4), biomass production, energy output and related GHG emissions and mitigation. The latter impacts are presented in Chapter 6. Using the Miterra model, the land use change anticipated in each storyline could be translated into impacts on water, soil, air and biodiversity presented in Chapter 7.

5.4 Land availability for biomass cropping

The general starting points for the translation of the three storyline specifications into land use changes, including assumptions, available data and instruments, were discussed above. In this section the calculation steps are explained and the resulting land use changes per storyline presented.

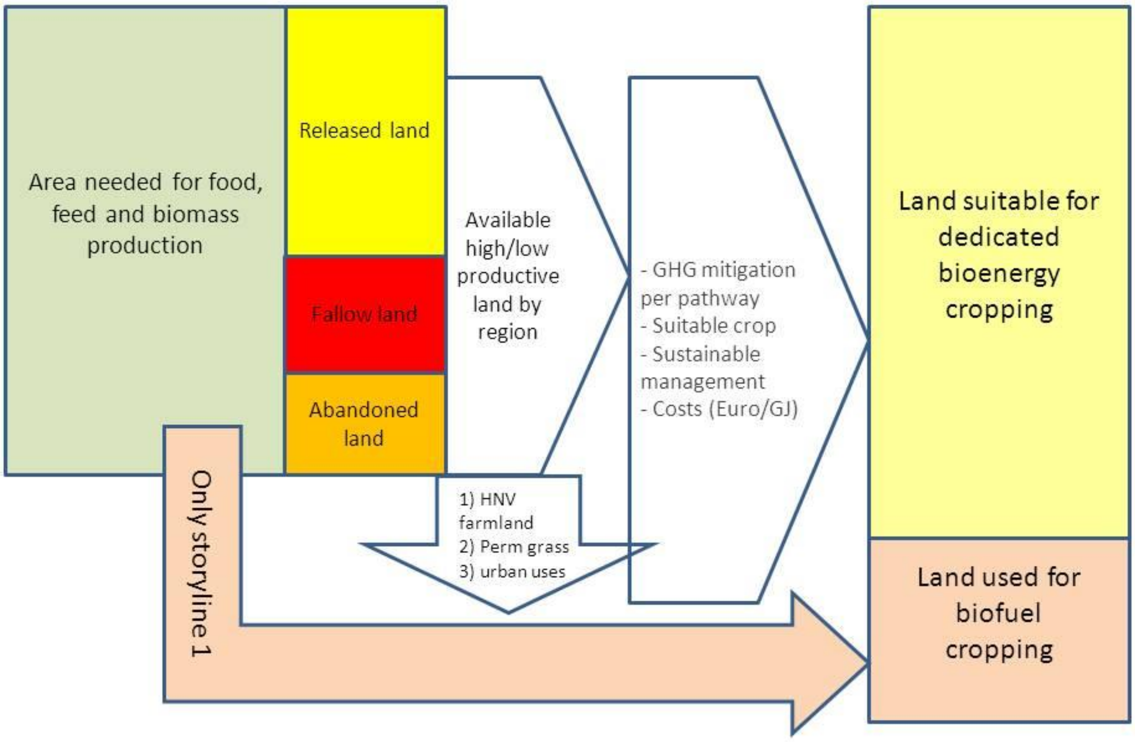
In Figure 5.4 a schematic overview is given of the land categories assumed to be available for bioenergy cropping in 2020 and the source of information used to estimate their extent and presence.

As in the EEA (2006) study, the main land resource is agricultural land that falls out of use for economic reasons between 2004 and 2020 as well as fallow land. The set-aside category, which was an important land resource in the 2006 study, is deemed to have practically disappeared in 2020, based on the CAPRI 2020 baseline. In addition, there are two categories of land which were not included as land potential in the 2006 study but which are relevant here. These relate to:

• Land used for biofuel production in 2020 as modelled by CAPRI for the 2020 baseline scenario. In Storyline 1 this is assumed to be fully used for biofuel production. In Storylines 2 and 3 it is not used for first-generation biofuel cropping since the 50% mitigation obligation, including compensation for emissions from indirect land use change, is never reached. Instead, this land may be used for perennial cropping for both heat and power conversion. This can only happen, however, if positive mitigation is reached in Storyline 2; in Storyline 3 this requires 50% mitigation for the whole pathway, including compensation of emissions from indirect land use change. This only occurs in regions where relatively high perennial yields are realised in combination with relatively high fossil comparator emission levels (Table 5.6).

• Former agricultural land abandoned before 2004. In the CAPRI data for 2004, used in this study, this category of land is not included in the total utilised agricultural area. The extent of this had to be estimated separately at a regional level. How this was done is explained in Annex 13. It is assumed that in Storylines 2 and 3 there is enough economic incentive to take up to 5%, of this category into use for dedicated biomass cropping with perennial crops, provided the minimum greenhouse gas emission mitigation potentials are met.

Figure 5.4 *Estimation of land availability for bioenergy potential calculation*



To determine whether a specific land type is used, there are three requirements, in addition to those for minimal mitigation, regarding direct and indirect land use:

• The at-gate cost of the feedstock produced should not be more than €3/GJ for Storyline 1 and €6/GJ in Storylines 2 and 3. It should be clear that yield levels will be one of the strongest determining factors in estimating production costs (€/GJ) but also for greenhouse gas efficiency (GJ/ha).

• The second requirement relates to the prevention of use of biodiverse land and/or land with high carbon stocks. In Storylines 2 and 3, released land and fallow land can only be taken into use when not HNV farmland. The reason why HNV farmland can be seen as a good proxy for highly biodiverse farmland and why it can be assumed to have a strong overlap with areas of high carbon stock is a described above and in Annex 11.

• The third requirement also applies only to Storylines 2 and 3 and is related to the assumption of environmentally sustainable management. When extensive land use categories are taken into use, it is assumed that measures are taken, especially when establishing perennial crops, to limit the loss of soil carbon. These are no-till and drilling measures, which minimise soil disruption and prevent large emissions of carbon dioxide. These measures are assumed to be standard practice when establishing perennial crops on categories such as released lands formerly used for olives and vines, fallow land and abandoned land.

The presence and areas of the types of land available vary markedly between regions and countries. Their inclusion in the total bioenergy land potential and the calculation steps involved are illustrated by two country examples (Tables 5.8 and 5.9) and for the whole EU (Table 5.10).

Table 5.8 *Calculation steps for estimating land availability and use for biomass cropping in Poland*

	Data given in 1000 ha		
	Storyline 1	Storyline 2	Storyline 3
Total arable land released (cereals, oilseeds, fodder etc.)	147.8	106.5	107.8
Land released from permanent crops	6.0	4.3	4.4
Land released from olives, vines and former set-aside	75.6	56.6	58.6
Total fallow land available	981.3	749.0	181.6
Total abandoned land available	0.0	301.3	301.3
Total land released, fallow and abandoned	**1210.7**	**1217.6**	**653.7**
Total land released, fallow and abandoned corrected for competing uses	**734.8**	**859.5**	**521.2**
Total biofuel cropping land in CAPRI 2020 baseline	227.4	227.4	227.4
Available released grassland for use of grass cuttings (no cropping)	0.0	202.5	202.5
Available as land for biofuel crop production	227.4	0.0	0.0
Available as land for dedicated perennial-crop production	734.8	1123.1	667.7
Total net available land	**962.2**	**1123.1**	**667.7**
Total used after applying additional constraints	**674.0**	**1040.3**	**600.6**

Source: Own elaboration

Table 5.9 *Calculation steps for estimating land availability and use for biomass cropping in France*

	Data given in 1000 ha		
	Storyline 1	Storyline 2	Storyline 3
Total arable land released (cereals, oilseeds, fodder etc.)	1268.0	1084.3	1392.6
Land released from permanent crops	74.2	49.3	63.3
Land released from olives, vines and former set-aside	885.6	804.2	1032.8
Total fallow land available	1325.1	1233.0	42.4
Total abandoned land available	0.0	61.9	61.9
Total land released, fallow and abandoned	**3552.9**	**3232.6**	**2593.1**
Total land released, fallow and abandoned corrected for competing uses	**2724.0**	**2556.6**	**2172.9**
Total biofuel cropping land in CAPRI 2020 baseline	1694.8	1694.8	1694.8
Available released grassland for use of grass cuttings (no cropping)	0.0	891.9	891.9
Available as land for biofuel crop production	1694.8	0.0	0.0
Available as land for dedicated perennial-crop production	2724.0	2556.6	2172.9
Total net available land	**4418.8**	**2556.6**	**2172.9**
Total used after applying additional constraints	**3792.6**	**1870.7**	**1316.7**

Source: Own elaboration

The following pages explain the calculation approach in five steps:

1) Land released from agricultural production between 2004 and 2020 is first calculated using the CAPRI-2020 baseline. In Storylines 2 and 3 this land is first diminished by an HNV-farmland share that is applicable according to NUTS 2 region as a means to exclude highly biodiverse land and land with high carbon stock. This land is then reduced by 40% to take account of competing uses – urban, forest, recreation, nature conservation etc.).

2) The next resource added to the potential is fallow land. In Storyline 1 it is assumed that this is fully available provided an economic use is found for it. In Storyline 2 it is

assumed that it is fully available provided a land use is found for it that mitigates greenhouse gas emissions – more than zero mitigation – and that it is economically feasible. In Storyline 3 this resource is only available to the extent that the fallow land share per region does not diminish to less than 10% of total utilised agricultural area (UAA). In addition, conversion can only take place if an economic land use is found that also leads to a greenhouse gas emission reduction of at least 50% of the fossil alternative.

Table 5.10 *Calculation steps for estimating land availability and use for biomass cropping in EU-27*

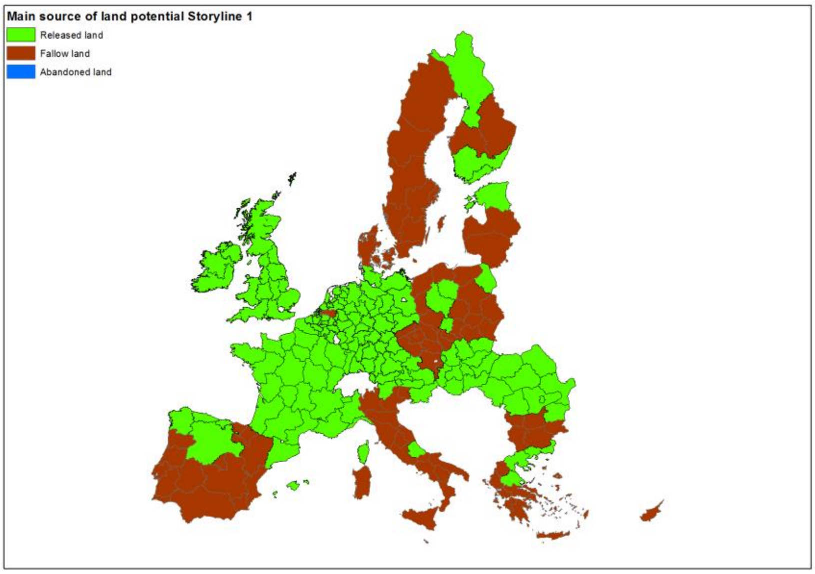
	Data given in 1000 ha		
	Storyline 1	Storyline 2	Storyline 3
Total arable land released (cereals, oilseeds, fodder etc.)	9150.5	7706.5	7706.5
Land released from permanent crops	407.6	305.6	305.6
Land released from olives, vines and former set-aside	3511.3	2927.7	2927.7
Total fallow land available	8657.4	5669.0	3592.2
Total abandoned land available	0.0	1519.0	1519.0
Total land released, fallow and abandoned	**21726.8**	**18127.8**	**16051.0**
Total land released, fallow and abandoned corrected for competing uses	**15383.2**	**13831.4**	**12585.4**
Total biofuel cropping land in CAPRI 2020 baseline	4751.3	4751.3	4751.3
Available released grassland for use of grass cuttings (no cropping)	0.0	3942.8	3942.8
Available as land for biofuel crop production	4751.3	0.0	0.0
Available as land for dedicated perennial-crop production	15383.2	13831.4	12585.4
Total net available land	**20134.5**	**13831.4**	**12585.4**
Total used after applying additional constraints	**16782.6**	**10890.5**	**7095.6**

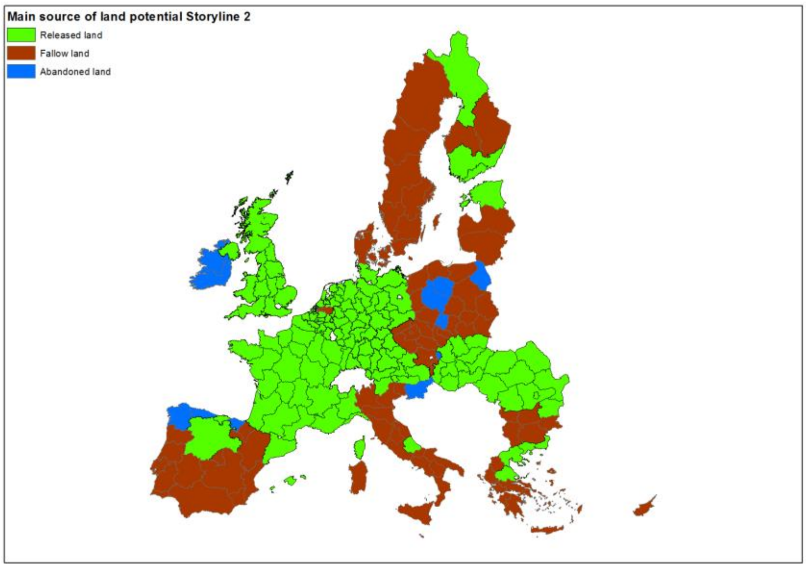
Source: Own elaboration

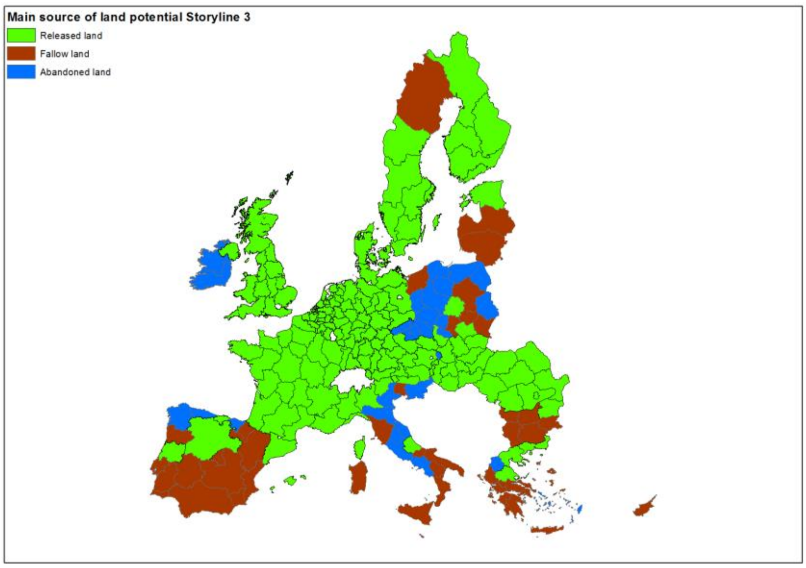
3) The next category, abandoned land, is only accessible for dedicated cropping in Storylines 2 and 3. This category, which has not been part of the used agricultural land resource registration before or since 2004, will not be available in Storyline 1 as there are no economic incentives to take this land into use again (Figures 5.4-5.6). Taking this land into use again will require specific investments, which will not be subsidised in the first storyline. Furthermore, this type of land will only be suitable for low-intensity dedicated cropping with perennial crops. In many regions this will not provide a high enough yield to make up the minimal mitigation and maximum cost-level requirements of Storyline 2 and even less likely for Storyline 3.

4) The next land resource comes from the area under biofuel crops as predicted in the CAPRI 2020 baseline. In Storyline 1 this land is assumed to be fully available for biofuel crops as the economic assumptions for biofuel cropping are taken to be identical to those in the EC outlook study used for the CAPRI run (Box 5.1). In Storylines 2 and 3 this land is available for bioenergy production, provided the minimal greenhouse gas mitigation requirements, including those for indirect land use change, are met. In practice this implies that biofuel crops can no longer be grown on this land in either storylines as mitigation of 50% or more is never reached in the EU if indirect land use change is also to be compensated. However, use of this land for perennial crops is feasible in a limited number of regions where yields for perennials are very high and the greenhouse gas emissions of the greenhouse gas fossil comparators are relatively high, for example, several regions of Bulgaria, Germany and Poland.

Figure 5.5 *Dominant land types available for bioenergy cropping in the storylines*







Source: Own assessment

5) In the penultimate row of Tables 5.8 to 5.10, the total net available land is given, but after applying all environmental constraints the land to be actually used for dedicated cropping becomes much smaller, especially in Storyline 3. The difference in

final land use between the storylines is rather different at the country level (Table 5.8, 5.9), but at an EU level (Table 5.10) it can be seen that in Storyline 1 there is almost three times more land use then in Storyline 3. Whether this also leads to a similar difference in total bioenergy potential and greenhouse gas emission per giga-joule remains to be seen – this depends on several other factors which will be discussed in Chapters 6 and 7, such as how efficiently the land is used for a specific biomass, in terms of energy production per hectare, the energy conversion pathways used, and, last but not least, how many residues are derived and how efficiently they are converted into energy.

An overview of the final land use changes for biofuel and dedicated cropping in 2020 in every country is given in Figures 5.6 to 5.8 for all three storylines, and total final land area in Table 5.11. It is clear that the potential is largest in Storyline 1, followed by 2 and 3, respectively. This is because in Storyline 1 all land predicted to be used for biofuel production in 2020 in the CAPRI baseline situation is included. Furthermore, the initial released-land potential is larger as there is no need to exclude the biodiverse and high-carbon-stock land. This together strongly compensates for the 5% additional abandoned land resource which can be used in storylines 2 and 3, but not in soryline 1 because of lacking economic incentives. And finally, on all released and fallow land in storyline 1, the only limiting factor is cost, which should be a maximum of €3/GJ, while a minimum greenhouse gas emission threshold is not applied. All in all, this implies that in Storylines 2 and 3, the initially available released land resource is almost 20% lower because of the combination of stricter environmental constraints on the use of biodiverse land and land with high carbon stock, and the minimum greenhouse gas mitigation level. In relation to Storyline 3, it can be concluded that stricter measures regarding greenhouse gas mitigation for heat and power and stricter rules for the use of fallow land would still lead to a significant decline in land used for bioenergy cropping, as shown by the differences between Storylines 2 and 3.

The effects of all the constraints together also work out differently for each country because of specific local circumstances, as seen from the comparisons in Table 5.11. In all storylines, France and Romania contribute most, followed by Spain, Germany and Italy in Storyline 1, and Germany, Spain and Poland in Storylines 2 and 3. Poland and also Romania show rank higher in Storylines 2 and especially 3 because the contribution of abandoned land in these countries is much larger. Because of this but also because the cost of biomass feedstock, production can be twice as high in Storylines 2 and 3. Several central and eastern European countries and Ireland show a significantly larger land potential in Storylines 2 and 3 than in Storyline 1. The higher price threshold is also the main reason for the land used for dedicated crops in the Netherlands increasing significantly in Storylines 2 and 3.

Figure 5.6 *Land use changes for bioenergy production in Storyline 1 ('000 ha)*

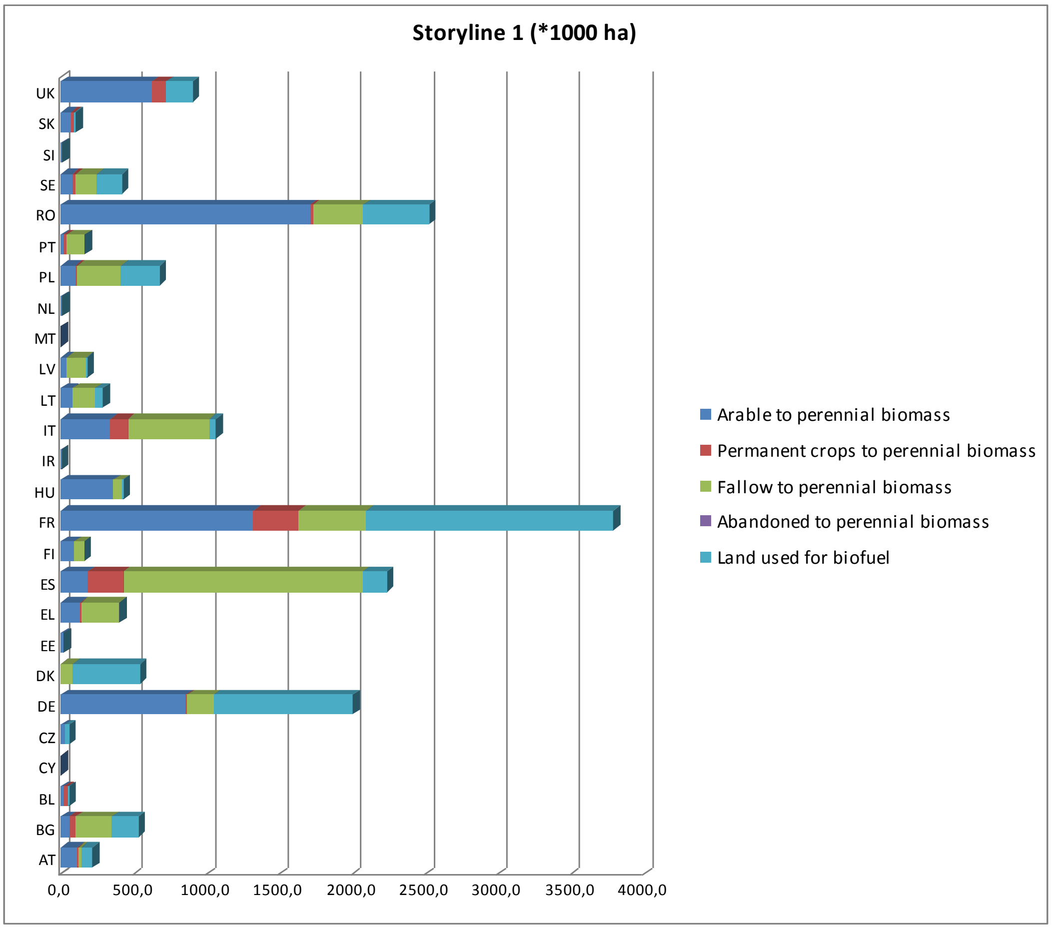


Figure 5.7 *Land use changes for bioenergy production in Storyline 2 ('000 ha)*

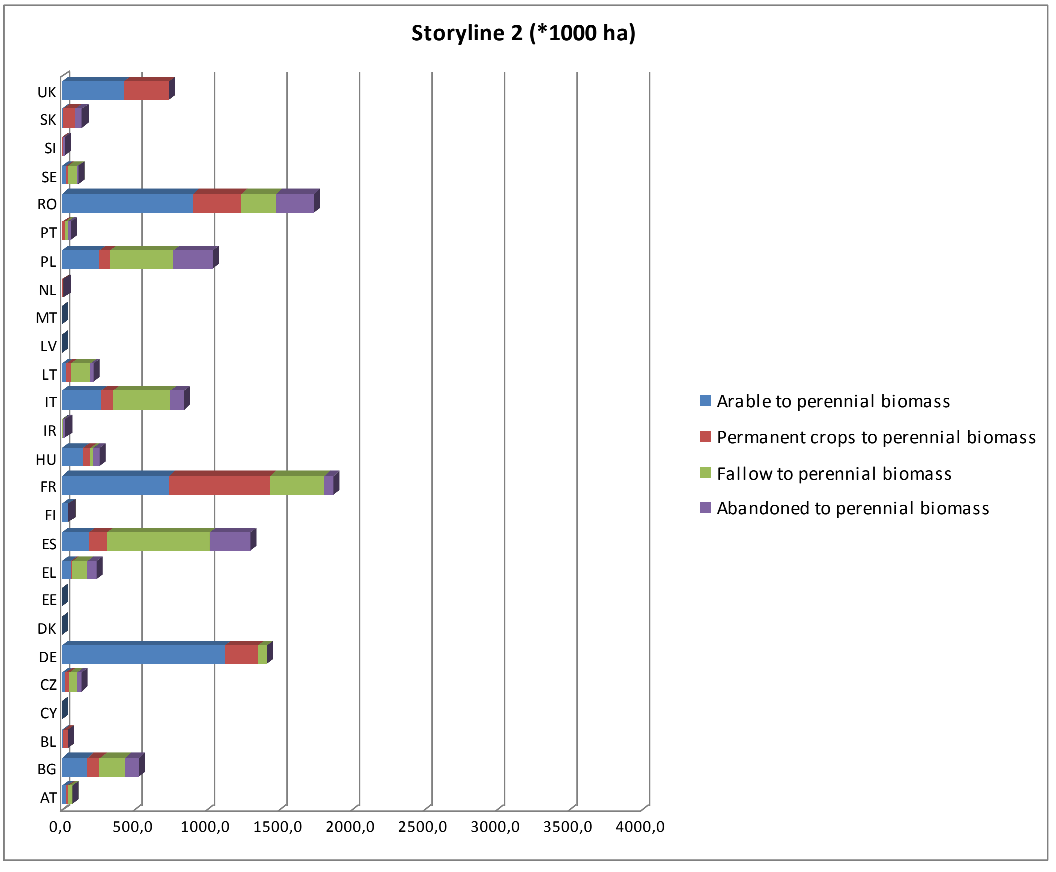
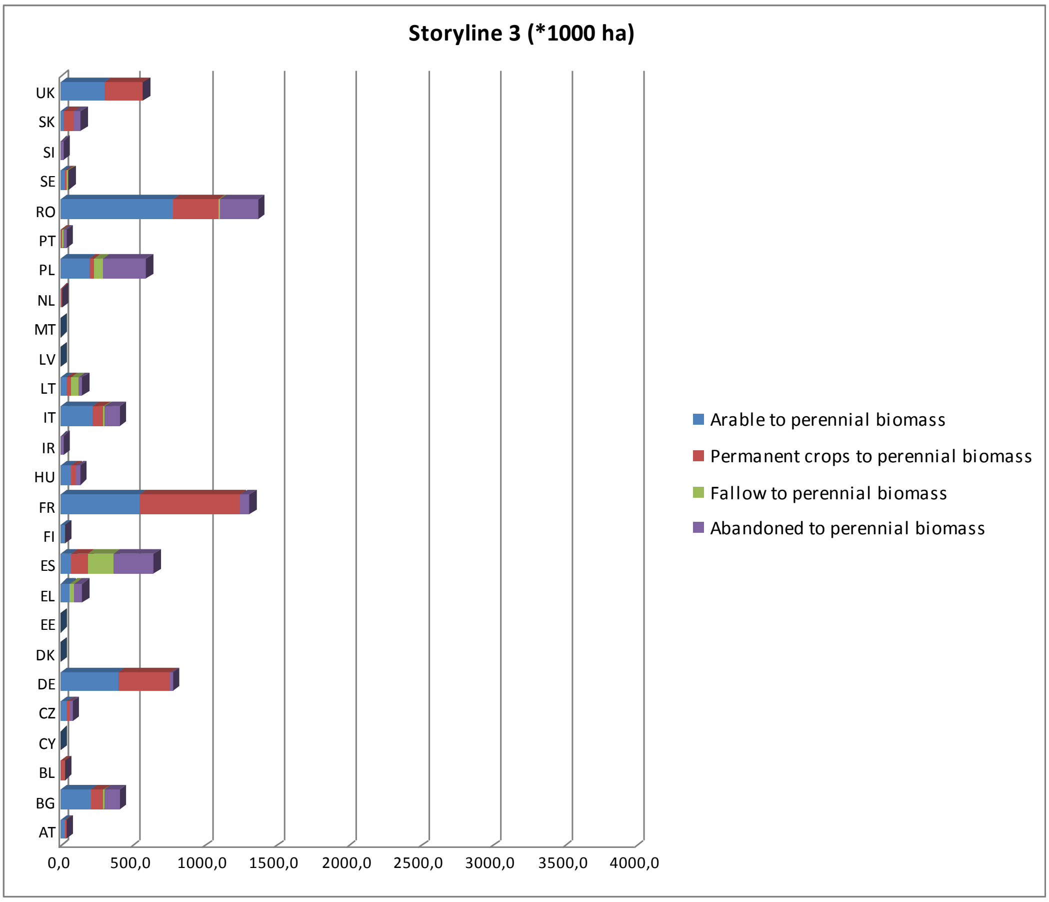


Figure 5.8 *Land use changes for bioenergy production in Storyline 3 ('000 ha)*



In countries such as Estonia, Finland and Sweden the dedicated area in Storylines 2 and 3 drops significantly, to zero in in the case of Estonia. As dedicated cropping is still feasible in Storyline 1, willow can be produced for a cost of €3/GJ, but in terms of greenhouse gas mitigation potential it is practically no longer feasible in Storylines 2 and 3 in these countries. The reason that Denmark has no land resource in Storylines 2 and 3 is because it is not expected to release land by 2020. So in Storyline 1 only fallow is used for dedicated cropping, but in Storylines 2 and 3 this resource is no longer available because of the higher mitigation requirements for use of this land and stronger restrictions on reducing fallow land. For countries such as Bulgaria, Denmark, France, Germany, Poland, Romania and the United Kingdom large differences between Storyline 1 and the other storylines occur for a combination of reasons of which the most important is the decline in biofuel land. In Storyline 1 this is included and is relatively large, but in Storylines 2 and 3 this resource is almost excluded since mitigation levels, including compensation for indirect land use change emissions, are practically not met. For all remaining countries that show very large declines in land used for bioenergy production, the differences are explained by a combination of all the above-mentioned factors.

Table 5.11 *Total land finally used for biofuel and dedicated bioenergy cropping*

		Data given in '000 ha	
Country	**Storyline 1**	**Storyline 2**	**Storyline 3**
France	3 792.6	1 870.7	1 316.7
Romania	2 527.6	1 741.3	1 373.9
Spain	2 236.6	1 299.6	651.8
Germany	2 004.6	1 416.8	783.2
Italy	1 062.1	846.1	411.7
United Kingdom	903.8	739.0	578.3
Poland	674.0	1 040.3	600.6
Denmark	539.3	0.0	0.0
Bulgaria	531.5	536.1	413.8
Hungary	430.2	258.4	142.1
Sweden	419.7	112.0	60.8
EL	403.1	235.6	156.7
Lithuania	288.5	221.1	155.2
Austria	213.5	72.3	46.5
Latvia	178.2	0.0	0.0
Portugal	161.5	67.4	47.7
Finland	160.8	47.5	33.7
Slovakia	101.4	140.5	145.9
Bulgaria	56.1	42.9	30.4
Czech Republic	54.7	137.2	88.0
Estonia	19.1	0.0	0.0
Slovenia	9.8	23.8	23.6
Netherlands	8.5	16.2	9.2
Ireland	5.5	25.9	25.7
Cyprus	0.0	0.0	0.0
Malta	0.0	0.0	0.0
EU-27	**16 782.6**	**10 890.5**	**7 095.6**

Source: Own assessment

Perennial crop mix

The differences between Storyline 1 and Storyline 2 and 3 perennial crop mixes are determined by price levels, quality of land that is available and GHG efficiency (Table 5.12).

Table 5.12 *Perennial mix by storyline in 2020 (1000 ha)*

	High yields (*1000 ha) (medium yield in Storyline 3)						**Low yields (*1000 ha)**						
	miscan-thus	switch-grass	RCG	willow (high)	poplar (high)	*total*	miscan-thus	switch-grass	RCG	willow	poplar	*total*	**total**
Storyline 1	277	133	215	2978	2636	*6239*	16	31	837	1060	3849	*5793*	**12031**
Storyline 2	548	2592	217	692	1311	*5359*	2539	232	189	1734	1293	*5986*	**11345**
Storyline 3	1945	357	133	514	199	*3148*	2243	245	121	828	249	*3686*	**6834**

In Storyline 1 the dominant perennials on good-, medium- and low quality land are willow and poplar as these can be produced at a cost of €3/GJ in most regions and types of land. In Storylines 2 and 3 the cost level can reach €6/GJ which makes perennial energy grasses economically feasible but also preferred because of the larger greenhouse gas mitigation potential of these crops. The large difference in miscanthus and switchgrass area between Storylines 2 and 3 is caused by the obligation in Storyline 3 to reach 60% mitigation for heat and power pathways as well. In many regions this is not reached by switchgrass because of slighly lower average yield levels, but is by miscanthus. However, since the costs per giga-joule are slightly lower for switchgrass in Storyline 2, the preferrence is often placed on this crop, at least on good to average soils.

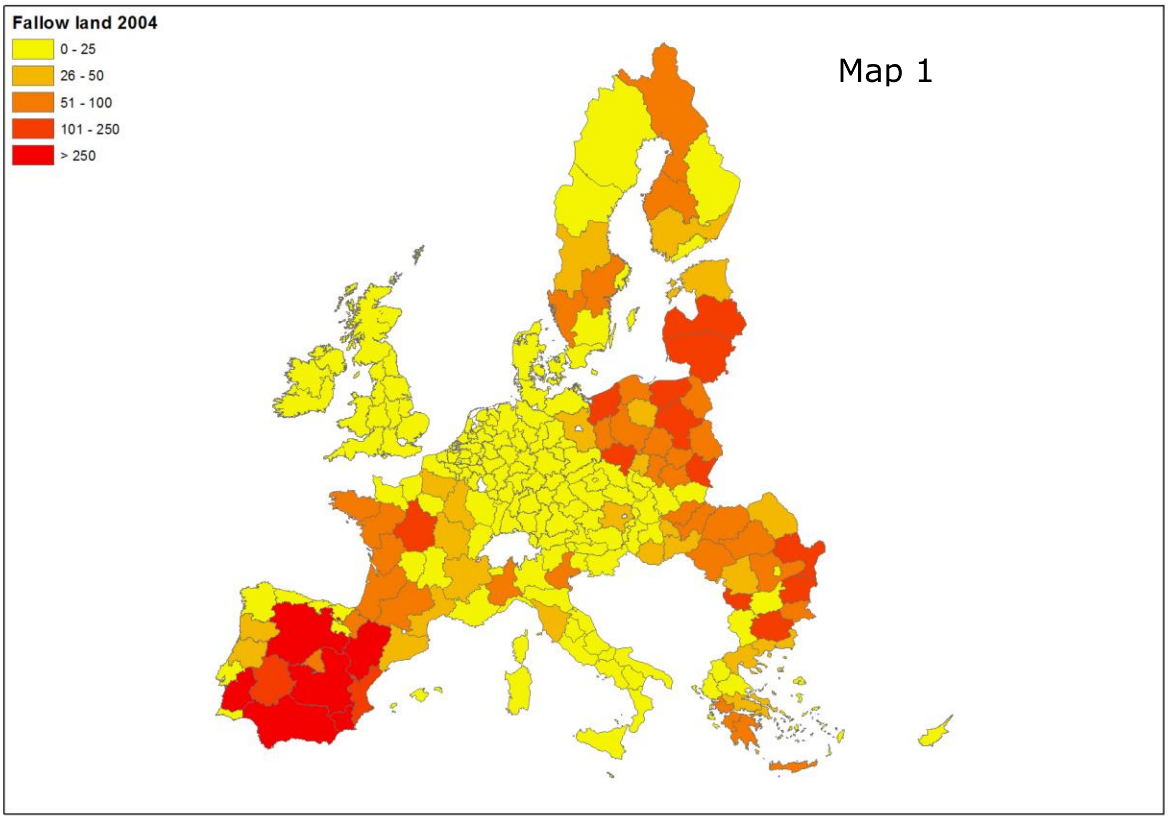
Use of fallow land

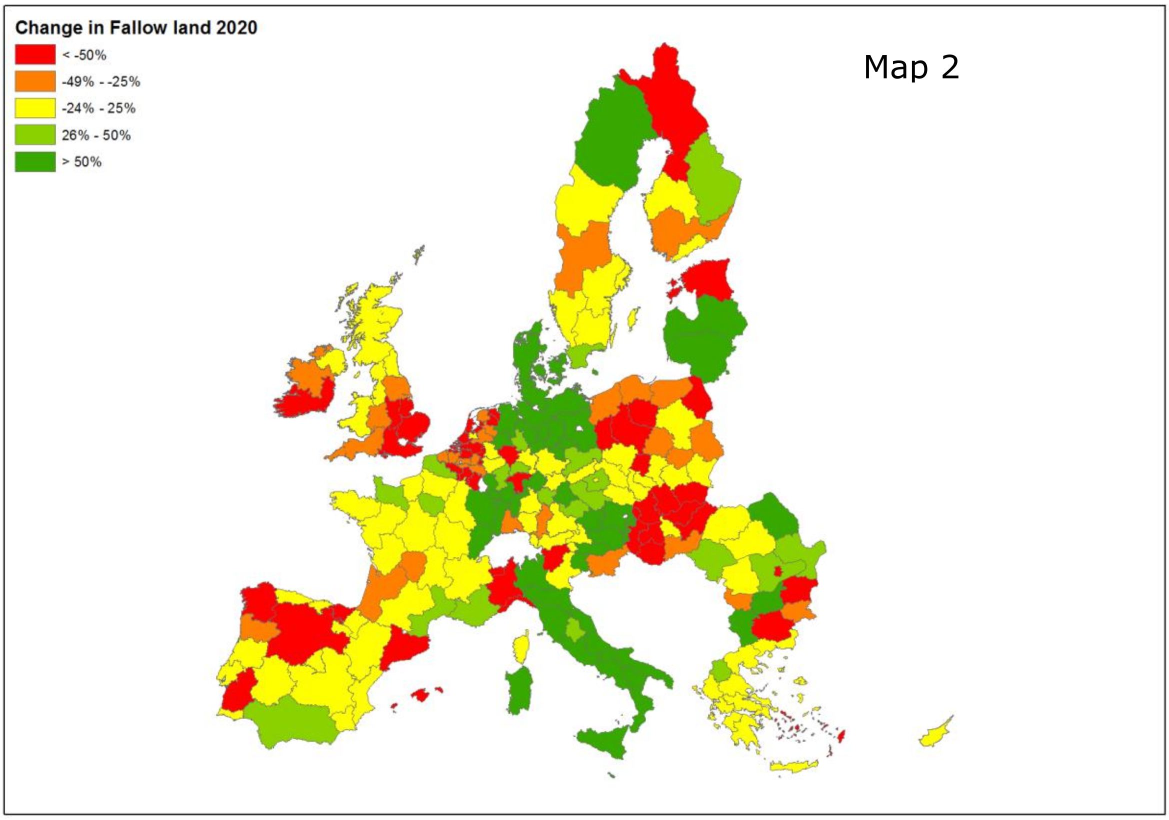
As a final discussion, it is interesting to focus on the contribution of fallow land in the three storylines and the way changes in this resource between 2004 and 2020 could be influenced by demand for bioenergy. To understand the change, Table 5.13 and the maps in Figure 5.9 provide an overview of the changes in fallow land between 2004 and 2020 in the three Storylines. According to the CAPRI 2020 baseline, the area of fallow will increase by 18 % between 2004 and 2020 (Figure 5.9, second map). Since the CAPRI baseline includes the renewable energy/NREAP targets for biofuels in 2020, it can be concluded that biofuel crops will generally not be grown at the expense of this land resource while dedicated crops for heat and power purposes will. However, it is also clear that there are many other factors that influence the development of this land resource, generally related to changes in the Common Agricultral Policy, socio-economic trends in rural areas and agricultural markets.

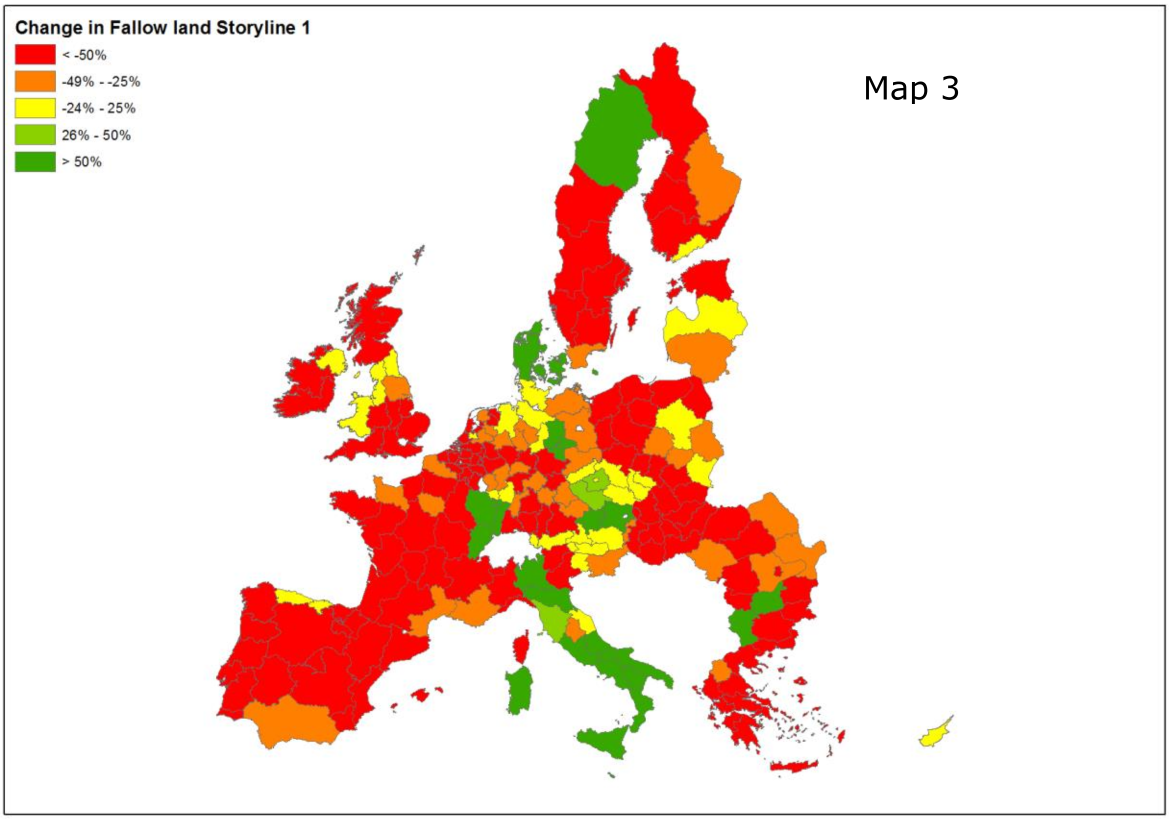
Table 5.13 *Fallow land area in absolute and relative figures between 2004–2020*

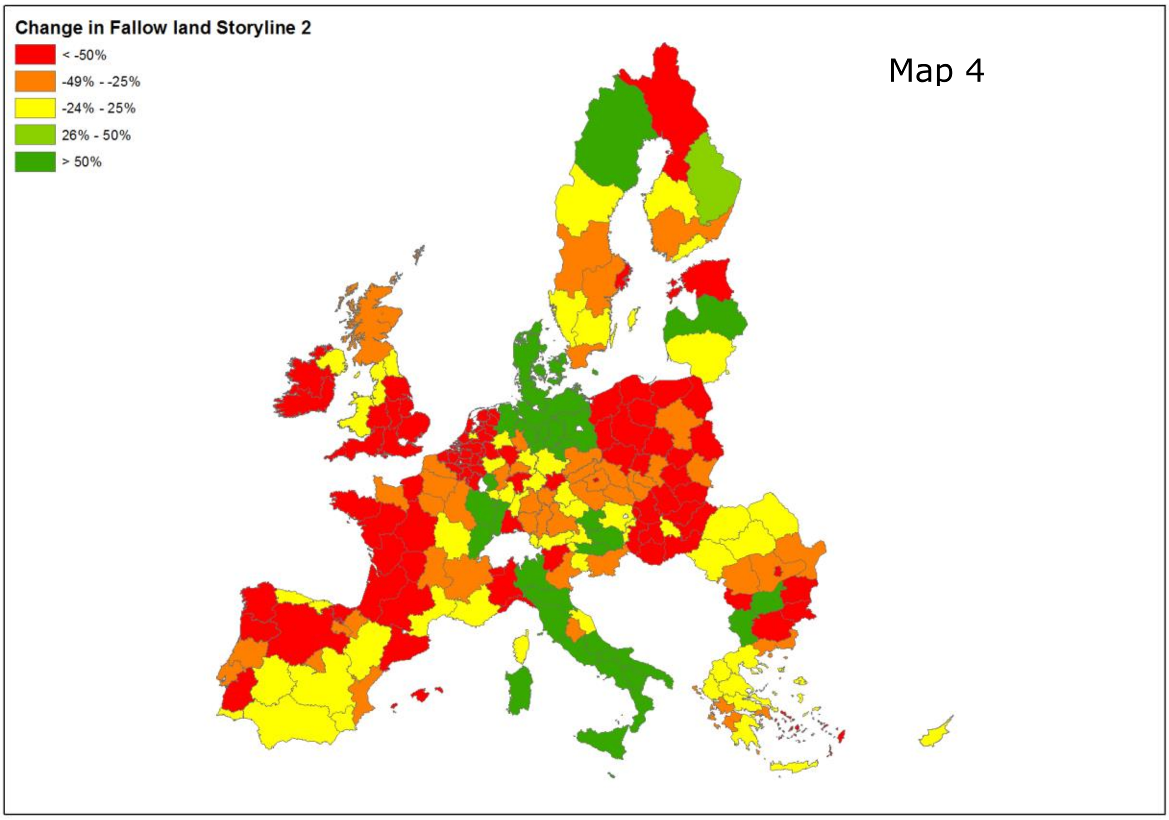
	1000 ha	% (2004 = 100)
2004	696.5	100%
CAPRI 2020 baseline	822.3	118%
Storyline 1 2020	330.3	47%
Storyline 2 2020	514.2	74%
Storyline 3 2020	803.4	115%

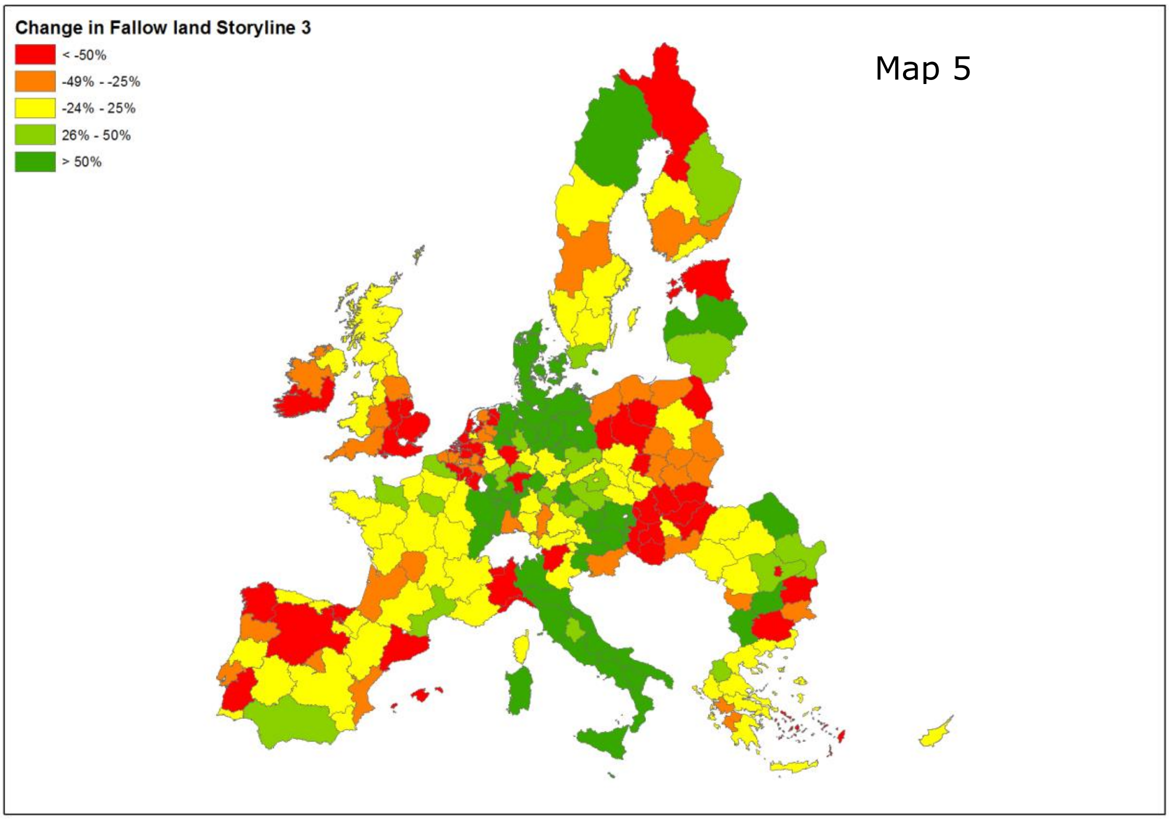
Figure 5.9 *Fallow land resource 2004 (Map 1) and relative changes 2004–2020 in CAPRI baseline without implementation of storyline (map 2) and in Storylines 1 (map 3), 2 (map 4) and 3 (map 5)*




Change in Fallow land 2020
< -50%
-49% - -25%
-24% - 25%
26% - 50%
> 50%
Map 2


Change in Fallow land Storyline 1
< -50%
-49% - -25%
-24% - 25%
26% - 50%
> 50%
Map 3





Source: Own assessment

If however part of the NREAP targets for electricity and heat are to be met by dedicated cropping (see last 3 maps in Figure 5.9), fallow land will be one of the potential land resources used, the amount depending on a number of criteria. Examination of the three storylines shows that the decline in this resource is likely to be significant if no environmental criteria are set, as in Storyline 1, in which case the resource may decline by more then 50%, with larger declines particularly in the regions where the fallow land resource is largest such as in Spain, Southern France, Poland, Romania and Bularia and the Baltics (Figure 5.9 map 3). This decline is also significantly larger then in the CAPRI baseline scanrio. If limits on the use of biodiverse lands and high carbon stock areas are set, with minimum mitigation requirements as in Storyline 2 (4th map in Figure 5.9), the decline would still be negative but would decrease to an average -26%. If additional requirements are set on the maximum declines in fallow land in each region, as in Storyline 3, this land resource may be maintained (see last map in Figure 5.9). Such measures will not necessarily exarcerbate other concerns regarding competition with food and fodder production, indirect land use changes and greenhouse gas mitigation, as will be shown by the consideration of bioenergy potential and greenhouse gas savings in Chapter 6. This also results in a significantly better performance in terms of biodiversity effects for this storyline as is further discussed in Chapter 7.

6 Energy and greenhouse gas mitigation potentials of energy cropping trends in the EU

6.1 EU bioenergy potentials and NREAP targets

This section discusses the potential contributions of the EU-27 agriculture, forest and waste sectors to reaching the 2020 NREAP targets set for bioenergy. It also estimates what additional bioenergy potential could be obtained through imports. The analysis initially focuses on the agricultural sector and presents the bioenergy potential from land-based biomass production and agricultural residues. This is followed by the bioenergy potential from the forest and waste sectors together with remaining import needs.

The analysis in this chapter follows the logic set out in Chapter 5 and thus builds on three storylines: 1) Market First, 2) Climate Focus and 3) Resource Efficiency. Different assumptions for the price of biomass, the development or viability of different bioenergy technologies, as well as different levels of environmental constraints are combined in these three storylines to explore the importance of individual factors for the EU bioenergy potential as well as relative greenhouse gas efficiency of different bioenergy pathways. For details on the storyline assumptions as well as bioenergy technologies please refer back to Chapter 5.

6.1.1 Energy potential from agriculture

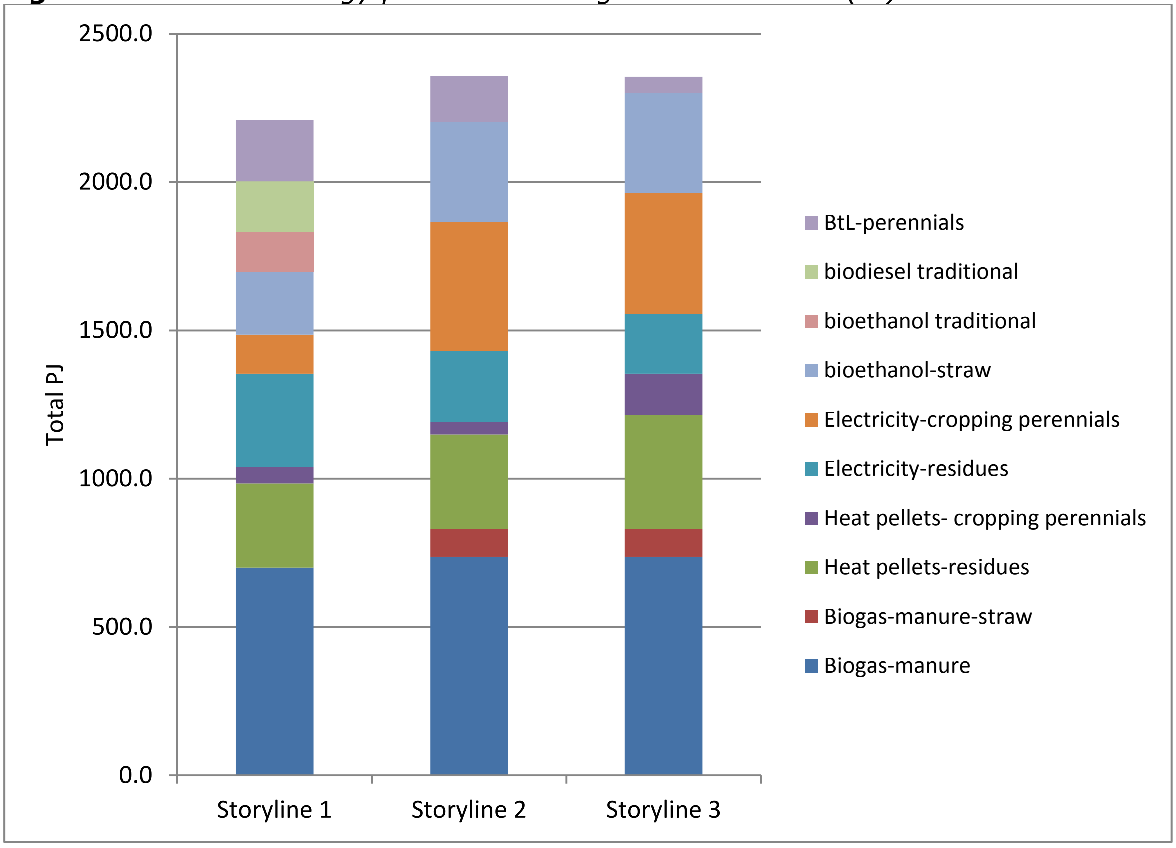
The bioenergy potential from agriculture by 2020 is estimated to range between 2,210 – 2,358 peta joules (PJ), or 53–57 million tonnes of oil equivalent (MtOE) depending on the type of environmental constraints and stimulation measures implemented as specified in the three storylines. It is clear that the potential in a situation of maximum environmental constraints (Storylines 2 and 3) is not smaller than in a situation of limited policy intervention (Storyline 1). The potential of all 3 storylines is however significantly lower than the environmentally compatible bioenergy potential from agriculture (EEA, 2007) as estimated in 2006 that amounted to 96 MtOE. The differences in assumptions behind the current and the EEA study (2006) were discussed in Chapter 1 and it is already clear that economic limitations as well as minimum greenhouse gas efficiency thresholds and indirect land use change compensation are the key factors limiting the potentials presented in this study.

Table 6.1 *Potential based on domestic biomass production from agriculture in 2020 per storyline*

	Bio-heat	Bio-electricity	Biofuels	total PJ	total MtOE
Storyline 1	339	1146	725	2210	53
Storyline 2	362	1504	492	2358	57
Storyline 3	524	1440	392	2355	57

When looking at the total potentials per sector (Table 6.1 and Figure 6.1) it becomes clear that in a situation where greenhouse gas economic viability is the starting point and no attention is paid to greenhouse gas efficiency and compensation for indirect land use change (Storyline 1), a larger share of the domestic agricultural biomass will go into first generation biofuels. Also the production of bioenergy from domestic agricultural sources will be lower. In Storylines 2 and 3 the requirements for greenhouse gas efficiency and indirect land use change compensation lead to a decline in the overall domestic biofuel production and an increase in the renewable heat and electricity from domestic agricultural sources. In this situation the lower biofuel production will not lead to a significantly higher import of biofuels as the higher share of second generation biofuels also enables double counting to the final targets set by the RED Directive (EC, 2009a) and the NREAPs. Overall, it can therefore be seen that the stricter requirements and the stronger stimulation in these storylines lead to a higher share of domestic renewable energy sources used for reaching the NREAP targets and lower import demands.

Figure 6.1 *Total bioenergy potential from agriculture in 2020 (PJ)*



Note: (1 PJ=0.024 MtOE)

The first striking difference in the bioenergy mix between Storyline 1 and Storylines 2 and 3 is that there will be no first-generation biofuel production based on domestic crops which is all related with the requirement for indirect land use change compensation for biofuel production. First-generation biofuels are not included in Storylines 2 and 3 due to their overall low greenhouse gas efficiency. However, perennial cropping for second-generation biofuels will remain possible in all storylines. This is either because high yields (Joules/ha) can be reached which makes it economically feasible (Storyline 1) and enables compensation for indirect land use change (Storylines 2 and 3), or because lower quality soils on abandoned/released lands are used that are brought back into agricultural production for this purpose. In the latter case this only involves lands that, from an economic perspective, are not attractive to be used for food and fodder production in the expected price market situation as assessed by CAPRI in the *Agricultural outlook 2020*. On these types of land no indirect land use change compensation is required as their use will not have displacement effects.

Another important difference between Storyline 1 and the others is the larger production of both heat and electricity. This is because in the two more environmental storylines prices paid for biomass feedstock are higher, making the total availability of lignocellulosic material from residues and dedicated crops larger. This leads to a higher production of both heat and electricity from pellets based on straw and perennials. Larger production of biogas and particularly biogas-straw combination and second-generation bioethanol from straw is assumed for the more environmentally-oriented Storylines 2 and 3. This relates to a stronger stimulation of technologies and higher support levels for more efficient pathways, which makes it likely that the time-to-market for these new biogas and second-generation technologies is speeded up. Furthermore scale requirements, requiring strong spatial concentration of biomass, become less significant.

The Market First storyline (1) assumes an important role for biomass-to-liquid based on dedicated cropping in the total biofuel mix. This is because it is expected that these pathways will become economic if based on perennials grown on land resources such as fallow and released arable lands. These lands are considered not to be economically viable for food and feed production given world market prices as assessed by CAPRI in the *Agricultural outlook 2020* study. However, according to the cost level calculations in this study part of those released lands can still deliver positive returns on investment when used for energy crops provided a demand for this perennial biomass becomes reality. In Storyline 2 and 3 the opposite trend is seen as the biomass-to-liquid share declines. This is caused by stricter criteria on greenhouse gas efficiency, prioritising the perennials towards electricity and heat, and because only the yields from highly productive fields can be used to reach the stricter minimal mitigation requirements. In Storyline 3 limits placed on the decline of fallow land further restrict production of perennial biomass leaving even less potential to go into the biomass-to-liquid pathway but also electricity pathways, while the perennial to heat conversion occurs more often.

The largest domestic biofuel potentials in Storylines 2 and 3 will come from straw, which has the highest greenhouse gas efficiency, as it is based on a residue, but which can only become economic in a situation with higher financial support arrangements. This is also a reason why, in a purely market driven situation, Storyline 1, this is much less of an option, particularly in regions with a low straw availability.

The most important source of electricity in all three storylines is manure, as it is both a cheap and greenhouse gas efficient pathway. Maize-based biogas was not included in Storyline 1 because costs are too high when no support payments are available nor in Storylines 2 and 3 because the greenhouse gas efficiency of this pathway is low and more efficient pathways are possible to produce bio-electricity. Some biogas is also produced in Storylines 2 and 3 from a mixture of manure and straw. This option is still in technological development, but expectations are that it will deliver electricity at higher efficiency than when based on manure alone. This is why it is expected to be promoted more strongly in futures in which policies prioritise the more greenhouse gas efficient technologies. This is also the main reason why bio-heat production based on pellets from dedicated cropping delivers importantly to the bio-heat shares in Storylines 2 and 3.

The contribution of the different perennials at EU-27 level is given in Table 6.2 and the contribution per country per storyline is presented in Figures 6.2-6.4. It becomes clear that this mix differs strongly between countries and so does the relative size of the dedicated crop potential per country.

Table 6.2 *Contribution of different types of perennials to the biomass production and final energy potential*

	1000 ton DM						PJ	
	Miscanthus	Switchgrass	RCG	Willow	Poplar	Total	total	% with displacement (ILUC compensation)
Storyline 1	3	1	7	33	43	86	395	0%
Storyline 2	38	31	7	36	6	118	633	20%
Storyline 3	29	30	23	7	8	98	604	22%

In Storyline 1 willow and poplar dominate in the mix of perennials because of overall lower per hectare production costs while in the more environmental storylines there is much more miscanthus, switchgrass and Reed Canary Grass (RCG) as these deliver an overall lower GHG emission per ton of dry mass on the types of lands available. The potential from the perennials is the largest in Storyline 2 in which there are no limits put of the use of fallow land, like is the case in Storyline 3. However, also between storylines 2 and 3 there is still large differences in the perennial mixes, certainly at country level. This is mainly driven by the stricter GHG efficiency criteria which in Storyline 2 only apply to biofuels, while in storyline 3 the mitigation threshold of 50% also needs to be reached in the electricity and heat sector. This implies that in Storyline 2, the mix for the electricity and heat sector is still driven by the combination of efficiency and low cost, while in Storylines 3, it is primarily GHG efficiency, which also explains the larger production of heat from perennials in this Storyline and less going into BtL (see Figure 6.1). The higher efficiency stimulation also becomes clear from the total energy produced from the perennials which is significantly larger in Storylines 2 and 3 not only because of the larger perennial biomass production, but also because of the prioritisation towards more efficient conversions. While for Storyline 1 1 ton of DM delivers 4.6 MJoule of energy, this amounts to 5.4 MJoule in Storyline 2 and even 6.2 MJoule in Storyline 3.

The countries contributing the largest dedicated cropping potentials are Romania, France, Germany, Spain and Italy and this does not really change between Storylines. However, setting a limit on the use of fallow land in Storyline 3 does imply that the perennial biomass contribution declines significantly for Spain, Italy, France, UK, Bulgaria.

About one fifth of the perennial potential in both Storyline 2 and 3 is produced on land where displacement takes place. This involves land that in Storyline 1 is used for biofuel cropping, but in Storyline 2 and 3 this type of land is not used by rotational biofuel crops because these do not reach the 50% mitigation threshold. In Storylines 2 and 3 these lands can then be used for perennial cropping provided the mitigation threshold is reached. The displacement requires a full compensation for ILUC and a 50% mitigation threshold for biofuels in Storyline 2 and for all pathways in storyline 3.

Figure 6.2 *Perennial cropping mix per country in Storyline 1*

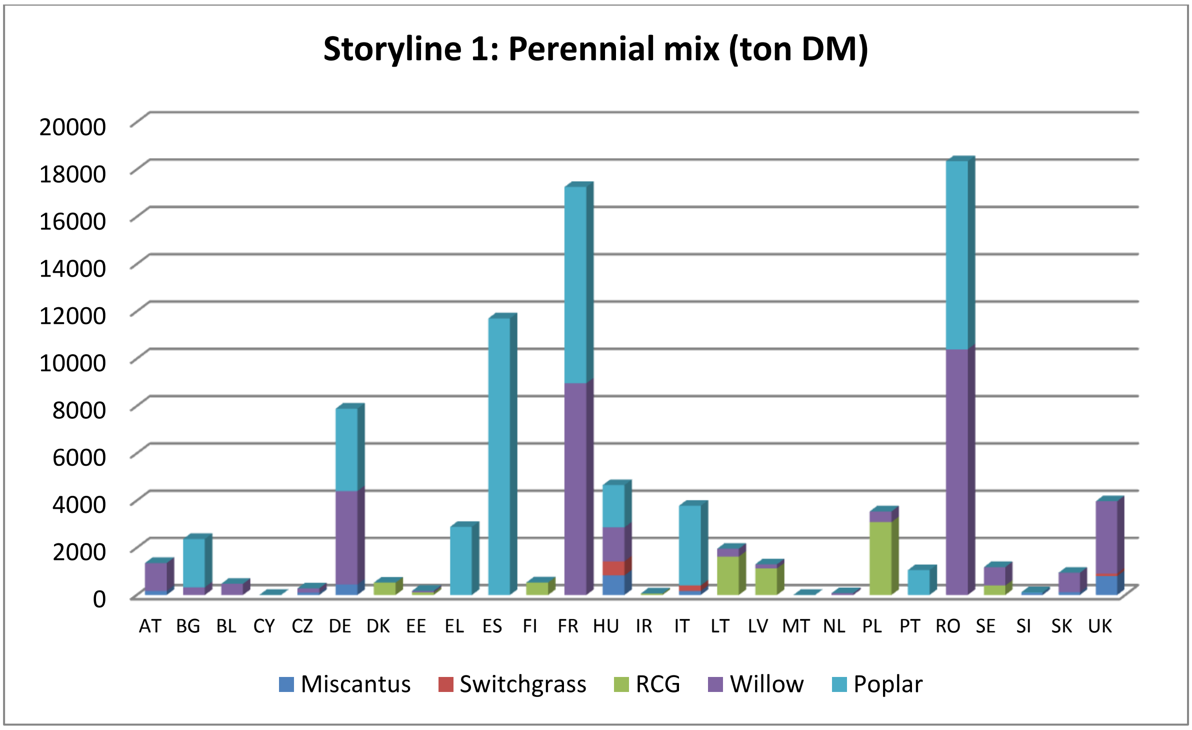


Figure 6.3 *Perennial cropping mix per country in Storyline 2*

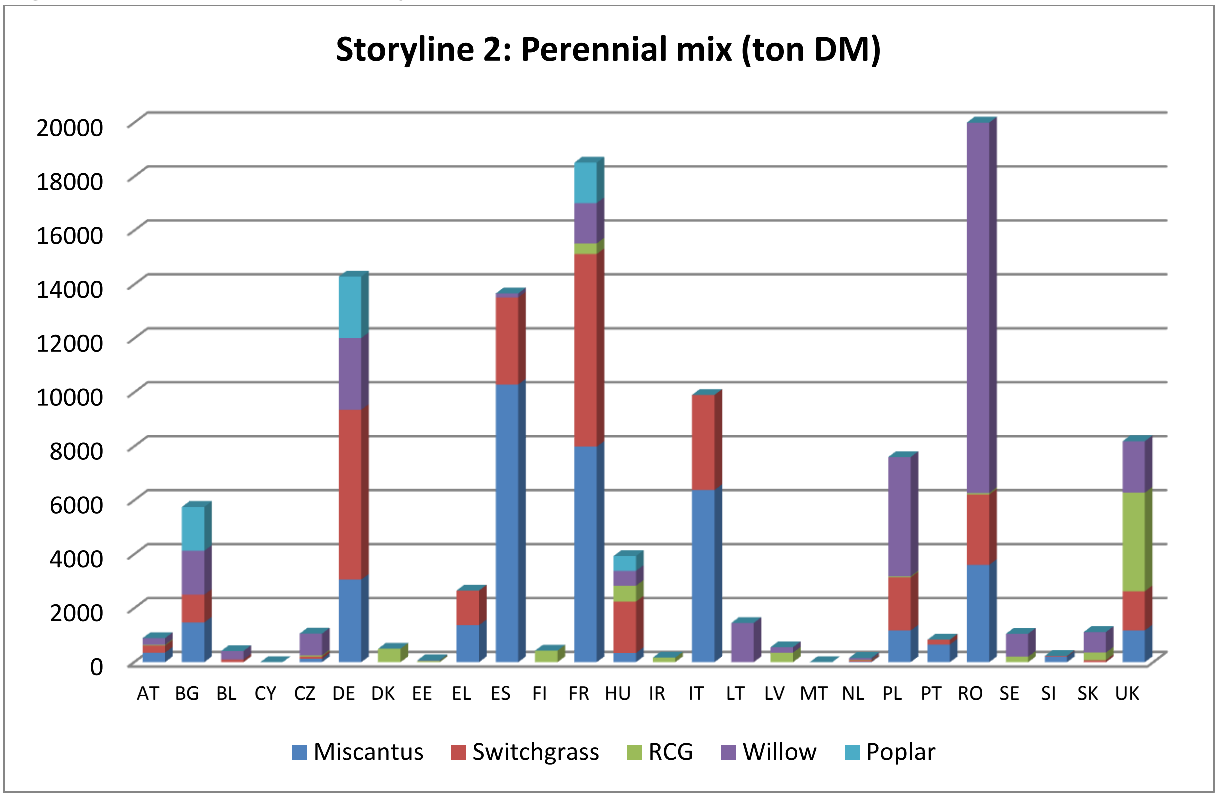
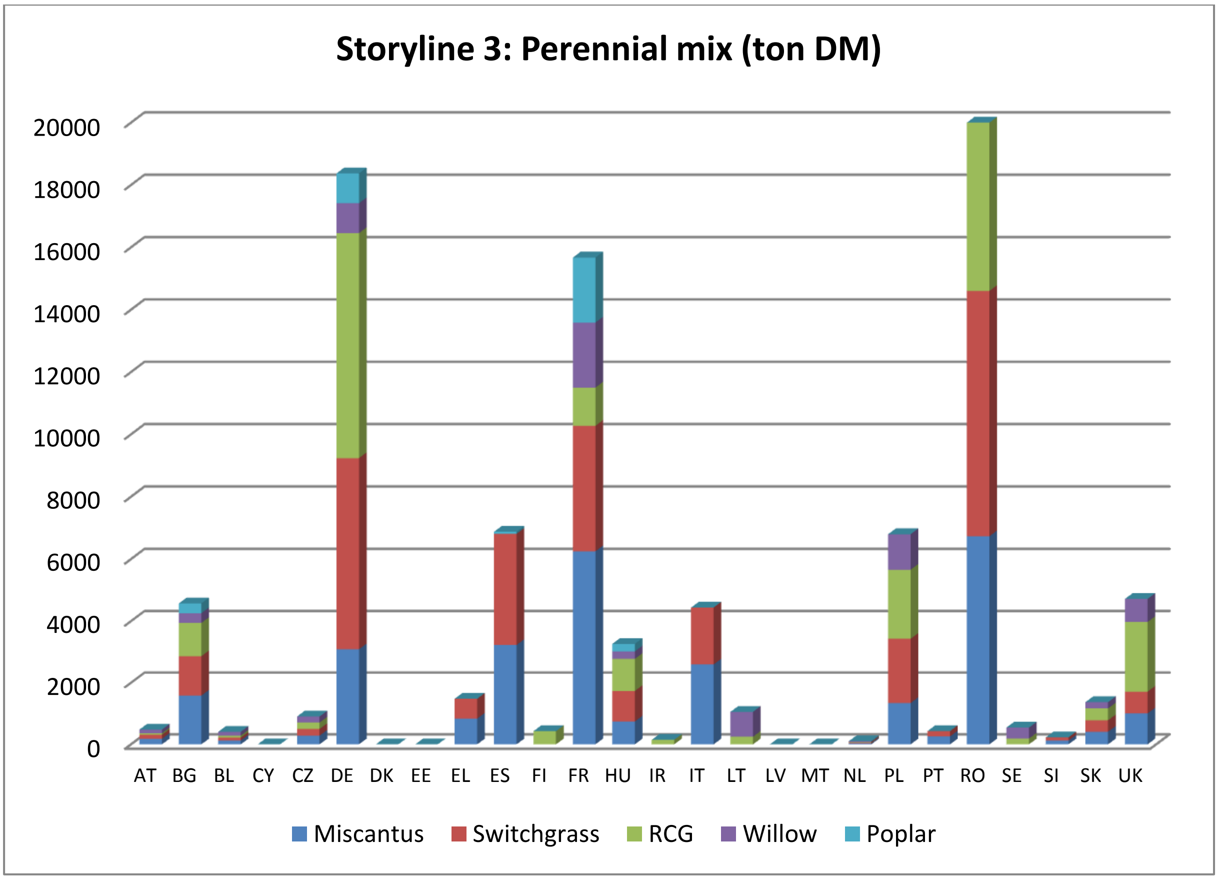
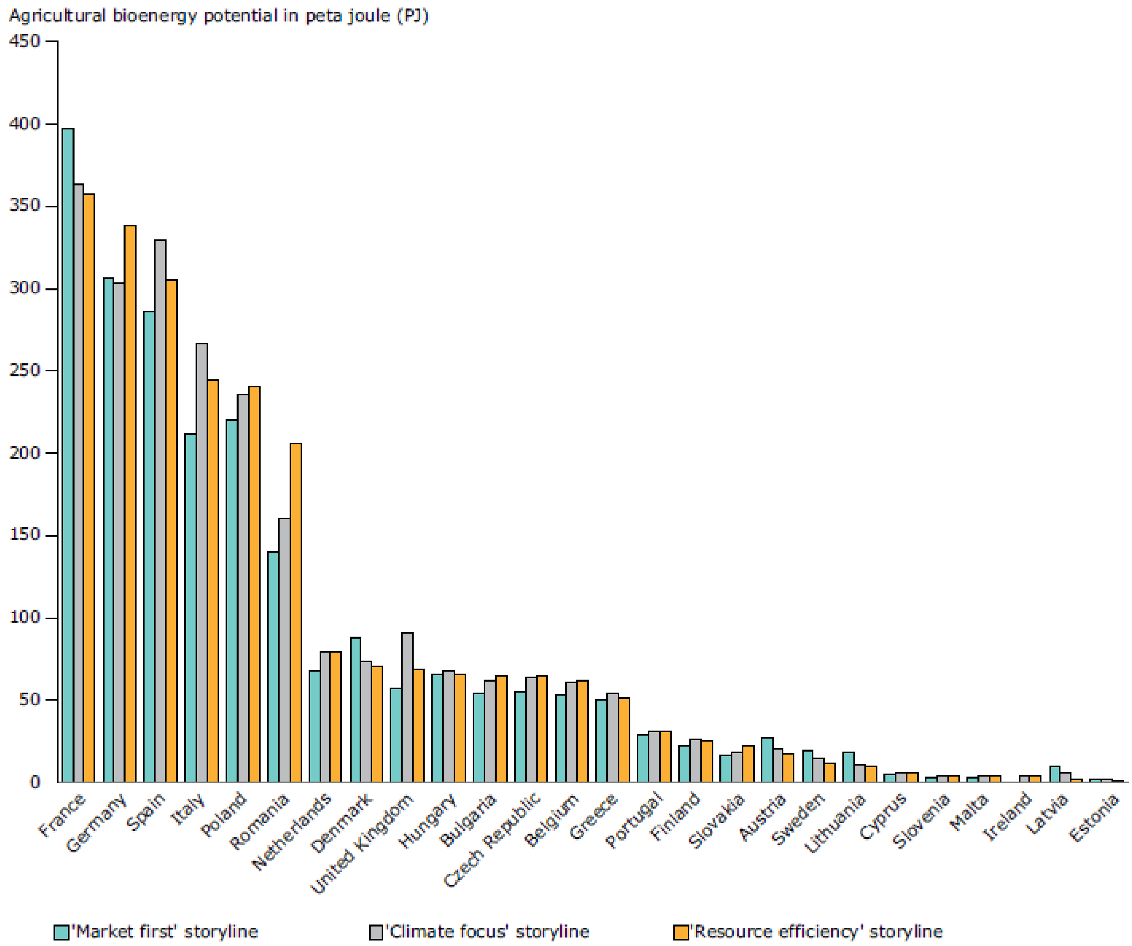


Figure 6.4 *Perennial cropping mix per country in Storyline 3*



The countries with the largest contribution to the overall EU domestic agricultural potential are France, Spain, Germany, Italy, Poland and Romania and this order does not differ in the three storylines (Figure 6.5). When looking at the different mixes in energy potential at country level (Figure 6.6) there are many differences. Countries such as Germany, France, Italy and Poland for example derive a large potential from manure and other residues. These countries do not show much bioenergy production based on dedicated cropping in the economic storyline, but in Storylines 2 and 3, when higher prices can be paid for the feedstock, it becomes more economic and contributes up to more than half of the potential. It should be mentioned, however, that the land-based potential in Storyline 1 in these countries comes mainly from arable land in competition with food and fodder crops, while in Storylines 2 and 3 the cropping potential comes mostly from lands not used for food and fodder production. These are lands that have been released from agricultural production for longer or shorter times or fallow lands, as was discussed in Chapter 5.

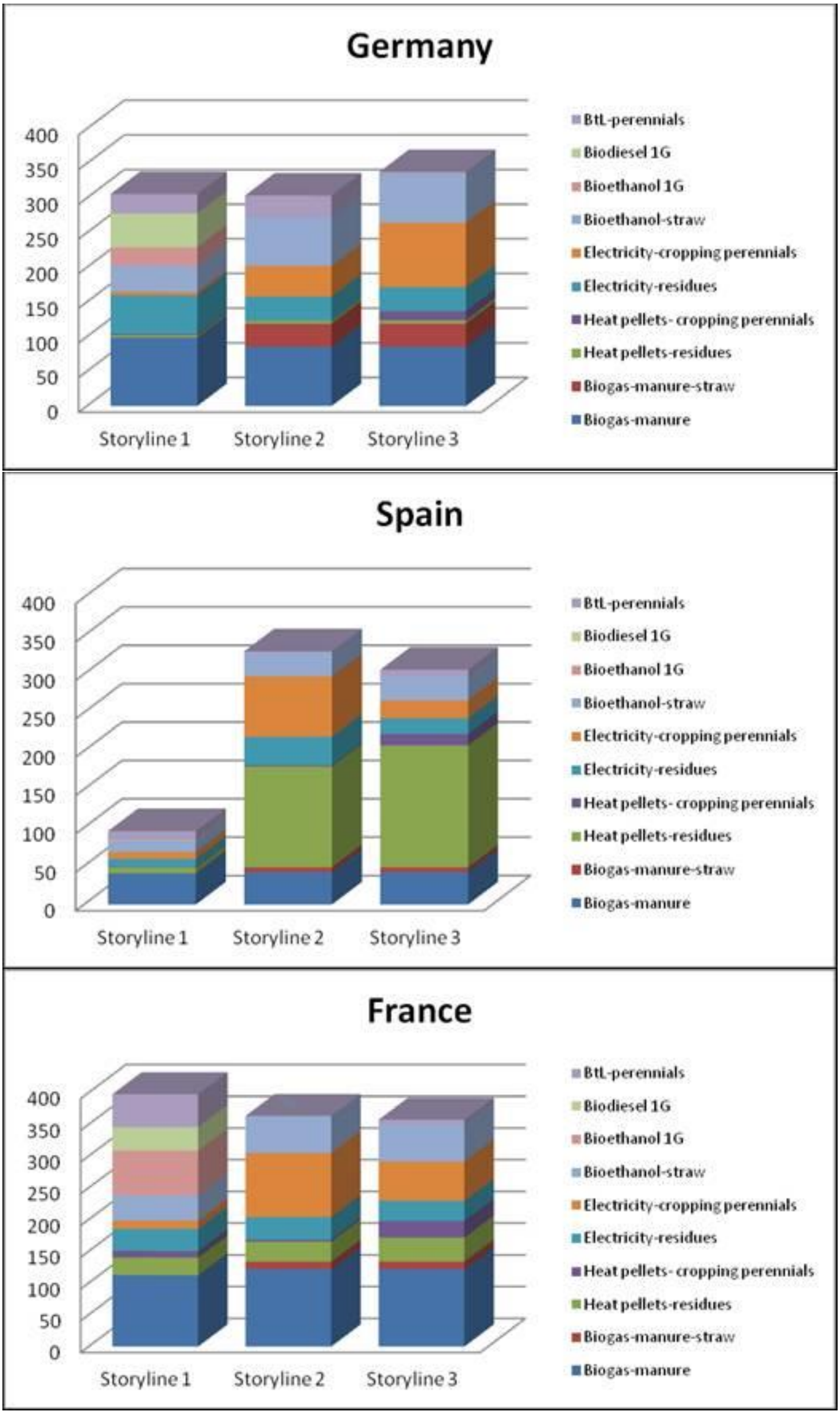
Figure 6.5 *Total domestic agricultural bioenergy potential per country in 2020 (PJ)*

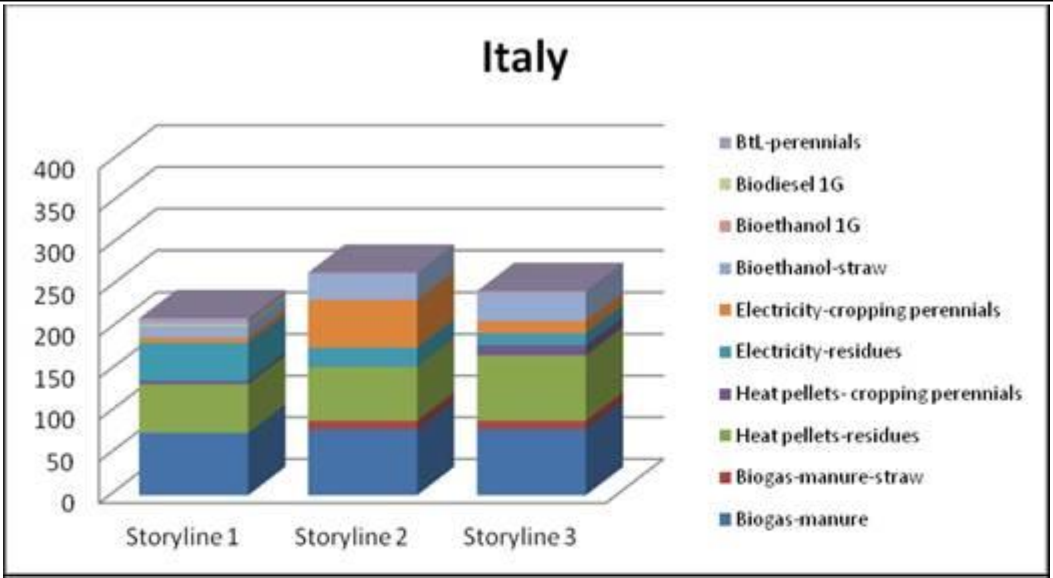


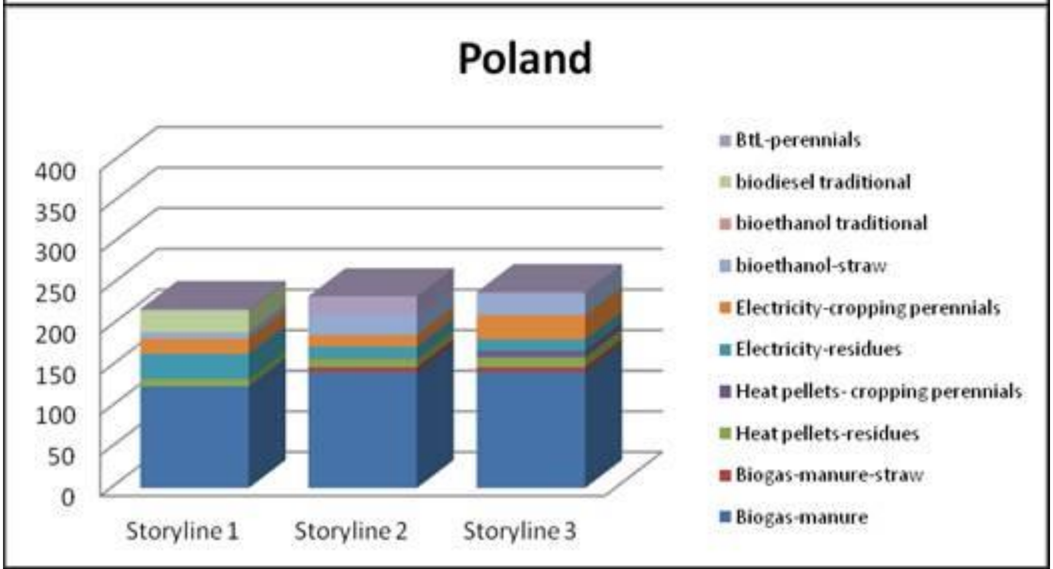
In Spain, the potential of residues derived from permanent crops is very large but is realised in Storylines 2 and 3 when prices for biomass are high enough to make their use economic. The same applies for dedicated cropping. The land potential for these types of crop is very large and land is expected to be brought back into use when there is demand for biomass at higher prices than currently. In Romania, the land potential is also very high for both biofuel and perennial biomass cropping and part of it can become economic in Storyline 1 at lower price levels than is the case for Spain.

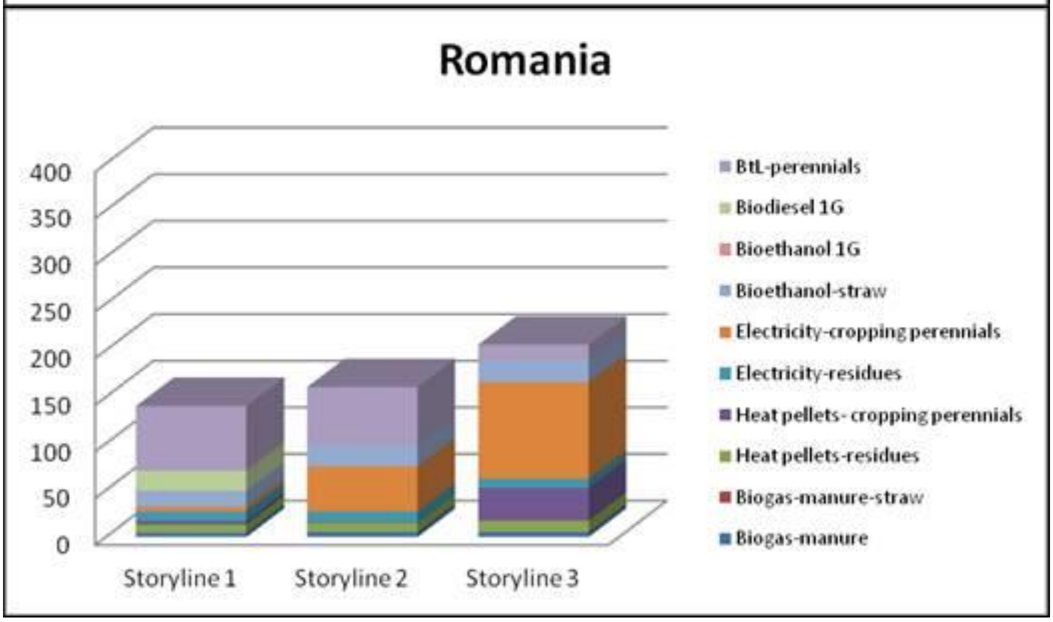
In summary it is evident, that the large countries shown in Figure 6.6 have significantly large bioenergy potentials both under the lower price levels in Storyline 1 and in more environmentally constrained futures. Spain and, to a lesser extent, Italy and Romania are exceptions, as with lower economic incentives, as is the case in Storyline 1, much less bioenergy can be produced than in a situation with higher support levels in combination with more environmental constraints.

Figure 6.6 *Bioenergy potential for selected countries in 2020 in the three storylines (PJ)*




Italy
400
350
300
250
200
150
100
50
0
Storyline 1
Storyline 2
Storyline 3
BtL-perennials
Biodiesel 1G
Bioethanol 1G
Bioethanol-straw
Electricity-cropping perennials
Electricity-residues
Heat pellets- cropping perennials
Heat pellets-residues
Biogas-manure-straw
Biogas-manure


Poland
400
350
300
250
200
150
100
50
0
Storyline 1
Storyline 2
Storyline 3
BtL-perennials
biodiesel traditional
bioethanol traditional
bioethanol-straw
Electricity-cropping perennials
Electricity-residues
Heat pellets- cropping perennials
Heat pellets-residues
Biogas-manure-straw
Biogas-manure


Romania
400
350
300
250
200
150
100
50
0
Storyline 1
Storyline 2
Storyline 3
BtL-perennials
Biodiesel 1G
Bioethanol 1G
Bioethanol-straw
Electricity-cropping perennials
Electricity-residues
Heat pellets- cropping perennials
Heat pellets-residues
Biogas-manure-straw
Biogas-manure

6.1.2 Potential from forest and waste sectors and import needs to reach NREAP targets

a) Introduction and overview

In this study the focus is on the contribution of the agricultural sector to reaching the 2020 NREAP targets in the most environmentally compatible way. However, to reach these targets, a large contribution of the domestic waste and forest sectors as well as imports will be needed also. Therefore, the contribution of these sectors and imports is estimated to deliver a full picture on the greenhouse gas mitigation potential when reaching the NREAP targets in the three storyline situations[30].

The analysis presented here needs to be considered as a fast-track approach to integrating forest and waste potentials into the overall study. It is based in the first instance on the work presented in previous EEA analysis (EEA, 2006 and 2007) on the environmentally compatible bioenergy potential in the forest and waste sectors. However, an attempt was made to use two more recent studies [31] for integrating updated information into the estimate of volumes and likely costs of different types of forest biomass. Still, a further re-analysis of this biomass sector would be beneficial, especially regarding imported woody bioenergy. The adjustment of waste potentials in relation to the EEA 2006 estimate only built on integrating minimum cost levels into the estimate of available waste biomass.

In the analysis, first an estimate was made what share of the NREAP targets can be reached with **domestic** biomass derived from the agriculture, forest and waste sectors. The contribution of these three sectors to the NREAP targets differs per storyline (see summary in Table 6.3). The potentials taken from the waste and forest sectors are those biomass volumes projected to be available below the maximum price paid for biomass feedstock in every storyline (see Table 6.3 and for maximum price levels Table 5.3 in Chapter 5).

***Table 6.3** NREAP final energy demand 2020 and supply from agriculture, forestry and waste sectors and import needs per storyline (PJ)*

	Total agriculture			Forest	Waste			
	Bio-heat	Bio-electri-city	Bio-fuels*	Heat	Heat	Electri-city	NREAP dem-and	Import needs
Storyline 1	339	1146	936	585	602	607	5800	1585
Storyline 2	362	1504	984	1057	636	620	5800	637
Storyline 3	524	1440	783	928	355	577	5800	1193

*In Storylines 2 and 3 biofuels are counted double since they are 2nd generation fuels based on waste and perennials.

b) Development of the domestic forest potential

The approach used in this study builds on the estimated amount of forest biomass from domestic presented in the EEA (2007)[32] study. However since that time new studies have been published estimating the biomass availability from forests in Europe, e.g. in the EUwood project (Mantau, 2010a, b). To better align the EEA 2007 estimates with newer work the share of different types of forest biomass that has

30 See Chapter 2.6 for a discussion of the carbon balance of forest bioenergy which was not explicitly addressed in the analysis of this study.

31 EU wood project (Mantau et al., 2010 a,b): http://ec.europa.eu/energy/renewables/ studies/doc/bioenergy/ euwood_final_report.pdf) accessed 2 May 2013; and the Biomass Futures project (Elbersen et al., 2012): http://www.biomassfutures.eu/work_packages/work_packages.php.

32 EEA (2007). Environmentally compatible bio-energy potential from European forests.

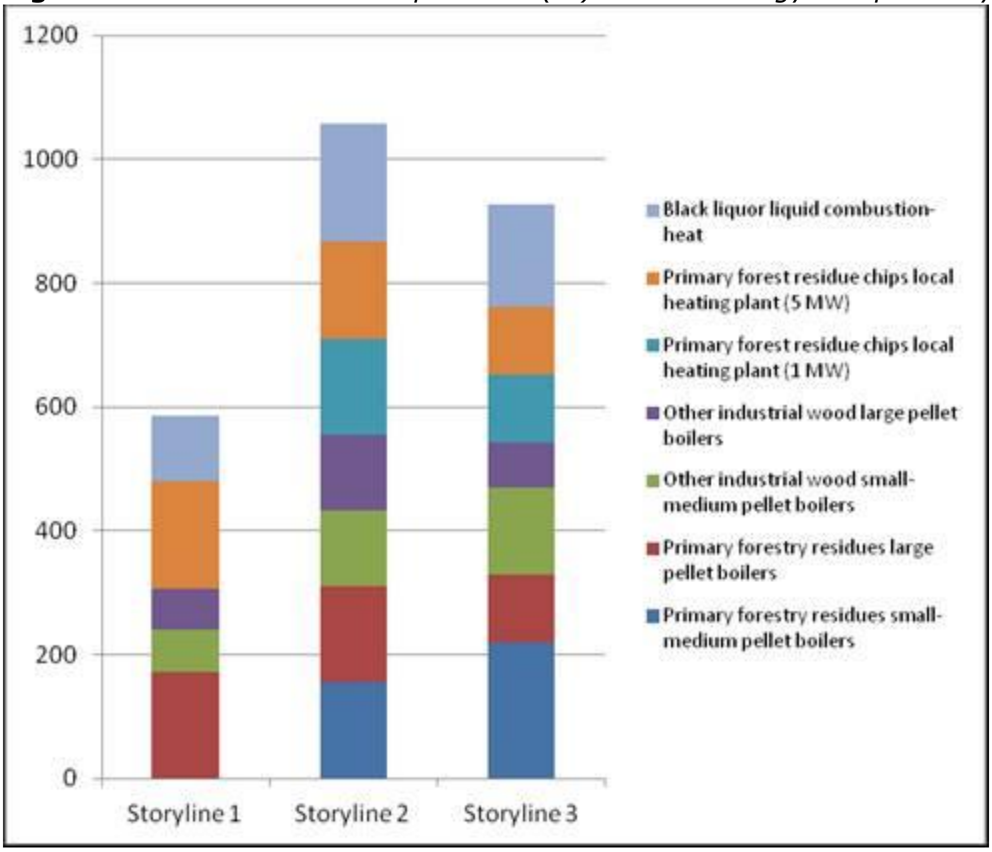
been elaborated in the EUwood project was assumed to apply to the total forest volume estimated in EEA (2007). These volumes of different types of forest biomass were then combined with new cost estimates in the Biomass Futures project (Elbersen et al., 2012). The assumption is that all residues available at the maximum price per storyline are automatically used to their full extent to satisfy the NREAP heat targets per country. However, the combined wood residues are not sufficient to satisfy the full heat demand which implies that the remaining demand can be topped up with pellets based on stem wood that is available at the storyline-specific competitive prices.

In matching of biomass to the pathways, the same rules were applied as for the agricultural biomass potentials. In the Market First storyline, the forest potential is much smaller than in the other two storylines because lower maximum prices are paid. In the Storyline 1, this price is set at 3 Euro/GJ (equivalent to 35 Euro/m^3), while this is twice as high in Storylines 2 and 3. The difference in maximum price does not lead to an additional contribution of stem wood, but rather to an increase in the contribution from forest residues and residues from complementary fellings in Storyline 2 (see Figure 6.7) which consist of pre-commercial thinnings and low-quality roundwood, both implying rather young trees. In Storyline 3, the much stricter criteria set on removing forestry residues from protected forest areas lead to a significant reduction in the use of primary forestry residues.

The above approach integrates more recent knowledge into the EEA 2007 estimates. Nevertheless, the outcome is still not fully satisfactory as too many modelling assumptions and imperfect input data had to be used. For example, it should be noted that the price estimates by Elbersen at al. 2012, are rough estimates of average EU level prices and therefore do not provide a real continuous cost-supply relationship as is available in the EEA (2007) study. An update of that work would also have to take into account variation in price levels of different types of forest biomass between countries and seasons of the year. In addition, there is not necessarily a good alignment between the definition or use of different types of forest biomass in the different studies available so far. Overall, therefore the combined cost-supply information from Mantau et al. (2010a,b) and Elbersen et al. (2012) only enable a better approximation of the share of stem wood, harvesting residues and other biomass types in total forest biomass for energy generation. However, a full re-assessment of the EEA (2007) estimates would be necessary to arrive at more reliable quantitative estimates. This would also enable a better estimate of the potential carbon debt associated with the use of forest biomass for energy (see box 6.1 for a related discussion).

In spite of the points made above, the available estimates of total forest biomass volume and likely share of different biomass types were considered a sufficient input for reviewing options for the resource-efficient use of forest biomass in different energy end use sectors. The resulting conversion routes in terms of technology and potential mix for the forest and waste sectors are provided in Figure 6.7 below.

Figure 6.7 *Domestic forest potential (PJ) and technology mix per storyline in 2020*



The main difference in technology pathways between the storylines is the scale and the much larger amount of forest potential going into heat pathways (Figure 6.10). In Storylines 2 and 3 there is a large potential coming from small to medium sized pellet boilers and small scale (up to 1 MW) heating plants, while this pathway is absent in Storyline 1. In Storyline 3 these pathways are also larger than in Storyline 2.

Box 6.1 First reflections on potential 'carbon debt' associated with the use of forest biomass for energy

The remit of this study did not include an analysis of the potential 'carbon debt' arising from the use of forest biomass for energy. However, a review of literature in relation to the carbon debt concept is provided in section 2.6. In addition, the EEA report that summarises ETC results discusses the estimated forest potential in relation to 'carbon debt'. However, it seems worthwhile to briefly review recent academic literature on the topic and to discuss the nature of currently available data in relation to estimating the size of potential carbon debt arising from different types of forest biomass.

The first step to take is to look separately at domestic and imported forest biomass as these can differ substantially in their composition. Only first estimates on the composition of imported biomass was available at the time of finalising the quantitative analysis for EEA (2013). More recent results from IEA Bioenergy Task 40 work (Junginger 2013; Lamers, Junginger 2013; Lamers *et al.* 2012) and JRC (2013) indicate that solid bioenergy imports to Europe will - up to 2020 - come mostly from forest residues and additional thinnings from Canada and Southeastern US states where C debt risks are seen as low, but less is known about imports from Russia[33].

[33] This question will partly be addressed in two new EU studies (BiomassPolicies, and S2Biom), but first results of this work will become available only in 2014.

On the domestic side, there are recent studies by Díaz-Yánez *et al.* (2012 and 2013) which provide estimates of the type of forest biomass used and expected to be used in the future for wood chips for heat and electricity generation. The study confirms that stemwood-based biomass use is likely to occur already and likely to increase, although the amount in absolute terms is rather low for the EU as a whole, and it must be noted that the term "stemwood" does not necessarily imply high-quality roundwood (e.g. sawlogs), but also included small trees from thinnings. For the 17 EU countries involved in the assessment on average it was estimated that 19% of the forest chips are based on whole trees or stemwood from pre-commercial thinnings. For countries such as Spain, Denmark and Ireland, whole trees and stemwood from pre-commercial thinnings and industrial roundwood from thinning were even the most important sources already for the energy chips - but again, the overall share of these countries in the total bioenergy use of the EU is quite small. For the future in most countries, experts involved in the study expect the share of chips based on roundwood from thinning will increase in wood-energy consumption. In addition, the use of stumps and roots is expected to increase to up to 10 % of total wood supply for biomass by 2020. Such forest biomass would also carry a potential carbon debt.

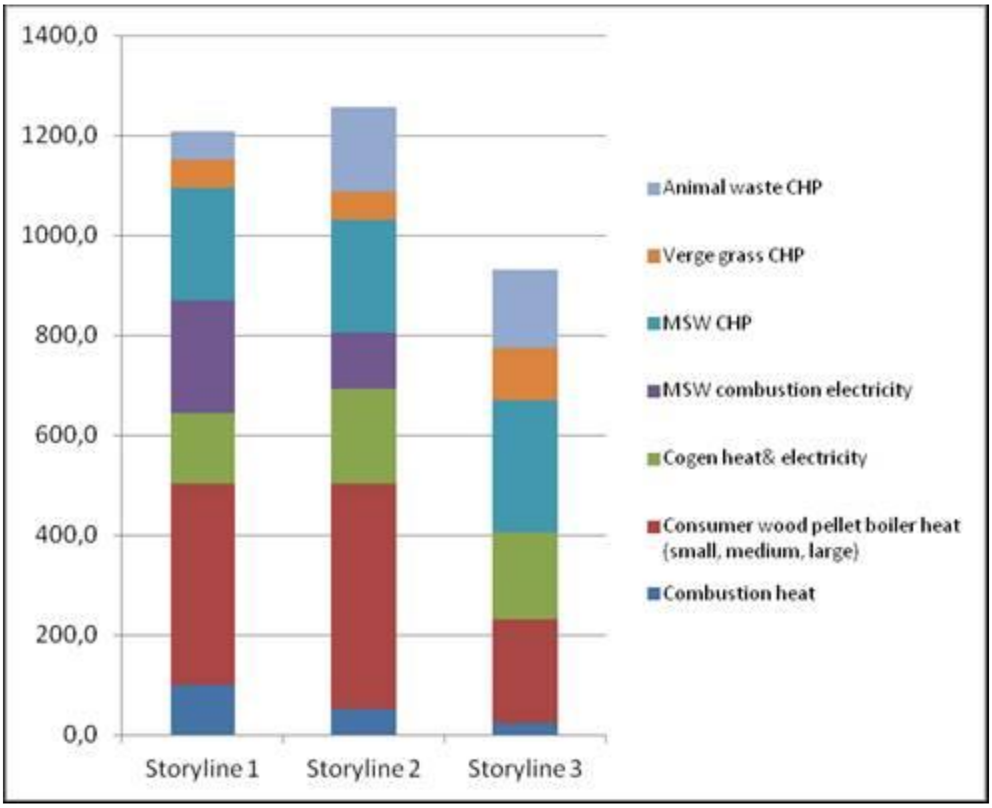
The figures on both the domestic and import forest biomass mixes available at the time of this study allow only a first estimate of GHG emission and mitigation potential of forest biomass, particularly in relation to the carbon debt issue. Further expert contribution is necessary to shed better light on this issue (JRC 2013).

c) Development of the waste potential

The waste potential was derived from EEA (2007) in combination with the minimum level of acceptable cost at which biomass would be used for energy generation in the three storylines. The resulting conversion routes in terms of technology and potential mix for the waste sector are provided in Figure 6.8. (It becomes clear that the amount of waste is smallest in Storyline 3, and also the composition of the waste is different. The MSW combustion in electricity, a very inefficient pathway, is completely absent in Storyline 3 and combustion into heat is very limited. In Storyline 2 the share of combustion is also smaller than in Storyline 1 but the total energy potential is larger because of a more optimal technology mix with a higher heat share.

The total potentials from the forestry, waste and agricultural sectors can be added up to determine how far this matches with the NREAP targets and what the remaining import needs are. From this it becomes clear that import needs are very limited if compared to the total energy demand from the NREAPs, and the total domestic supply in final energy (see Table 6.4). In the Storylines 2 and 3 this low import need is particularly caused by the possibility of double counting for 2nd generation biofuels and for biofuels based on residues and waste. Since in these two storylines this applies to almost all biofuels produced it is a significant factor.

Figure 6.8 *Waste potential (PJ) and technology mix per storyline in 2020*



d) Fulfilling NREAP targets via additional imports

Now that all domestic biomass has been quantified, it becomes clear that there are still imports required to fulfil the NREAP targets. Table 6.4 gives an overview of how many imports are needed to fulfil the final NREAP targets. An overview of how many globally available biomass resources are needed is taken from van Vuuren *et al.* (2009) and is further explained in Box 6.2.

Table 6.4 only shows the import demand and the total import availability if we assume that the EU is "entitled" to the share of biomass resources that equals to the share of its Gross Domestic Product (GDP) in the global GDP (see Box 6.2).

Table 6.4 *Demand, supply and imports in 2020 by scenario (PJ)*

	Total NREAP demand	Domestic supply**	Required imports	Globally available for EU imports*
Storyline 1	5 742	4 215	1 527	19 785
Storyline 2	5 742	5 163	579	10 837
Storyline 3	5 742	4 607	1 135	7 393
NREAP	5 742	4 800	1 000	19 200

*Based on Van Vuuren *et al*, 2009.
** Biofuel supply that can be double counted is included in this potential as double counted.

Box 6.2: Estimating biomass availability and import mix

In the first instance it seems that in the three storylines, available imports are much larger than required imports (Table 6.4). This is based on the assumption that the availability of the global biomass potential by world regions is based on regional GDP shares in world total GDP (based on Van Vuuren *et al*., 2009). Hence, the biomass volumes available for import to the EU correspond to its share in total global GDP. In Storyline 1 the global biomass potential is estimated to be 150 EJ (van Vuuren *et al*., 2009). If the amount available for the EU-27 is equal to its share of global GDP, the EU-27 can use 24,000 PJ in 2020. Domestic supply (from domestic agriculture, forest and waste sectors) is estimated at 4,215 PJ (Table 6.4), therefore 19,785 PJ would still be "available" for imports. In Storyline 2 the global biomass potential in 2020 is assumed to be 100 EJ (taking into account restrictions on indirect land use change, see van Vuuren *et al.*, 2009). Again, it is assumed that the EU-27 can import a share based on its regional GDP (medium value between Storyline 1 and Storyline 2 approach). This translates in an EU share of 16,000 PJ minus 5,163 PJ of domestic supply which leaves 10,837 PJ available for imports (see Table 6.4). In Storyline 3, the global biomass potential is only assumed to be 75,000 PJ in 2020 (due to several additional restrictions, see van Vuuren *et. al.*, 2009), which translates into a total EU share of 12,000 PJ. That is diminished with the domestic production of 4,607 PJ, leaving a total available EU import potential of 7,393 PJ in 2020 (Table 6.4).

The data from van Vuuren *et al.* (2009) were further subdivided in types of biomass sources by Ros *et al.* (2011). In this study it is estimated that about 63% of the global biomass potential would come from agricultural crops. Projected on the 19,785 PJ available for Europe this implies that more than 12,465 PJ of 1st generation biofuels can be imported (Table A).

Table A: *Availability of bioenergy sources for imports in the three storylines*

	Market First	Climate Focus	Resource Efficiency
Available for imports (total) (PJ)	19 785	10 837	7 393
Fraction per source			
Fraction agriculture[34]	0.63	0.63	0.63
Fraction residues from forests and perennials	0.12	0.12	0.12
Fraction agricultural residues	0.09	0.09	0.09
Fraction waste[35]	0.12	0.09	0.04
Availability per source			
Availability agriculture (PJ)	12 465	6 827	4 658
Availability residues from forests and SRC wood (PJ)	2 374	1 300	887
Availability agricultural residues (PJ)	1 781	975	665
Availability waste (PJ)	2 374	975	296
Total available	18 994	10 078	6 506

Source: Based on van Vuuren *et al.*, 2009 and Ros *et al.* (2011)

It also becomes clear that the total estimate for imports in every NREAP is not so far away from the amount of imports needed in the three storylines (Table 6.4). Overall

[34] Ros *et al*. (2010), Table 3.1, based on IEA (2007); IPCC (2011); Sterner (2009); Vuuren *et al.* (2010); WBGU (2009)

[35] Based on EEA (2006) and economic threshold (3, 5, 10 Euro per GJ)

the required imports fit well with the available imports when only looking at total energy potential. In the following, a more detailed analysis shows that this is not necessarily the case when available imports are further classified and matched with demands for the heat, electricity and biofuel sectors.

Imports by energy end use sector

The question now arises whether the total available imports also match with the detailed demand and with the environmental criteria, particularly in Storylines 2 and 3 which have determined the mix provided in Table 6.3. Therefore, the potential imports in the three storylines are discussed with regard to the demand for heat, electricity and transport (see Table 6.5).

***Table 6.5**: NREAP demand (PJ) for heat, electricity and transport and remaining import requirements per storyline for EU-27 in 2020*

	heating	electricity	transport
NREAP required	3 692	831	1 219
Storyline 1	2 165	-922	283
Storyline 2	1 637	-1 293	235
Storyline 3	1 885	-1 186	436

*= negative figures represent sectoral surplus

It turns out that there is a particular mismatch between the domestic supplies and the biofuel and heat sector demands, while for the electricity sector there is a much larger supply than what is demanded in all storylines (see Table 6.5). In Storyline 3 it is specifically difficult to match the biofuel demand with the domestic supply (Table 6.5). Domestic supply can be divided in forestry (for heat), waste (for electricity and/or heat) and biomass from agriculture. A part of this domestic production is for heat and electricity and a large part is for transport (biofuels) (Table 6.3 and Table 6.5).

In the Storyline 1 the higher import needs are especially caused by lower domestic potentials for heat. Heat can be produced from agricultural, forest and waste biomass as far as feedstock costs fit with the maximum prices assumed to be competitive in the storylines. Since in Storyline 1 (open market situation) the maximum prices to be paid for biomass are (much) lower than in the other two Storylines, the domestic potentials are lower, particularly for heat. This increases the demand for (cheaper) wood-chip imports unless part of the excess electricity can be converted to heat[36].

In the Storylines 2 and 3 price levels paid for feedstock are higher, making it possible to use a larger part of the agricultural and forestry biomass for heat, electricity and also 2nd generation biofuels. The latter compensate partially for the lack of 1st generation biofuels because of stricter mitigation targets including indirect land use change compensation. In addition, the 2nd generation lignocellulosic based fuels are also double counted in Storylines 2 and 3 and this also helps to bring down import needs. In spite of this, the strictest Storyline 3 still has a high import need for heat and for transport fuels. These pathways are not only limited by the greenhouse gas efficiency criteria (in both , Storylines 2 and 3), but also due to wider environmental criteria limiting fallow land availability and banning irrigation in dedicated energy cropping (Storyline 3). Furthermore, the waste potential is lower in this storyline because of lower waste production.

[36] Due to time restrictions, the use of ”excess” bioelectricity in heat pumps was not considered, but should be evaluated in future work.

In order to limit imports, an option would be to use excess electricity production from domestic resources. This particularly applies to the part of the electricity that is based on biogas (from manure). Part of this energy can be applied flexibly, although in Table 6.3 it has initially been put into the electricity demand category. Biogas could however also be fitted in the transport sector. This switch can only be applied in Storylines 2 and 3 in which sufficient economic and technological incentives are given to speed up the wider scale introduction of these innovations both in the energy and transport sectors. One important measure is the stimulation of the use of biogas in public transport, through converting green biogas to liquid to be used as transport fuel. An important incentive to reach this is by counting double the biogas used in the public transport sector. This leads to an enormous reduction in import demand for biofuels. However, there is of course a limit to the amount of biogas that can be fed in the transport sector as the turnover rate of vehicles is long (> 8 years) and the 2020 targets are only eight years from now. A maximum of 10% of the NREAP target is therefore set to come from biogas-to-liquid in Storylines 2 and 3. In Storyline 1 these incentives are absent and a large part of the total electricity potential will fall above the NREAP electricity targets.

How the shifts from electricity to heat and/or transport sectors work out is shown in Table 6.6. They can be illustrated by Storyline 1 (see Table 6.6) in which the total available biogas amounts to 829 PJ. Part of this (10% of the biofuel target) can be used for gas-to-liquid in transport. Since the biogas is based on waste it implies that when put into the transport sector it double counts to the renewable transport target. This implies that only 117 PJ of biogas is to be converted to liquid gas to reduce the remaining transport import needs of 234 PJ to zero.

Table 6.6 *Potential imports (PJ) for heat, electricity and transport in EU-27 in 2020 after switching electricity to transport*

	Available domestic biogas	**Heat**	**Electri-city**	**Transport**			**Total real imports**	**Total imports coun-ting to NREAP targets**
		Imports; SRC and pellets from forests		Imports: agricultu-ral biofuels 1 + 2G*	Waste **	Domestic biogas**		
Storyline 1	700	2 165	0	494	0	0	2 660	2 660
Storyline 2	829	1 637	0	0	0	117	1 637	1 637
Storyline 3	829	1 885	0	109	55	109	2 049	2 104

*If 2nd generation biofuels are imported they count double in Storylines 2 and 3
**Contributions in these categories in Storylines 2 and 3 count double. This also implies that the domestic biogas going into the biofuel gas to liquid route counts double.

In the Storyline 3 a maximum of 829 PJ of biogas is available that does not necessarily needs to be used to reach the electricity target. Part of it can, therefore, also be converted to biogas-to-liquid for transport to reduce import needs. However, this cannot be assumed in an unlimited way as already pointed out in the former, so only 109 PJ (around 12% of the excess biogas) is used. Thus, it is assumed that in Storyline 3 there will also be enough stimulation measures to fulfil the rest of the biofuel import requirements with 2nd generation biofuels.

Import specification per storyline

To translate the import figures in Table 6.6 into a final import mix, a selection needs to be made of the logical feedstock pathways taking account of availability and carbon reduction potentials. The mix will differ per Storyline as will be discussed underneath.

Market First Storyline:
In this storyline there is no constraint on imports of bioenergy on the basis of greenhouse gas mitigation requirements. So, even though some of the biomass pathways have higher CO_2 emissions than the fossil reference, they can still be used. The preference will, therefore, be entirely based on price and thus on the cheapest biomass/final energy type. In the transport sector, all available biofuels can potentially be imported which includes 1st generation bioethanol and biodiesel, as well as 2nd generation bioethanol from straw and 2nd generation biodiesel (BtL = Biomass to Liquid, i.e. synthetic diesel from Fischer-Tropsch) and biofuels from waste. However, the straw-based 2nd generation (2G EtOH) is not expected to be used, as it would be more expensive than the 1st generation biofuels and it is, therefore, not included in the import mix in this storyline. For the heat demand, pellets from forest by-products and from perennials can be used. Since the market will determine which bioenergy sources will be imported in Storyline 1, the majority is likely to be based on forest residue pellets as these are cheaper than those based on perennials.

As indicated before (see Table 6.4) based on total biomass availability in the world (Box 6.2), 19,785 PJ is available in Storyline 1 and more than 63% of that is likely to be based on agricultural crops (see Box 6.2, Table A). This implies that the remainder transport fuel import needs (283 PJ) in this storyline can easily be covered by imports. It is estimated that residues from forests and perennials make up 12% of the available global biomass (see Box 6.2, Table A). In Storyline 1 this would be around 2,374 PJ. The projected import needs for heat (2,165 PJ) could just be met in this storyline[37]. Together with the biofuel import needs, this results in a total final energy import need of 2,660 PJ.

Table 6.7: *Availability of bioenergy sources for imports in the three storylines*

	Market First	Climate Focus	Resource Efficiency
Available for imports (total) (PJ)	19 785	10 837	7 393
Fraction per source			
Fraction agriculture[38]	0.63	0.63	0.63
Fraction residues from forests and perennials	0.12	0.12	0.12
Fraction agricultural residues	0.09	0.09	0.09
Fraction waste[39]	0.12	0.09	0.04
Availability per source			
Availability agriculture (PJ)	12 465	6 827	4 658
Availability residues from forests and SRC wood (PJ)	2 374	1 300	887
Availability agricultural residues (PJ)	1 781	975	665
Availability waste (PJ)	2 374	975	296
Total available	18 994	10 078	6 506

Source: Based on van Vuuren *et al.*, 2009

Climate Focus Storyline
In Storyline 2, the same environmental criteria are applied to imported biomass energy as to European biomass. This implies that only highly efficient cropping and conversion systems for biofuels and bioenergy are used, having a mitigation capacity

[37] Note that the uncertainties in the estimations of Ros *et al.* (2011) are large and that the estimates to define the available biomass in this report (i.e. based on van Vuuren *et al.*, 2009) are in the conservative range as compared to other relevant literature
[38] Ros et al (2010), Table 3.1, based on IEA (2007); IPCC (2011); Sterner (2009); Vuuren *et al.* (2010); WBG U(2009)
[39] Based on EEA (2006) and economic threshold (3, 5, 10 Euro per GJ)

of at least 50% as compared to fossil alternatives. This mitigation capacity should include a compensation for indirect land use change related emissions. Because of the latter, domestic 1G biofuels are not included. Biofuels that do qualify are 2nd generation fuels such as bioethanol from straw and BtL-based diesel from ligno-cellulosic agricultural and forest residues and biofuels from waste (e.g. based on used fats and oils, and manure to (liquid) gas), see also Chapters 2 and 5).

For heat and electricity, pellets from residues and perennials (short-rotation coppice = SRC) can be used in bioenergy pathways that reach a positive mitigation, but a 50% target is not obligatory for these. However, priority is given to the most efficient pathways from a mitigation perspective as these receive higher support through the carbon credit system. Table 6.5 indicates that the projected heat import needs amount to 1,637 PJ in this storyline. With the available imported feedstock from residues from forests and agriculture (See Box 6.2, Table A) this can be covered. To cover the biofuel demand in of 117 PJ (which amounts to 50% of the required imports for transport of 335 PJ- see Table 6.5 - because it can be double counted) there is more domestic biogas available than needed to cover this. Thus, there is no need to additionally import transport fuels from to the EU (see Table 6.6).

Resource efficiency storyline
In Storyline 3, the same criteria are applied to European and imported biomass for energy. In this storyline, the mitigation target of 50% (including compensation for indirect land use change-related emissions) not only applies to biofuels (as in Storyline 2), but also to heat and electricity pathways. Like in Storyline 2, much more stimulation is available for production of waste based bioenergy and/or 2nd generation biofuels, inter alia through high carbon credit payments (see Chapter 5.4).

In this storyline, domestic biogas can be used for heat requirements, as can pellets from forest residues and perennials, provided the latter are grown on degraded lands not competing with land for food and fodder crops. This implies that to cover the total heat import requirement of 1,885 PJ all available residues from both forest and agriculture need to be used. According to Table 6.6, this amounts to 1,552 PJ, including cropped biomass from perennials such as SRC. Thus, the import requirement for heat can be met with the projected globally available biomass resources (see Box 6.2, Table A).

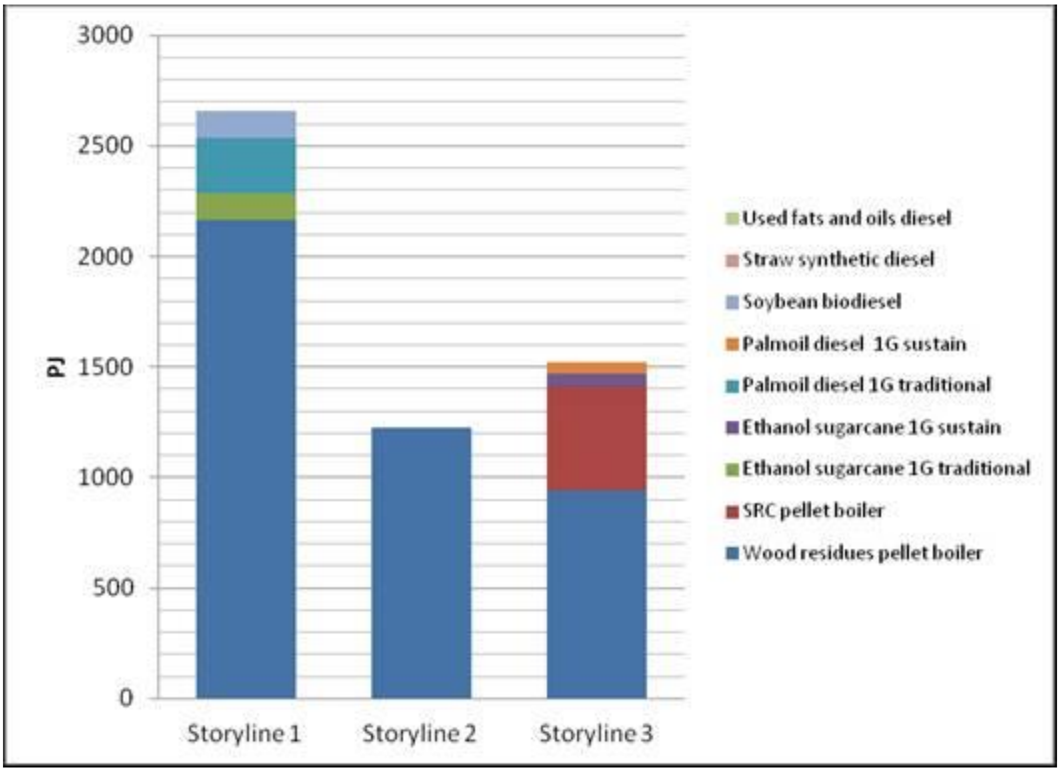
For transport, there is a total import need of 436 PJ in this Storyline 3 (Table 6.5). As in the Storyline 2, 1st generation biofuels do not qualify. Firstly, part of the biogas can be used in the transport sector as biogas-to-liquid which can be double counted because it is based on waste. As mentioned before the turn-over rate of cars and public transport vehicles to biogenic GtL is slow, only part of the biogas can be used to cover the domestic biofuel deficit. This implies that as in Storyline 2, about 12% of the excess biogas (109 PJ) can be used for transport. The other half is still imported (see Box 6.2, Table A). Most of the imported biofuels will need to be based on, for example, waste (e.g. oils and fats) and crops produced on degraded lands in very sustainable systems with very low emissions (so no indirect land use change effects are possible), and/or lignocellulosic material converted to 2nd generation fuels. However, as for the latter, all of the residual lignocellulosic resources are needed to cover the heat imports. This implies that the rest should come from waste and crops from indirect land use change-free land. This is why in Table 6.6 the remaining biofuel imports are distributed over agricultural crops and waste. The waste based fuels double count to the target and amount only to half of that coming from crops. This is because it cannot be expected that very large volumes of used oils and fats are still available for imports to the EU. Third countries are likely to use most of it for own biofuel consumption.

6.1.3 Summary of total energy potential and technology mix

The analysis above indicates that in spite of the large excess bioelectricity production from domestic sources in all storylines, there is still a large requirement for imports, particularly to reach heat and biofuel targets. In Storyline 1, the optimal mix of domestic bioenergy production is determined by the cost and the technological developments until 2020. In the more environmentally oriented Storylines 2 and 3 there is more heat production. Nevertheless, the stimulation of technological developments and production incentives cannot be expected to be so effective that heat and second generation targets in the NREAPs can be based on domestic biomass only by 2020.

A summary of the final technology mix used to convert the imported biomass into bioenergy is provided in Figure 6.9. A large amount of imports of pellets for heat production is assumed in all 3 Storylines. Imports of 1st generation biofuels only occur in Storyline 1. In Storyline 3 the imports to cover the biofuel needs consist of more efficient biofuels based on used fats and oils and crops grown on degraded lands, but are small in total.

***Figure 6.9** Imports (PJ) and technology mix per storyline 2020*



6.2 Effects on overall greenhouse gas emissions and mitigation potential

In the previous section the total potential for bioenergy from agriculture, forestry, waste and imports was presented. This section analyses the greenhouse gas emissions that are associated with the different mixes of biomass sources, technologies applied and environmental constraints in the three storylines. First the emissions related to domestic agricultural bioenergy potential are discussed. This is done by the total well-to-wheel emission of agricultural bioenergy based both on cropped biomass and waste and residues from EU-27.

In the next section, the emissions for the biomass potential from the waste and forest sectors are presented together with the emissions associated with imports needed to completely fulfil the NREAP targets in 2020. All emissions presented here include both land-based and downstream (life-cycle) emissions. The final section analyses the total mitigation potential of bioenergy production in the three storylines. A distinction is made between the total potential required to reach the NREAP targets and the overall potential that is estimated for the three storyline situations, including the excess electricity production above the NREAP target.

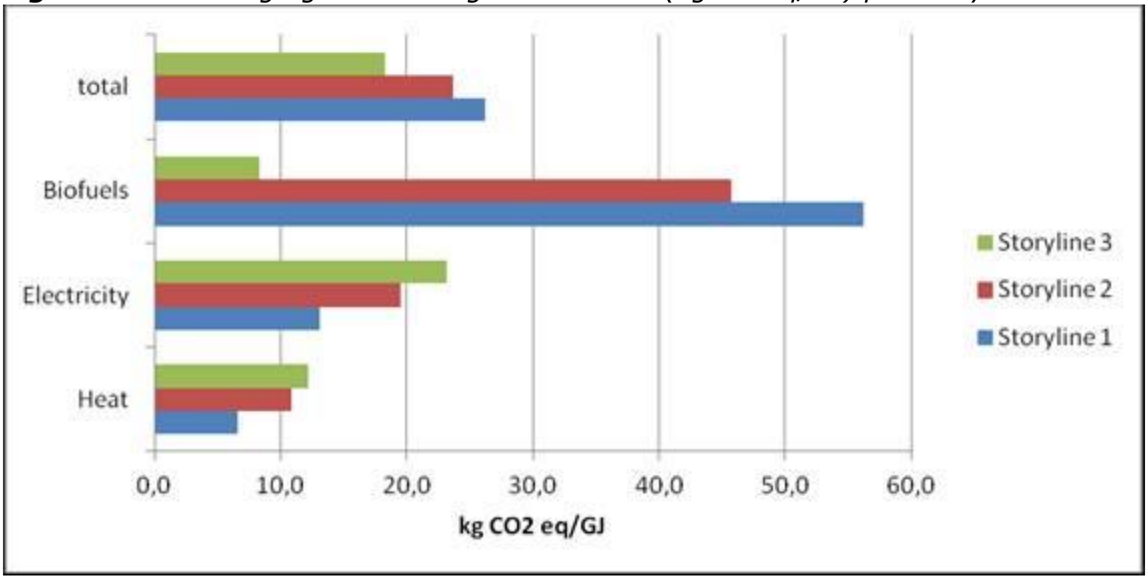
6.2.1 Effects on total well-to-wheel greenhouse gas emissions from agricultural domestically produced bioenergy

Based on the total potential and bioenergy mix presented in the previous section, domestically produced bioenergy from agriculture can reach an average greenhouse gas emission per GJ in 2020 ranging from 26 kg CO_2eq/GJ in Storyline 1 to 24 kg CO_2eq/GJ in Storyline 2 to only 18 kg CO_2eq/GJ in Storyline 3 (Table 6.8 and Figure 6.10). The greenhouse gas mitigation gains in Storylines 2 and 3 are particularly reached with biofuels, but the average emissions from electricity and heat are even higher in these storylines. This is because more biomass is used for heat and electricity instead of biofuel pathways, as this is more efficient in terms of greenhouse gas emissions than when converting it into biofuels.

Table 6.8 *Total domestic agricultural potential (PJ), total (Kton CO_2eq) and average greenhouse gas emission (kg CO_2eq/GJ)*

	total domestic agricultural potential (PJ)				**total emissions (Kton CO2 eq.)**				**average emissions (kg CO2 eq./GJ)**			
	heat	elect-ricity	biofuels	**total**	heat	elect-ricity	biofuels	**total**	heat	elect-ricity	biofuels	**total**
Storyline 1	339	1146	725	**2210**	2231	14985	40778	**57994**	6,6	13,1	56,3	**26,2**
Storyline 2	362	1504	492	**2358**	3934	29338	22508	**55780**	10,9	19,5	45,7	**23,7**
Storyline 3	524	1440	392	**2355**	6417	33436	3272	**43126**	12,2	23,2	8,4	**18,3**

Figure 6.10 *Average greenhouse gas emissions (kg CO_2eq/GJ) per storyline in 2020*

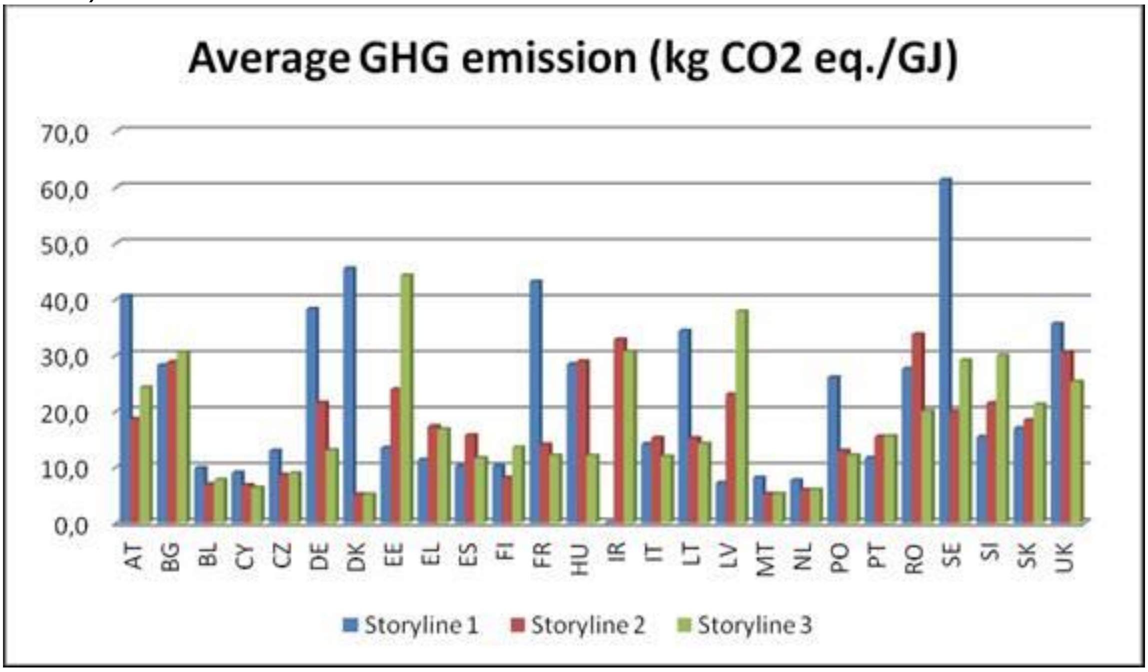


The analysis shows that the extra mitigation can especially be reached in the biofuel sector with strict mitigation targets and compensation for indirect land use change related emissions as is the case in Storylines 2 and 3. The reason that domestic biofuel emissions in Storyline 3 are even lower than in Storyline 2 is that in Storyline 3 stricter rules on the maximum conversion of fallow land areas to dedicated perennial cropping are in place. This leads to lower availability of woody biomass from perennials to be converted into BtL. So the share of more efficient fuels in this storyline in the total biofuel mix is higher. However, the amount of biofuel production in this storyline is lower which leads to higher import requirements.

The higher average greenhouse gas emissions in electricity generation in Storylines 2 and 3 are related with larger shares of perennial-based electricity and with a larger amount of biogas going into the transport sector. In Storyline 1 the straw-based electricity generation is higher. This is more efficient, but in Storylines 2 and 3 a large part of this straw is going into ligno-cellulosic ethanol making straw use more efficient than when used for electricity production. Another part of the straw is used as substrate in combination with manure to produce biogas which is partly used as liquefied biogas for the transport sector. Overall, the use of straw in Storylines 2 and 3 work out more efficiently in reaching the total NREAP targets.

The heat production in the Storylines 2 and 3 are, on average, not more efficient because the total domestic heat production is larger. This implies that it needs to be based on a larger mix of biomass-technology combinations then in Storyline 1. In Storyline 1 most of the biomass sources are first prioritised towards fuels because of the higher prices that can be paid for biomass in this sector, while heat and electricity is based on the cheapest, and not necessarily most efficient, resources.

Figure 6.11 *Average greenhouse gas emissions (kg CO_2eq/GJ) per storyline per country in 2020*



Countries which are able to reach the largest increase in greenhouse gas efficiency for their bioenergy potential are countries which have a large potential from domestically grown biofuel crops in Storyline 1 as 1st generation biofuels have very high direct and indirect greenhouse gas emissions. This explains why countries such as France and Germany show large reductions in greenhouse gas emission per GJ from Storyline 1 to Storylines 2 and 3 (Figure 6.11). Still, there are several countries showing an increase in their average emissions from Storyline 1 to Storyline 2 and 3. This is because these countries are not providing any cropped-based (1st generation) potential in Storyline 1, while in the other storylines the domestic dedicated cropping potential is significantly more important.

The comparison of changes in emissions per sector per storyline shows that the highest gains can be reached in the biofuel sector. As for the average emissions in the electricity sector, these even go up, especially in Storyline 2, which can be explained by the larger contribution of bioelectricity and heat based on dedicated cropping in these storylines. In spite of this, the average greenhouse gas emission remains relatively low for these sectors. Some exceptions to this are countries that base their bio-heat and electricity on perennial crops which deliver relatively low yields, but still reach the mitigation target set at 50% because the emission of their fossil mix is among the highest in the EU. This is particularly the case for countries such as Bulgaria, Hungary and Romania.

6.2.2 Effects of imports and biomass use for waste and forest sector on greenhouse gas emissions

For electricity no imports are required as the targets can be met very easily with domestic resources from agriculture, forest and waste. For biofuels the imports can also be more limited in Storylines 2 and 3 because of the double counting options. The use of lignocellulosic biofuels (e.g. straw, perennials) and gas-to-liquid applications in these storylines lower the risk for increased greenhouse gas emissions and other pressures related to increases in land use.

Table 6.9 *Total import needs (PJ) and related total (Kton CO_2eq) and average greenhouse gas emissions (kg CO_2eq/GJ)*

	total imports (PJ)				total emissions (Kton CO_2 eq)				average emissions (kg CO_2eq/GJ)			
	heat	elect-ricity	biofuels	**total**	heat	elect-ricity	biofuels	**total**	heat	elect-ricity	biofuels	**total**
Storyline 1	2165	0	494	**2660**	63740	0	56003	**119743**	29		113	**45**
Storyline 2	1228	0	0	**1228**	36141	0	0	**36141**			0,0	**0**
Storyline 3	942	0	164	**1106**	29147	0	-3419	**25728**	31		-21	**23**

Table 6.9 shows that the biofuel imports are still significant both in Storylines 1 and 3 but that the largest import requirements are in the heat sector. In Storylines 2 and 3 it is more problematic to derive this heat requirement efficiently as there are less forest residues available for imports then in Storyline 1. This makes the imports of pellets based on dedicated biomass even.

When looking at the pathways foreseen for the imports (see Figure 6.9) the much higher biofuel emissions in Storyline 1 are logical as they are based on 1^{st} generation biofuels. These are mostly based on the cheaper palm oil and soy-based biodiesel which have very high direct and indirect land use change effects. In Storyline 3 the imported biofuels can only be based on crops produced in sustainable systems using degraded lands, otherwise they will not reach the mitigation targets. This should be feasible if the right incentives are in place and the demand remains modest, which is the case in Storyline 3 because of double counting.

The domestic forest potential is entirely used to reach the heat targets, which is the most efficient choice (Table 6.10). In Storylines 2 and 3 the prices paid for biomass are higher than in Storyline 1 making it possible to derive more domestic potential and rely less on imports. Since there are not many choices in relation to the pathways to convert forest biomass to heat in all storylines, practically the same efficiency is reached for the domestic part (Figure 6.7). For the imported pellets converted to heat this is different as greenhouse gas emissions for these pellets may differ strongly according to region from where they are imported. In the Storylines 2 and 3, most of the imports, therefore, come from the US. A higher import share in forest biomass for heat in Storyline 1 is also a reason for higher emissions as the domestic forest products for heat generation are more diverse and provide very efficient pathways, such as all secondary and tertiary forest products, including black liquor converted into heat.

Table 6.10 *Total EU forest potential (PJ) and related total (Kton CO_2eq) and average greenhouse gas emission (kg CO_2eq/GJ) per storyline*

Forest	total (PJ)				total emissions (Kton CO_2 eq)				average emissions (kg CO_2 eq/GJ)			
	heat	elect-ricity	bio-fuels	**total**	heat	elect-ricity	bio-fuels	**total**	heat	elect-ricity	bio-fuels	**total**
Storyline 1	585			**585**	10070			**10070**	17,2			**17,2**
Storyline 2	1057			**1057**	18309			**18309**	17,3			**17,3**
Storyline 3	928			**928**	16443			**16443**	17,7			**17,7**

The domestic waste potential is used for both heat and electricity generation. In Storyline 3 the potential from this source is smaller as there is less waste expected to be produced in this storyline which results in a lower potential. In the waste sector very efficient conversions to heat can take place when based on used fats and oils and post-consumer wood (see Figure 6.8). However, conversions to electricity are less efficient and are difficult to be avoided as the largest amount of waste consists of municipal solid waste. In Storyline 3 this amount is expected to be lower, explaining the better performance in average greenhouse gas emissions (see Table 6.11).

Table 6.11 *Total EU waste potential (PJ) and related total (Kton CO_2eq.) and average greenhouse gas emission (kg CO_2eq/GJ) per storyline*

Waste	**total (PJ)**				**total emissions (Kton CO_2 eq)**				**average emissions (kg CO_2 eq/GJ)**			
	heat	elect-ricity	bio-fuels	**total**	heat	elect-ricity	bio-fuels	**total**	heat	elect-ricity	bio-fuels	**total**
Storyline 1	602	607		**1209**	5327	99696		**105023**	8,8	164,4		**86,9**
Storyline 2	636	620		**1256**	6621	69420		**76041**	10,4	111,9		**60,5**
Storyline 3	355	577		**932**	4873	44391		**49264**	13,7	77,0		**52,9**

6.2.3 Total greenhouse gas emissions and mitigation potential of bio-energy in 2020

When putting all domestic potentials together with the import needs required for reaching the NREAP targets in 2020 we see that different environmental constraints applied per storyline still deliver different solutions. In Storyline 1, putting no environmental constraints and letting the market do its work will lead to an average emission of 44 kg CO_2eq per GJ, while in the most strict Storyline 3 this target can also be reached with only 25 kg CO_2 eq per GJ (see Table 6.12). The latter, however, will lead to extra costs, but will also yield much better results in relation to other environmental externalities as discussed in Chapter 7.

Table 6.12 *Total potential (PJ) from domestic agricultural, forest and waste sectors and import needs and average greenhouse gas emissions (kg CO2 eq/GJ)*

Domestic agriculture, forest, waste and imports	**total (PJ)**				**total emissions (Kton CO_2 eq)**				**average emissions (kg CO_2 eq/GJ)**			
	heat	elect-ricity	bio-fuels	**total**	heat	elect-ricity	bio-fuels	**total**	heat	elect-ricity	bio-fuels	**total**
Storyline 1	3692	1753	1219	**6664**	81368	114681	96781	**292830**	22,0	65,4	79,4	**43,9**
Storyline 2	3282	2124	492	**5898**	65005	98758	22508	**186271**	19,8	46,5	45,7	**31,6**
Storyline 3	2750	2016	556	**5322**	56880	77828	-147	**134561**	20,7	38,6	-0,3	**25,3**

The total amount of energy produced will also be lower though in the more environmental Storylines 2 and 3. This is encouraged by the possibility to let certain biofuel pathways count double for the 2020 renewable transport fuel target. This makes reaching the target more feasible, but also reduces the mitigation potential as less fossil energy is exchanged for renewables.

Table 6.13 *Total potential (PJ) from domestic agricultural, forest and waste sectors and import needs and average greenhouse gas emissions (kg CO2 eq/GJ) - when domestic electricity production is limited to NREAP demand only*

Domestic agriculture, forest, waste and imports	total (PJ)				total emissions (Kton CO_2 eq)				average emissions (kg CO_2 eq/GJ)			
	heat	elect-ricity	bio-fuels	**total**	heat	elect-ricity	bio-fuels	**total**	heat	elect-ricity	bio-fuels	**total**
Storyline 1	3692	831	1219	**5742**	81368	54362	96781	**232512**	22,0	65,4	79,4	**40,5**
Storyline 2	3282	948	492	**4722**	65005	38632	22508	**126145**	19, 8	40,8	45,7	**26,7**
Storyline 3	2750	940	556	**4245**	56880	32069	-147	**88801**	20,7	34,1	-0,3	**20,9**

In Table 6.13 the total emissions and average emission per GJ have also been calculated assuming only that part of the electricity potential that is needed to reach the NREAP target. This is possible as for this bioenergy potential an excess production can be expected by 2020 in all storylines (see Table 6.5). Limiting this amount would indeed lead to a better average greenhouse gas performance per GJ for the bioelectricity production in Storylines 2 and 3 (see Table 6.13 and compare with 6.12). However, this will at the same time lead to a lower amount of total greenhouse gas savings as compared to the fossil alternative as is shown in the next section.

To further analyse the best way to reach the NREAP targets it is interesting to compare the total mitigation potential per storyline. This can be assessed for the bioenergy mix based on domestic and imported biomass including the total potential produced in all three storylines (Table 6.14). But it can also be assessed by taking out the part of the excess domestic bioelectricity which was above the NREAP electricity target (Table 6.15).

The results show that the largest absolute gain in mitigation is reached in the stricter Storylines 2 and 3 and that these gains are largest in the heat and electricity sectors and lower in the transport sector. The latter is not surprising given the fact that the absolute contribution of biofuels to the NREAP targets in Storylines 2 and 3 is much smaller than in Storyline 1 because of double counting of a large part of total biofuel production (100% of biofuel production in Storyline 2 and 85% in Storyline 3).

Table 6.14 *Mitigation potential per storyline against the fossil comparator for total bioenergy potential*

Total: domestic agriculture, forest, waste and imports	Total emissions fossil equivalent (Mt CO_2eq)				Difference: gain in CO_2 mitigation (Mt CO_2eq)			
	heat	electricity	biofuels	**total**	heat	electricity	biofuels	**total**
Storyline 1	354	312	102	**768**	272	197	5	**475**
Storyline 2	314	378	41	**734**	249	279	19	**547**
Storyline 3	263	359	47	**669**	207	281	47	**534**

Table 6.15 *Mitigation potential per storyline against the fossil comparator for bioenergy potential - when domestic electricity production is limited to NREAP demand*

Total: domestic agriculture, forest, waste and imports	**Total emissions fossil equivalent (Mt CO_2eq)**				**Difference: gain in CO_2 mitigation (Mt CO_2eq)**			
	heat	electricity	biofuels	**total**	heat	electricity	biofuels	**total**
Storyline 1	354	148	102	**604**	272	94	5	**311**
Storyline 2	314	169	41	**524**	249	130	19	**338**
Storyline 3	263	167	47	**477**	207	135	47	**343**

The comparison of a situation in which the total bioelectricity potential is used (Table 6.14) and in which the total bioelectricity production is limited to the NREAP target (Table 6.15) shows that this leads to more than 50% reduction in mitigation gain for electricity. From this perspective it is therefore logical to encourage the optimal use of biomass. However, this is only based on a comparison with the fossil alternative. It is quite possible that other renewable energies for electricity production would yield an even higher mitigation gain. This is likely to be the case for renewables such as wind, photovoltaics and hydropower, among others. Such options would need to be investigated and compared carefully in order to put the right incentives in place to stimulate the most optimal renewable energy pathways.

Table 6.16 *Relative mitigation potential per storyline against the fossil comparator when total domestic bioenergy is used and imports are involved to reach the NREAP targets*

Total: domestic agriculture, forest, waste and imports	**Gain in CO_2 mitigation compared to fossil fuels (%)**			
	heat	electricity	biofuels	**total**
Storyline 1	77.0	63.2	5.3	**61.9**
Storyline 2	79.3	73.9	45.4	**74.6**
Storyline 3	78.4	78.3	100.3	**79.9**

To conclude: The analysis here shows that no environmental restrictions and no technological stimulation, as in Storyline 1 will still lead to a mitigation gain as compared to the fossil equivalent of 62% (Table 6.16). This gain is particularly reached through the bio-heat and electricity production and practically no contribution is obtained from the biofuel sector. In Storyline 2 this gain could be increased to 70% which is particularly caused by much higher mitigations reached with biofuels and electricity as compared to Storyline 1. Storyline 3 shows that stricter mitigation and wider environmental restrictions can even increase the mitigation gain by a further 10% as compared to Storyline 2 (Table 6.16). The contribution to this gain is by all sectors, but most significantly by the transport fuel sector.

7 Other environmental implications of energy cropping trends

7.1 Introduction

This chapter provides an overview of the environmental implications of the direct land use change effects of implementation of the three storyline situations in the EU-27. The environmental effects assessed involve effects on water quality and quantity, land based greenhouse gas emissions, soil and farmland birds. Detailed descriptions of the environmental impact assessments, including methodology, input data and analysis are provided in factsheets included in Annexes 16-20.

Before the detailed effects per environmental issue are discussed, an overview of the main variables is given in Table 7.1, explaining differences between storyline effects.

Table 7.1 *Main explaining variables for the three storylines*

	2004	Storyline 1	Storyline 2	Storyline 3
Area cropped (10^6 ha)	111	119	116	113
Of which:				
Perennial energy crops (10^6 ha)	*0*	*12*	*1*	*7*
Biofuel crops (10^6 ha)	*0*	*4.8*	*0*	*0*
Other crops (10^6 ha)	*111*	*102*	*105*	*106*
Area grassland (10^6 ha)	65	62	62	62
Area set-aside / fallow (10^6 ha)	10.6	7.8	9.7	12.2
Area abandoned (10^6 ha)	9.9	8.7	9.2	9.8
Livestock units (10^6)	162	158	158	158
Mineral fertilizer N input (Mton N)	11.21	11.06	11.11	11.15
Manure N input (Mton N)	8.04	7.62	7.62	7.62

In terms of land use it is clear that Storyline 3 has the smallest cropped area and the largest unused land area, i.e. set-aside/fallow and abandoned. In Storyline 1 perennial energy crops are cultivated in most regions of the EU, whereas in Storyline 2 and 3 there is relatively more in Eastern Europe. Furthermore, in Storyline 1 there is a larger area of land dedicated to either rotational biofuel crops or perennial crops, while in Storylines 2 and 3 arable crops dedicated to biofuel cropping are absent as they do not reach the stricter mitigation targets set in these storylines. Therefore the area of set-aside, fallow and abandoned land is larger in Storylines 2 and 3.

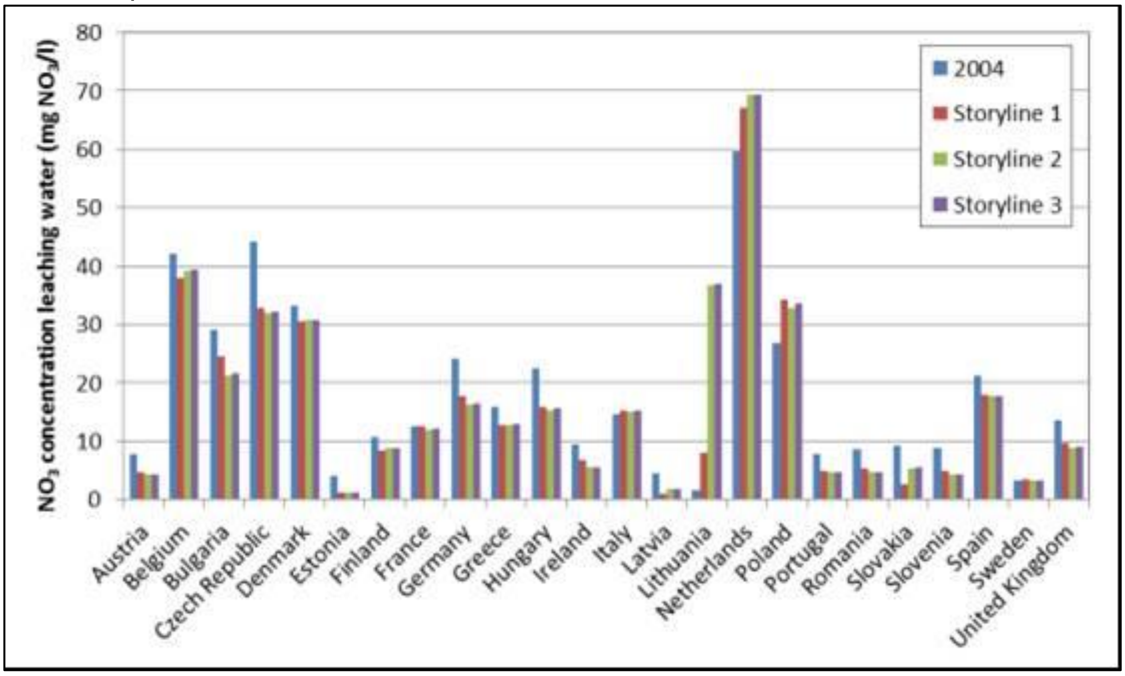
In the 2020 scenarios the number of livestock units is lower, especially the number of beef cattle is projected to decrease (-25%), whereas pig and poultry numbers will increase (11% and 16% respectively). However, the total manure input is lower for the 2020 scenarios, and also a small decrease in mineral fertilizer use is projected. Between the storylines, the manure input and the grassland area remains equal, since the number of livestock does not change between the storylines. The mineral fertilizer input does change, since in all three storylines a fixed amount of fertilizer per hectare is applied for each crop type. Thus, differences in cropping shares lead to different mineral fertilizer N inputs, since no fertilizer is applied on fallow and abandoned land and perennial energy crops have a lower fertilizer demand compared to rotational arable crops. Therefore, a decline in fertilizer input between 2004 and 2020 is seen in those regions where the storyline results in the smallest rotational arable area share.

7.2 Effects on water quality

The indicator for water quality chosen is the nitrate (NO_3) concentration in leaching water expressed in mg NO_3 per liter. It was selected because nitrate is the main pollutant of water from agriculture (Galloway *et al.*, 2003), and causing eutrophication in surface water and health risks for drinking water. The World Health Organisation (WHO) uses a maximum level of 50 mg NO_3 per liter as acceptable for drinking water. Nitrate contamination of water due to agriculture is caused by the use of fertilizer and manure application. A change in the use of these nutrients due to shifts in cropping and livestock patterns will have an impact on water quality. The shifts in cropping patterns caused by the production of biomass for bioenergy are therefore also expected to have an impact on nitrate concentration in leaching water. The indicator is calculated for 2004 (the available base year of CAPRI) and for the three storylines for 2020 as described in Chapter 5. What is assessed here is therefore the impact on water quality through setting different environmental constraints on the production of biomass for bioenergy for reaching the 2020 renewable energy targets.

The land use changes in Storyline 1 (Market first), Storyline 2 (Climate Focus) and Storyline 3 (Resource Efficiency) are the main input for the impact assessment with the MTERRA model as presented here. In all storylines, farm management is assumed to remain stable between now and 2020 and in all three storylines the same number of livestock is used. Thus, the storylines mainly differ in the crop distribution, and indirectly in fertilizer application. A detailed description of the approach, the input data used and the full assessment is presented in the water quality impact fact sheet presented in Annex 16.

Figure 7.1. *NO_3 concentration of leaching water per country for 2004 and the three 2020 storylines*



The assessment results show that changes in water quality are larger between 2004 and 2020 than between the three storylines, with overall lower NO_3 concentrations for most countries and higher for some other countries, e.g. Italy, Netherlands, Poland and Lithuania. The comparison of the storyline results in terms of changes in water quality between 2004 and 2020 shows that the different environmental criteria applied per storyline only lead to minor differences in nitrate concentration in leaching water at EU level. Differences between the storylines at national and regional level can be larger. At EU-27 level total nitrogen (N) leaching is generally lowest for Storyline 2, since this storyline has the largest area of grassy perennial energy crops at the expense of rotational arable cropping. These perennial energy crops have a lower fertilizer need and a better N uptake, which results in lower nutrient surpluses and less nitrate leaching. More regions in particularly France, Germany and some Central and Eastern European countries show a decline in nitrate concentration in Storylines 2 and 3 as compared to Storyline 1 (see Figure 7.1).

The differences between the three storylines by 2020 are small. The highest NO_3 concentration of the leaching water occurs for 15 EU-countries under Storyline 1, for six countries under Storyline 3 and for two countries under Storyline 2 (Figure 7.1). These differences can be explained by the different cropping shares for the storylines, especially the share and type of perennial energy crops. The N input for perennial energy crops is lower compared to rotational arable crops, but in Storyline 1 the area with rotational arable crops is the largest, which results in a higher N surplus and therefore higher leaching rate. Furthermore, in Storyline 1 most of the perennial energy crops are poplar and willow, whereas in Storyline 2 and 3 there is a larger contribution of miscanthus and switchgrass to the perennial mix. The latter have a more dense rooting system and a more efficient nutrient uptake.

7.3 Effects on water quantity

In recent years, there is a growing concern about water scarcity because the number of Member States that experience seasonal or long term droughts has increased over the years. In 2007 the Commission adopted a Communication on Water Scarcity and Droughts which identified an initial set of policy options to be taken at European, national and regional levels to address water scarcity within the EU. This set of proposed policies aims to move the EU towards a water-efficient and water-saving economy. One important factor in this context is future land use, which is crucial for mitigating water stress in the long run. Since bioenergy production could potentially have important future land use implications the effects on water consumption are further analysed here. The indicators included to analyse this effect are the absolute and relative level of water use for irrigation in bioenergy cropping between 2008 and 2020 in the three storyline situations.

The irrigation water requirement has been calculated as the total amount of water (in cm water layer per unit area) needed by a certain crop in addition to the rainfall for the realization of maximum potential yield. This maximum potential yield is defined as the maximum yield under prevailing weather conditions without any other growth constraints. In the absence of irrigation the maximum yield under rainfed conditions is determined by the amount of rainfall and its distribution over the growing season. This maximum water-limited yield is equal to the potential yield in the case of sufficient rainfall, and is lower than the potential yield in the case of drought. For the rotational arable crops used for bioenergy production both the potential and water-limited yield and the amount of water directly used by the crops for transpiration under potential conditions have been extracted from the data base of the Crop Growth Monitoring System (CGMS) of the MARS project of the Joint Research Centre (for further information see Annex 12). For the calculation of irrigation water needs and yields under rainfed and irrigated conditions of perennial biomass crops new model runs were done with the GWSI model as is described in Annex 12.

Once the per hectare irrigation water requirements per crop and NUTS region were calculated, these were multiplied by the total irrigated area every crop was estimated to use in every storyline situation. Whether a crop will be irrigated is also determined by the storyline assumptions. This multiplication resulted in total irrigation water requirements per NUTS-2 region per crop and for the total cropping area on which the assessment focuses.

The estimation of the irrigation share per rotational crop builds on the data from the JRC spatial database on water requirements for irrigation (Wriedt *et al.*, 2008). This baseline situation is used to extrapolate the 2004 to 2020 irrigation share per crop. It is assumed that the irrigation share per rotational crop per region in 2020 will be the same as in 2004 (provided by Wriedt *et al.*, 2008). For perennial crops the irrigation share depends on the storyline specifications, which determine the amount of perennials grown, the mix of perennials, and the type of land used. In Storyline 3 perennials cannot be grown with irrigation. So in this storyline irrigation water use for bioenergy crops will be absent, while in the other two storylines no measures are taken to limit irrigation water use in bioenergy cropping. It is therefore the impacts on irrigation water consumption of these two storyline specifications that is specifically assessed in this section.

The results show that irrigation water use in 2008 and also in 2020 in Storyline 1 (Market first) is modest while Storyline 2 shows by far the largest water use in 2020 (see Figure 1 in Annex 17). The reason for this is that in Storyline 2 there is by far the largest production of switchgrass and miscanthus in high yielding systems, which require additional irrigation if produced in the more arid parts of Europe, such as the whole Mediterranean and several regions in Central and Eastern Europe. In the Storyline 1 situation there is also a large area with perennials, but these are mostly willow and poplar as these produce more biomass per Euro invested, and these are normally not produced with irrigation. The largest irrigation water demand in Storyline 1 comes from the rotational arable biofuel crops which are mostly produced in Southwestern France, mostly maize and sunflower. The larger occurrence of switchgrass and miscanthus in Storyline 2, and also Storyline 3, is related to the higher efficiency in terms of kg biomass per hectare and also per GJ and thus in greenhouse gas mitigation per GJ. In Storyline 3 irrigation is not allowed which results in larger share of medium yielding perennials, provided they still reach the mitigation target of 50%. Therefore in this storyline there is no irrigation but this also implies a smaller perennial biomass potential and less efficient production per hectare in the more arid parts of the EU.

When total bioenergy irrigation water demand is related to the total irrigation water demand of a region, the largest shares are seen in Storyline 2 where many regions show that bioenergy crops would exploit 50% or even more than 100% of the irrigation water available. The reason behind these extreme shares is beside the large areas with miscanthus and switchgrass also that often these perennials are grown on land that is released from food and fodder production between 2003 and 2020 and was not under irrigation in 2003. This implies that most of the irrigation water needs for perennials come additional to the irrigation water demands for food and feed crops for which the irrigation water demand remains relatively stable between 2003 and 2020. An additional reason is also that most of the land releases and abandoned land stock coincides in the EU with more (summer) arid regions of the EU such as the Mediterranean and the eastern parts of central Europe.

Overall it becomes clear that irrigation water needs for biomass production may put large pressure on scarce water resources in regions of southern and central Europe if plantations with perennial biomass crops indeed start occuring at large scale on released agricultural lands. And this is likely to happen if incentives to create these plantations are only driven by greenhouse gas mitigation considerations, as is the case in Storyline 2. However, if these incentives of high mitigation requirements are accompanied by limitations on irrigation water use, this will limit the production of perennial biomass production in the very arid regions, but will still provide ample opportunities to produce large amounts of ligno-cellulosic biomass with high greenhouse gas mitigation potential, as is shown in Storyline 3. A purely market driven approach to reaching the 2020 bioenergy targets, Storyline 1, will generally not lead to large additional pressures on water resources in the EU, but will put pressure on other environmental issues, especially biodiversity as is shown in other environmental impact assessments included in this study (e.g. fact sheet on farmland bird impacts). Finally it should be mentioned that stimulation of perennial biomass plantations on released agricultural lands, may be efficient from a greenhouse gas saving perspective. However, this analysis shows that the objectives set under the Water Framework Directive may limit targeted perennial energy cropping in several European regions, particularly in France, Bulgaria, Hungary and Romania and even Germany.

7.4 Land-based direct GHG emissions from cropped biomass sources

To calculate the direct land based GHG emissions of cropped biomass the MITERRA Europe model was used. The model calculated a GHG balance which was defined as the sum of the nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2) emissions from agriculture and is expressed in kg CO_2-equivalents per hectare. The CO_2 emission is derived from the change in soil organic carbon stocks. N_2O emissions related to managed land use are linked to fertilizer and manure application, urine and dung during grazing, and drainage of organic soils, and will change when land use changes. In addition, CO_2 emissions due to land use change are caused by changes in soil carbon stocks. Only changes in soil organic carbon were considered, since changes in biomass carbon are zero for arable crops. When land is converted from one land use to another carbon can accumulate (carbon sequestration) or diminish (carbon emissions). Carbon stocks under land that is not subject to land use change or a change in land management are assumed to remain constant. The carbon module of MITERRA-Europe (Lesschen *et al.*, 2009) assesses changes in soil organic carbon (SOC) based on the default IPCC Tier1 approach (IPCC, 2006). Further details on the approach and calculation are provided in the fact sheet in Annex 18.

Changes in CH_4 emissions are not related to land use changes, but to changes in the livestock population and are therefore not directly related to cropped biomass production.

The GHG balance indicator is calculated for 2004 (the most recent base year of CAPRI) and for three storylines for 2020 as described in Chapter 5. For the conversion to CO_2-equivalents global warming potentials (GWP) from the 2007 IPCC report were used (see also fact sheet in Annex 18).

The results of the calculation of the land based GHG emissions show that changes in GHG emissions and soil organic carbon stock are larger between 2004 and 2020 than between the three 2020 storylines. The largest changes in the GHG emissions are caused by a decline in livestock, mainly cattle, between 2004 and 2020 with a related decrease in CH_4 emissions and are thus not related to changes in cropping patterns caused by increased demand for biomass. The influence of dedicated biomass cropping is on N_2O soil emission and results show that there are relatively small changes between the three storylines (see fact sheet in Annex 18, Table 1), although differences between storylines at regional scale can be larger (see fact sheet in Annex 18, Table 3 and Figure 1).

At an EU-27 scale Storyline 2 has slightly lower N_2O emissions. However, when looking at regional level the picture is less straight forward. The explanation for (slightly) lower N_2O soil emissions is related to the total cropped area and the perennial area share in it, which is generally larger in Storylines 1 and 2 than in Storyline 3.

For most countries a decrease or increase in SOC stocks of less than 5% is projected (see fact sheet in Annex 18; Figure 3) and this does not differ much between the storylines. For several regions an increase in SOC stocks of more than 5% is projected, these are mainly the regions were a large increase in perennial energy crops is projected (see fact sheet in Annex 18; Figure 1). The differences between the three storylines in terms of soil carbon stocks are rather small. Storyline 2 has the smallest area of rotational crops, which results in higher soil carbon stocks for most regions (Germany, France, Romania and Spain).

The overall conclusion of this assessment is that effects of increased biomass cropping on the land based GHG emissions in agriculture are rather limited under the assumptions adopted for each storyline. The estimated effects are positive from a carbon storage perspective where they lead to increases in perennial cropping area, especially if these take place at the expense of rotational crops.

7.5 Effects on soil

For the assessment of the effect of changes in cropping patterns caused by different implementations of the RED as elaborated in the three storylines, the risk indicator "potential erosion" was chosen. An estimate was made of the change in soil loss on agricultural land caused by changes in cropping patterns between 2004 and 2020 in 3 storyline situations. For this assessment, the JRC-PESERA data layer (Soil Erosion Risk Assessment in Europe, see van der Knijff *et al.*, 2000) which provides the erosion estimates calculated by applying the well-known Universal Soil Loss Equation (USLE, see Wischmeier & Smith, 1978). The equation is designed to estimate long-term annual erosion rates on agricultural fields. In the JRC-PESERA map, the potential erosion risk was run applying the USLE model assuming "that there is a total absence of soil cover (i.e. $C = 1$)". For the purpose of this impact assessment for the different storylines, the specific C (Cover factor) had to be calculated. This was done by combining the NUTS-2 information on cropping areas per crop in 2004 and per storyline in 2020 with C factors for these specific crops as found in literature (see fact sheet soil quality in Annex 19). The C factors were collected from published literature, mainly from FAO sources. Once all C factors were identified per cropping type and area share it enabled the calculation of a weighted average C factor per region (see fact sheet in Annex 19). Changes in this C-factor between 2004 and 2020 for the three storylines could then be calculated. These C-factor values give an indication of the sensitivity to erosion. In order to calculate the real changes in erosion between 2004 and 2020 first an overlay was made with the arable land grids (see fact sheet in Annex 19) the combined parameters per grid were then used as input in the USLE formula to calculate final erosion levels for 2020 for the three specific storylines and for 2004. The changes between 2004 and 2020 for every storyline could then be derived (see fact sheet Annex 19, Figure 3).

The results of the assessment show that overall changes in soil erosion between 2004 and 2020 will be positive in practically all regions of the EU. Most of the changes are small and range between -0.02 to 0 ton/ha/year. Some exceptions to these positive declines are found in the south of Europe, particularly in Italy (Lombardia, Liguria, Toscana, Lazio, Calabria), France (Corsica) and Portugal (Algarve). The way the RED targets are implemented in relation to sustainability criteria in the three storylines only have a limited influence on this pattern. Overall the regions with increase in perennial cropping, particularly where this goes together with declines in row crops show a positive pattern towards (small) declines in soil erosion (see fact sheet in Annex 19, Figure 3). The importance of the introduction of dedicated cropping with perennials to prevent erosion is further emphasized as in Storyline 3 there are more limits set on the increase on this activity and this leads in 5 regions in the south to a worse performance in erosion change then in Storylines 1 and 2. The explanation is related to the fact that the dedicated perennial cropping area is generally smaller in Storyline 3, particularly in the southern regions of Europe. Where a large land release in agriculture between 2004 and 2020 goes together with an increase in dedicated cropping, the erosion goes down, as perennial crops provide good soil coverage all year round. But in Storyline 3 there are limits set on use of irrigation in dedicated cropping, making it more complicated to grow perennials on lower quality lands that reach a mitigation level of 50%. The area coverage with perennials is therefore lower in Storyline 3 then in Storylines 1 and 2 and if this coincides with regions with large land releases and high sensitivity to erosion it leads to an increase in erosion.

The overall conclusion as to the soil erosion effect between the storylines investigated here is that the way RED targets are met in terms of environmental criteria practically do not influence erosion. Where energy cropping leads to a larger coverage by perennial crops at the expense of rotational or row crops erosion will generally decline. This is particular relevant in regions that already suffer from high erosion soil loss like regions in central Italy and Greece, the Southwest of France and Portugal and several regions in Spain (see fact sheet in Annex 19, Figure 4).

7.6 Effects on farmland birds

For the assessment of different implementations of the RED targets in the three storylines, the indicator "status of a farmland bird assemblage" was used. This indicator is based on the one side on the species and their threat levels, their landscape and habitat type dependence and on the other side on the land use composition present in the farmland. It is assessed how the status of a farmland bird assemblage is affected by changes in cropping patterns occurring in the three storyline situations.

In order to assess the farmland bird assemblage score for 2004 and for 2020 in every storyline situation several steps are taken which are more extensively described in the impact fact sheet for farmland birds in Annex 20. First a farmland bird species pool was selected which was derived from four sources and for these the following characteristics were scored:

1) **Threat level** (1 = low threat to 4 = very high threat)

2) **Agricultural landscape association** (from 0 = loose association to 3 =very strong association as species spend most of their life in the agricultural landscape)

3) **Habitat association** of the species to a particular habitat type in the landscape mosaic. Four habitat types were distinguished: fallows (including set-asides), (intensively used) arable fields, perennials and recently abandoned fields. Scores from 0 (= habitat is avoided) to 3 (= habitat type is indispensable for the species) were assigned.

4) The combination of 1) 2) and 3) results in a threat weighted **habitat dependence score** per species per region and per type of habitat.

5) From 4) for each habitat type and NUTS region, a **regional assemblage score** is then calculated for all birds species included in the assemblage for the region.

6) Finally a **final status** score is calculated per NUTS region by adding the regional assemblage scores but weighting them according to the area proportion of the habitat type they refer to.

The final status score was calculated for the 2004 situation and for the 2020 situation of the three storylines. Flow statistics for the difference between the 2004 and the 2020 situation could then be calculated to assess the effect of the different sustainability criteria implemented for reaching the RED targets in the three storylines.

The results show that between 2004 and 2020, substantial changes will occur in farmland bird diversity in many EU regions. The way these changes are distributed differs clearly between the three storylines. Large biodiversity losses can be expected in regions in Bulgaria, Romania, Portugal, Spain Hungary and Greece and, in particular for Storyline 1, large losses are also projected for regions in Poland and Italy. Under Storyline 2, farmland biodiversity gains are predicted for regions in Sweden, Austria and the Czech Republic. In Finland, France, Greece and Italy, farmland biodiversity will benefit in some regions and be reduced pronouncedly in other regions. For many regions, the results differ largely between the storylines, with Storyline 3 (Resource Efficiency) usually yielding a much better farmland bird score than the other two storylines (Market First, Climate Focus, see fact sheet in Annex 20, Figures 4).

Aggregated across Europe, in Storyline 1 Market First the total EU-27 farmland bird score compared to 2004 will be reduced by 839 points. Storyline 2 Climate Focus will show a decline of 447 points and Storyline 3 will in total lead to a small increase of 70 (see fact sheet in Annex 20, Table 1). Important in a species conservation perspective is also the regional distribution of the change in score and it is clear that in Storyline 3 the large majority of the regions show an improvement. In Storyline 1 there are clearly more regions showing a decline then an increase in farmland bird score and Storyline 2 takes a middle position.

Metapopulation theory suggests that a habitat spread too thinly across a country might be of low value for the conservation of species, since extinction events in one habitat patch may no longer be compensated by re-colonisation once patches get too far apart. We thus analysed the behaviour of our modelling system by introducing a threshold of habitat proportion, below which the landscape composition is no longer suitable for a species assemblage. Introducing such a threshold does not change the ranking of storylines (3 better than 2004 better than 2 better than 1), but enlarges the differences between the storyline scores, if the threshold is selected to lie between 0 and 7% of the utilised agricultural area.

Overall it can be concluded that an unfettered development of bioenergy will lead to farmland bird losses in a majority of EU regions, but also on average across Europe. A focus on bioenergy production with perennials (Storyline 2, Climate Focus) will do considerably better, but still leads to overall farmland bird losses. However, Storyline 3 shows that biodiversity losses are not an inevitable consequence of bioenergy production. Under the Resource Efficiency concept, farmland bird biodiversity might even slightly improve on average across Europe, although some of the regions may still experience local losses compared to 2004.

7.7 Integration

From the impact assessments above one can conclude that an integration of the results is necessary before deciding which storyline performs best from an environmental perspective. A summary of results per storyline is given in table 7.2.

All impact assessments showed that results differed per region as they are a result of a combination of factors, including local environmental circumstances. But overall results did deliver dominant directions of impacts from which an EU average could be derived.

Table 7.2 *Average evaluation of environmental performance per environmental impact field per storyline*

	Storyline 1	Storyline 2	Storyline 3
Water quality (mg NO_3 per liter of leaching water)	+/-	+	+/-
Land based direct GHG emissions (N_2O emissions and changes in SOC)	+/-	+	+/-
Water quantity (Irrigation water use)	-	--	[no change]
Soil erosion	-	+	+/-
Farmland bird diversity	--	-	+

The smallest impacts of the bioenergy land use changes were assessed for the GHG and the water quality indicators. Overall it was seen that larger differences in these indicators occurred between 2004 and 2020 than between the three 2020 Storylines. This implies that the market and CAP reform changes have had a larger impact on these indicators than the way and total take up of bioenergy cropping. In spite of this the assessments did show that large production of biomass through perennial biomass cropping taking the place of rotational crops leads to an overall reduction in Nitrate leaching to water and this is why Storyline 2 will have an overall positive effect on water quality. The same applies to the effect of GHG emissions. In Storyline 2 there is a larger area of perennials and a relatively smaller area with rotational biomass crops as compared to the other two storylines and this results in smaller releases of N_2O (through lower fertilizer inputs and mechanization) and better fixation of Soil Organic Carbon (SOC) than in the other two storylines. Differences are however relatively small also at regional scales.

Much larger differences in impacts between the storylines occur in relation to the other environmental issues. Particularly the effect on sustainable water use and farmland birds can be very different. It is Storyline 2 that performs worst of all on water use and modest on farmland birds. Storyline 1 impacts negatively on farmland birds and soil erosion, but has only limited negative impact on water use. Storyline 3 does by far the best on farmland birds, and it has no effect at all on water use, as no-irrigation in bioenergy cropping is an inherent characteristic of the storyline assumptions. Storyline 3 impacts on soil erosion are neutral and on the other indicators it performs as modest as Storyline 1. The reason for Storyline 3 performing modestly is however not caused by a large area coverage with rotational arable crops for biofuel purposes, like is the case in Storyline 1, but by almost the same area coverage but then with arable crops for food and feed purposes. After all, in Storyline 3, it is expected that if no biofuel feedstock can be produced (because the mitigation target of 50% is not reached by the biofuel crop, nor by an alternative perennial for electricity or heat conversion) the rotational arable crop area will still remain the same, but the use of it when it enters the market will be different. In Storyline 2 this also applies, but it is more likely that part of the biofuel crop area is used for perennial cropping for conversion into heat or electricity because only biofuels need to reach the 50% mitigation target in this storyline. This therefore results in a higher perennial area share at the expense of rotational crops and this particularly leads to a better performance on nitrate and GHG emissions and soil erosion.

Very convincing is the much better performance of Storyline 3 on farmland bird impacts. It shows indeed that biodiversity losses are not an inevitable consequence of bioenergy production provided dedicated cropping of biofuel crops is avoided and perennial plantations do not diminish valuable farmland habitats like fallow. The fact that regional effects on farmland bird diversity also turn out negatively in some regions in Storyline 3 further shows that large scale perennial plantations are also undesirable in certain landscapes which indicates the need of careful planning of these sites taking account of local farmland biodiversity.

In conclusion, but not unexpectedly, it has been confirmed that Storylines 2 and 3 have a clearly better overall performance on environment. A purely market driven approach, as in Storyline 1, will not necessarily lead to larger land based emissions of GHG or nitrates or loss of SOC (under the assumptions made), but will particularly increase erosion and loss of farmland birds in Europe (not even considering the emission of GHG outside the EU through direct and indirect land use change effects).

The results also show that policy intervention entirely driven by GHG mitigation targets for biofuels only, as in Storyline 2, does not secure a fully environmentally compatible European bioenergy production either. This will come at the expense of unsustainable water abstraction and further loss of farmland bird diversity in many EU regions. An environmentally-oriented bioenergy production seems to be best secured by the package of measures belonging to Storyline 3. Emissions to air and water directly coming from European bioenergy crops will be lowest, loss of SOC and erosion limited, water resources will not be affected by additional irrigation requirements and conservation of the farmland bird population is best ensured.

In Chapter 6 it has already been shown that the total GHG performance of Storyline 3 is also better than in Storylines 1 and 2, but results in this chapter show that this is not caused by lower direct land based emissions and fixation of SOC in domestic energy crop production. It is the combination of all environmental requirements together also those related to higher efficiency in the downstream part of all bioenergy products, including that of imports, that ensures the best performance. However, it is also likely that all these requirements together lead to higher overall production costs.

8 Sensitivity analysis regarding ILUC and other limitations

8.1 Introduction

This chapter discusses the role of the size of the indirect land use change factor for the overall analysis of this report. As discussed in Chapter 2 many studies have estimated the level of indirect land use change related greenhouse gas emissions per feedstock type. For the calculations of the storyline results presented in previous chapters conservative median indirect land use change factors were taken into account. This chapter discusses the effects of realisation of the NREAP targets in the three storyline situations on final energy potential and related greenhouse gas emissions and mitigations when lower indirect land use change-greenhouse gas emissions are assumed. The effects are presented in terms of domestic potentials and greenhouse gas emission and mitigation levels.

Table 8.1 *ILUC-GHG emissions per crop (gr. CO2eq/MJ bioenergy) based on the review of studies used in the assessment of storylines in this report and from the ATLASS (Laborde, 2011) study*

Type of biofuel	ILUC values used in this study derived from inventory of studies reported in Chapter 2	Average ILUC emissions from ATLASS (2011)	% ATLASS of median ILUC in Chapter 2
Rapeseed	77	55	71%
Wheat	73	14	19%
Sugar beet	85	7	8%
Palm oil	77	54	70%
Soybean (from Latin America)*	140	56	40%
Soybean (from US)*	65	56	86%
Sugar cane	60	15	25%
Grain maize	60	10	17%
Ligno-cellulosic based land using 2nd generation ethanol**	52	15	29%
Ligno-cellulosic based land using 2nd generation biodiesel**	52	15	29%

*Atlass (Laborde, 2011) does not distinguish between the two biofuels.
**In this study this refers only to the 2nd generation biofuels produced from dedicated crops. The figure mentioned in the column for the ATLASS study includes a much wider range of ligno-cellulosic feedstock, including waste, which is probably one of the reasons for its lower ILUC factor. This emission factor was actually not a result of the IFPRI-MIRAGE model application but was a factor reported in the EC Impact Assessment (Commission staff working document, SEC (2011f)).

In the impact assessment on indirect land use change related to biofuels[40] ILUC factors are used from the IFPRI-MIRAGE-BioF model assessed in the ATLASS project[41] (Laborde, 2011). The estimates of this ATLASS study are lower and for some crops even considerably lower than the median values for indirect land use change emissions derived from a review of recent studies on indirect land use change analysed in Chapter 2 of this report (see Table 8.1). These median values were also used for the assessments of the mitigation impacts of the three storylines central to this study. The analysis in this chapter therefore focusses on a recalculation of the three storyline results using the lower indirect land use change factors derived from the ATLASS study (Laborde, 2011).

Crop specific indirect land use change factors used in this report and the IFPRI-MIRAGE-BioF based ATLASS study are given in Table 8.1. It becomes clear that the ATLASS 2011 study arrives at substantially lower indirect land use change emissions estimates related to starch and sugar crops used for the production of bioethanol, while for oil crops the ATLASS indirect land use change related greenhouse gas emissions are only somewhat lower, with the exception of Latin American soya.

8.2 Influence of lower ILUC GHG emissions on final energy potential

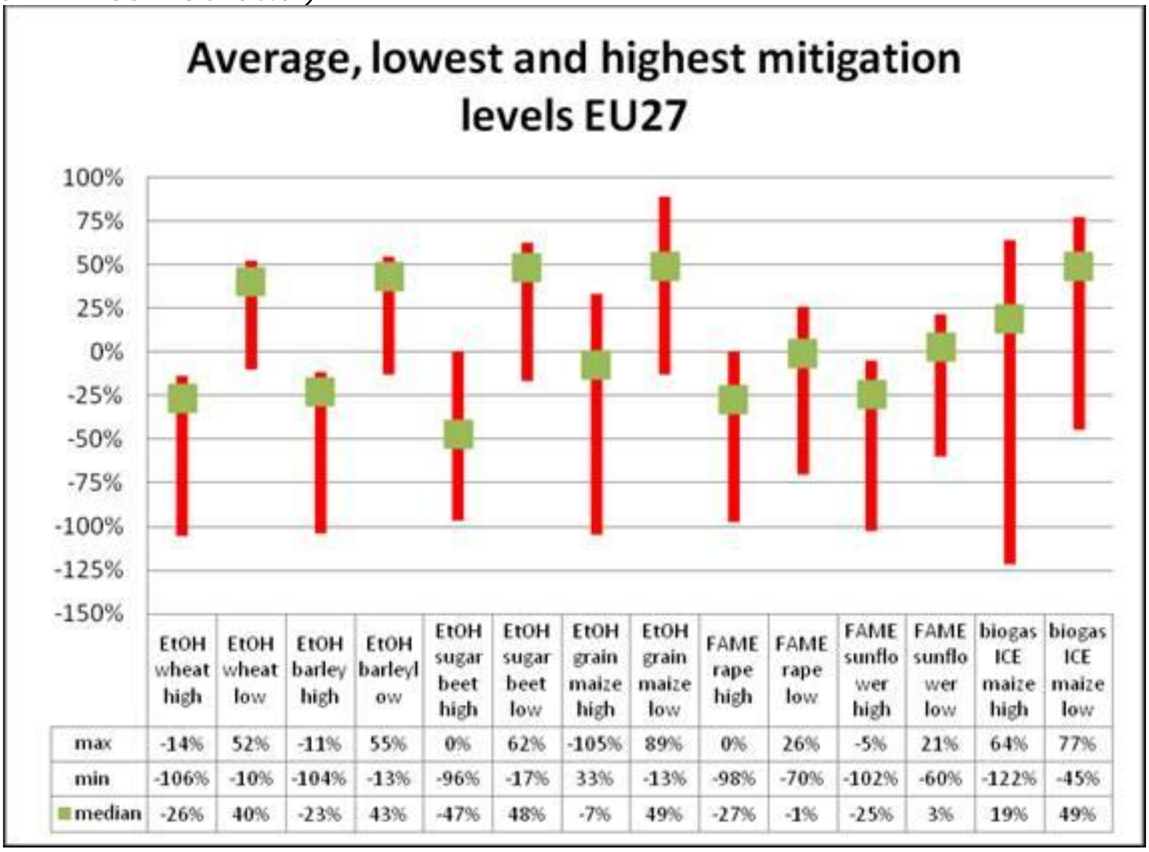
In order to assess the effect of the lower indirect land use change - greenhouse gas emission factors on the final domestic agricultural biomass potential and mitigation effect the assessment in all three storylines is re-run taking the ATLASS 2011 indirect land use change emission factors into account.

Figure 8.1 provides an overview of the well-to-wheel greenhouse gas mitigation potential for biofuels and for biogas based on maize as compared to fossil fuels, taking account of the high and low indirect land use change factors from Table 8.1 and the variation in land based emissions in the different EU-27 regions. It shows that when high (conservative) indirect land use change values are assumed, as was done in the calculations for Storylines 2 and 3, it is only possible at median levels to mitigate greenhouse gas for biogas pathways based on maize. But only in the most efficient maize production areas (with very high yields per hectare) of the EU can one reach more than 50% mitigation for biogas based on maize in regions. For many pathways the median greenhouse gas mitigation level does not even become positive.

40 Commission staff working document, SEC (2011f)

41 The ILUC factors calculated are the result of a combination of the IFPRI-MIRAGE-BioF model with Monte Carlo simulation which was performed in the ATLASS project in order to assess the ILUC emission uncertainties.

Figure 8.1 *Variation in well-to-wheel mitigation potential per 1st generation biofuel and biogas pathway based on rotational arable crops from the EU-27* (based on ATLASS ILUC factor)*



	EtOH wheat high	EtOH wheat low	EtOH barley high	EtOH barleylow	EtOH sugar beet high	EtOH sugar beet low	EtOH grain maize high	EtOH grain maize low	FAME rape high	FAME rape low	FAME sunflower high	FAME sunflower low	biogas ICE maize high	biogas ICE maize low
max	-14%	52%	-11%	55%	0%	62%	-105%	89%	0%	26%	-5%	21%	64%	77%
min	-106%	-10%	-104%	-13%	-96%	-17%	33%	-13%	-98%	-70%	-102%	-60%	-122%	-45%
median	-26%	40%	-23%	43%	-47%	48%	-7%	49%	-27%	-1%	-25%	3%	19%	49%

Note: positive values mean a GHG mitigation compared to the fossil fuel reference, negative values imply the opposite.

Analysis of the mitigation levels calculated with the much lower ILUC levels of the ATLASS study shows that it is still very difficult to reach a 50% mitigation level. The average mitigation levels for the starch and sugar crops (e.g. cereals, sugar beet and grain maize) are just below the 50% threshold specified in the RED. A look at the maximum levels shows, however, that the regions with high yields are able to produce within the RED minimum GHG saving threshold of 50%. This applies only to the ethanol and biogas pathways particularly based on grain maize and sugar beet as well as to silage maize for biogas[42]. The biodiesel pathways do not reach the RED mitigation level of 50%, not even in regions where land based emissions are low (see Figure 8.1).

Analysis in previous chapters assumed that in Storylines 2 and 3 all biofuel demand from domestic feedstock would be satisfied with domestic BtL from perennials and straw-based bioethanol and biogas converted to green biogas-to-liquid transport fuel. All these biofuel types count double to the NREAP targets and therefore the domestic production was enough in Storyline 2 and no imports of biofuels were required. In Storyline 3 only a limited amount of biofuels had to be imported, which were either based on used fats and oils, or were produced from biomass produced on degraded land.

[42] Note that the current RED sustainability criteria only apply to biofuel pathways and maize to biogas is thus not covered by the criteria.

In order to translate the new mitigation potentials into final potentials we again build on the agricultural outlook 2020 based on the CAPRI baseline run used for the EC study 'Prospects for agricultural markets and income in the EU 2010-2020' (see Box 5.1, Chapter 5). This CAPRI run was also used to estimate the 2020 potential in Storyline 1 Market First. However, in this CAPRI run no attention was paid to minimal mitigation requirements as these were not implemented in the Storyline 1 situation. The assumption for the sensitivity run for Storylines 2 and 3 is now that the same bioethanol targets are reached as set in the CAPRI baseline situation as these are based on the domestic targets specified in the NREAPs. However, the mix of biofuels incorporated comply with the minimal mitigation target of 50%. The contribution of every region to the final EU-27 bioethanol production is the result of a weighted contribution which is determined by two factors:

1) The total (CAPRI-baseline) area share in 2020 of crops reaching the 2020 mitigation target.

2) The production of bioethanol crops in 2008: areas which were not producing any bioethanol crops in 2008 are not expected to contribute significantly to the 2020 share.

The resulting bioethanol production and related GHG emissions per region in the three storylines is given in Table 8.2 for the original storyline calculations applying the conservative (high) and the lower (ATLASS study) ILUC factors.

Table 8.2 *Biofuel production and related GHG emissions in three storylines applying conservative (high) and low (ATLASS) ILUC factors*

	total(PJ)				**total emissions (Kton CO2 eq.)**			
	High ILUC		Low ILUC		High ILUC		Low ILUC	
	Bio-ethanol	Bio-diesel	Bio-ethanol	Bio-diesel	Bio-ethanol	Bio-diesel	Bio-ethanol	Bio-diesel
Storyline 1	136	170	136	170	14907	19384	7284	15239
Storyline 2	492	0	626	0	22507	0	28539	0
Storyline 3	392	0	528	0	3271	0	8441	0

For Storyline 1 there is no change in the total potential as mitigation levels of 50% do not apply in this storyline. However, the total emissions do change because of considerable lower ILUC factors from the ATLASS study. For bioethanol emissions this even declines by 50%.

In Storylines 2 and 3 domestic 1st generation bioethanol production becomes possible at lower ILUC factors. This also leads to higher total GHG emissions for domestic biofuels in both storylines (see Table 8.2). The reason that under the high ILUC factors the total GHG emissions related to domestic biofuels are so much lower in Storyline 3 as compared to Storyline 2 is because the share of crop-based 2nd generation biofuels is much lower in Storyline 3 which consists mainly of straw based ligno-ethanol. In Storyline 2 in addition to the same straw potential there is also room for more ligno-ethanol production from perennials, while these perennials go mostly in heat and electricity production in Storyline 3.

Table 8.3 *Changes in potential coming from domestic agricultural biomass and related GHG emissions applying conservative (high) and ATLASS (low) ILUC factors*

Results domestic agricultural potential	total (PJ)				total emissions (Kton CO2 eq.)				average emissions (kg CO2 eq./GJ)			
	heat	**electricit**	**biofuels**	**total**	**heat**	**electricit**	**biofuels**	**total**	**heat**	**electricit**	**biofuels**	**total**
Storyline 1 High	339	1146	725	2210	2231	14985	40778	57994	6.6	13.1	56.3	26.2
Storyline 1 Low	339	1146	725	2210	2231	14985	29009	46225	6.6	13.1	40.0	20.9
Storyline 2 High	362	1504	492	2358	3934	29338	22508	55780	10.9	19.5	45.7	23.7
Storyline 2 Low	362	1376	674	2412	3934	25612	28539	58085	10.9	18.6	42.4	24.1
Storyline 3 High	524	1440	392	2355	6417	33436	3272	43126	12.2	23.2	8.4	18.3
Storyline 3 Low	524	1263	528	2315	6417	25804	8442	40663	12.2	20.4	16.0	17.6

The decline in bioelectricity is related to the decline in land availability for dedicated cropping because of a higher bioethanol crop production. In the original storyline situation with high ILUC factors land not suitable for biofuels could still be used for cropping of perennials for bioelectricity and heat provided they comply with the minimal environmental constraints. The loss of this land resource to bioethanol leads in both Storylines 2 and 3 to a decline in the bioelectricity potential because this is the pathway that is less efficient, while the heat production remains more constant as it is a more efficient pathway with higher mitigation potential. In terms of GHG emissions it becomes clear that emissions in Storylines 2 and 3 go up under lower ILUC factors for biofuels, while they go down for electricity. For Storyline 2 this leads to a small net increase increase in emissions from domestic agricultural biofuels, while in Storyline 3 there is a small net decline in emissions.

The question now is what it will do to the total emissions and mitigation potential of the NREAP targets. This requires the involvement of all bioenergy potential required for reaching these targets including those from domestic forest and waste sectors and from imports. As for the forest and waste sectors, changes in ILUC factors do not change anything. The potentials from these two sectors remain the same as for the original storyline situations. For imports the situation does change, however, since higher domestic production of biofuels leads to lower import requirements. How this exactly works out is presented in Table 8.4.

Table 8.4 *Changes in potential coming from domestic and imported biomass/bioenergy sources and related GHG emissions applying conservative (high) and ATLASS (low) ILUC factors*

Domestic agriculture, forest, waste and imports	total (PJ)				total emissions (Kton CO2 eq.)				average emissions (kg CO2 eq./GJ)			
	heat	electricity	biofuels	total	heat	electricity	biofuels	total	heat	electricity	biofuels	total
Storyline 1 High	3692	1753	1219	6664	81368	114681	96781	292830	22.0	65.4	79.4	43.9
Storyline 1 Low	3692	1753	1219	6664	81368	114681	68207	264256	22.0	65.4	55.9	39.7
Storyline 2 High	3282	2124	492	5898	92604	98758	22508	213869	28.2	46.5	45.7	36.3
Storyline 2 Low	3282	1997	674	5952	92604	95032	28539	216174	28.2	47.6	42.4	36.3
Storyline 3 High	2750	2016	556	5322	56880	77828	-147	134561	20.7	38.6	-0.3	25.3
Storyline 3 Low	2750	1840	677	5267	56880	70196	4911	131986	20.7	38.1	7.3	25.1

It becomes clear that in Storyline 1 the emissions for reaching the NREAPs decrease considerably as can be expected when applying lower ILUC emission levels. This does not lead to any shift in imported and domestically produced biomass, however. In Storylines 2 and 3 the higher contribution of domestic bioethanol production decreases the demand for imports for biofuels. Net biofuel emissions go up however. This is because the share of 1st generation biofuels with relatively high LUC emissions in the total biofuel mix increases at the expense of biofuel sources that count double (e.g. Biogas-to-liquids and imported waste based biofuels and biofuels from biomass produced on degraded lands). Particularly in Storyline 3 this leads to a considerable increase in biofuel related emissions.

However, this increase in emissions on the biofuel side is compensated for by the decline in bioelectricity from domestic sources. This decline does not need to be compensated for by higher imports, since the bioelectricity potential from domestic sources exceeds by far the NREAP requirements. The overall conclusion can therefore be that lower ILUC factors encourage the production of 1st generation bioethanol from domestic sources and also lower the need for imported biofuels. At the same time it will also discourage the production of 2nd generation and waste-based biofuels.

8.3 Influence of lower ILUC GHG emissions on final mitigation potential

The last question to be answered here is whether lower ILUC factors lead to lower or higher net mitigation of GHG emissions. Table 8.5 provides an answer to this question.

Table 8.5 *Net mitigation of GHG at high and low ILUC factors in the 3 storylines*

Total: domestic agriculture, forest, waste and imports	Total emissions fossil (Mton CO2 eq.)				Difference: gain in CO2 mitigation (Mton CO2 eq.)			
	heat	electricity	biofuels	**total**	heat	electricity	biofuels	**total**
Storyline 1 High	354	312	102	**768**	272	197	5	**475**
Storyline 1 Low	354	312	102	**768**	272	197	34	**504**
Storyline 2 High	314	378	41	**734**	222	279	19	**520**
Storyline 2 Low	314	355	56	**726**	222	260	28	**510**
Storyline 3 High	263	359	47	**669**	207	281	47	**534**
Storyline 3 Low	263	328	57	**648**	207	257	52	**516**

Lower ILUC factors lead to a slightly lower mitigation gain in Storylines 2 and 3 and not surprisingly to a much higher gain in Storyline 1. Would one however make this comparison only within the limits of what is precisely required by the NREAPs, so excluding the excess bioelectricity, the difference in mitigation potential between the original storylines with high ILUC factors and the alternative with low ILUC factors becomes larger in Storylines 2 and 3 (see Table 8.6). The reason for this is that it encourages production of 1st generation bioethanol at the expense of more efficient biofuel pathways, which are no longer compensated for by emission mitigations in the bioelectricity sector.

Table 8.6 *Net mitigation of GHG at high and low ILUC factors in the three storylines when limiting the potential to the maximum NREAP demand for electricity*

Total: domestic agriculture, forest, waste and imports	Total emissions fossil (Mton CO2 eq.)				Difference: gain in CO2 mitigation (Mton CO2 eq.)			
	heat	electricity	biofuels	**total**	heat	electricity	biofuels	**total**
Storyline 1 High	354	148	102	**604**	272	94	5	**311**
Storyline 1 Low	354	148	102	**604**	272	94	34	**339**
Storyline 2 High	314	169	41	**524**	222	130	19	**311**
Storyline 2 Low	314	133	56	**504**	222	100	28	**288**
Storyline 3 High	263	167	47	**477**	207	135	47	**343**
Storyline 3 Low	263	136	57	**456**	207	111	52	**324**

In conclusion it becomes clear that the application of lower ILUC factors in the storyline calculations allows for higher domestic biofuel production and thus leads to lower imports of biofuels in the modelling framework adopted for this study. Consequently, the use of lower ILUC factors results in a larger land demand domestically for the production of rotational crops. This will increase the risk for adverse effects on soil (erosion risk), water quality (more nitrogen emissions to water) and biodiversity (risk for loss of farmland birds). The effects on irrigation water demand will not be larger, however, than when more biofuels are based on dedicated perennial crops as these latter present a risk of increasing irrigation water demand.

Nevertheless, the relative GHG efficiency of the different bioenergy pathways and technologies included in this study is not affected. The same order of GHG saving potential applies. The mitigation gains remain lowest for reaching the biofuel targets in the Storyline 1 situation while the heat targets have the largest mitigation contribution. The overall implications of this study for a more resource efficient use of biomass for energy do not come into question by applying the sensitivity analysis set out above.

8.4 Analytical limitations

Most, if not all, attempts at integrated analysis, of which the present study is one example, fall short in the eyes of users or specific expert communities in one way or the other. This can be due to the analytical boundaries employed but often also has origins in the limitations brought about by imperfect input data. This section briefly describes the shortcomings of this study (as perceived by its authors). In doing so it groups the listed limitations in two groups: those linked to the analytical framework adopted and those that derive from the limitations of the available modelling tools and input data sets.

8.4.1 Choices regarding the analytical framework

- Utilisation of biomass in different end uses: This study has only looked at the use of biomass for energy purposes. In this context it needs to be noted that the emerging discussion on a bio-economy — as part of the broader green economy paradigm (EEA, 2012; UNEP, 2012) — goes well beyond bioenergy. The bio-economy concept encompasses, inter alia, new biomaterials such as biopolymers, the use of biomass as construction materials and for fibres and textiles etc. Technological innovation should lead to bio-refineries which promise more resource-efficient, low-waste conversion of biomass for multiple uses (IEA BioT42, 2012). These uses of biomass generally also replace materials that are sourced from fossil fuel and hence provide alternative carbon saving options. Such a comparison is a very complex analytical task, however, and was therefore not tackled.

- Other options for increasing resource efficiency: an example of such options is the cascading-use concept which foresees biomass to be utilised for various functions throughout its lifecycle. These developments all require a broader view on biomass in a cross-sectoral way, requiring even more complex analysis of reference systems, trade implications, and the dynamic of market interactions as well as demand-side responses.

- Reflections on changing consumption patterns: In the context of an ever increasing demand of human society for energy and materials around the globe improving the efficiency of resource use alone will not bring total demand below sustainable levels of extraction or utilisation. Decreasing total demand via changing consumption and life style patterns therefore needs to be part of an integrated approach to resource management (EEA, 2012).

- Indirect effects and carbon balances linked to forest biomass: Various types of biomass, including from forest sources, are already traded widely across the world. This implies that indirect effects on intensity of forest utilisation globally can be expected from an increasing use of European forests for bioenergy production. Linked to that effect is also the question of potential 'carbon debts' due to the delayed carbon re-stocking in forests after utilisation of forest biomass for energy purposes. Both questions could not be tackled with quantitative analysis even though the carbon debt issue is reviewed in a qualitative manner (see section 2.5).

8.4.2 Limitations of available modelling tools and input data

- Time horizon: The timeline used for the current study only extends to 2020 compared to 2030 in previous studies. This is due to the fact that key modelling approaches used in the current study only allow projections to 2020. This period also corresponds with the timeframe of the NREAPs.

- Estimation of costs of available biomass: The potentials estimated for forest and waste biomass for 2020 were derived from the EEA 2006-2007 studies. However, their deployment for reaching the NREAP bioenergy consumption targets depends on the maximum price they can be expected to command in 2020. Input data on the cost of current biomass volumes in different EU Member States are very difficult to obtain, hence the cost assumptions for 2020 carry substantial uncertainty.

- Biomass transport logistics: as biomass is generally a very bulky feedstock with low energy density the logistics for collecting and transporting biomass volumes are often resource-intensive. No resources were available for reviewing how associated technology and logistics chains are likely to develop by 2020. Consequently, the estimation of available biomass volumes from agriculture, forest and waste resources may be over-optimistic.

- Progress in biomass conversion technology: the industrial-scale development and roll-out of 2nd generation conversion technologies (e.g. biomass-to-liquid or Fischer-Tropsch processes) is difficult to predict and actual deployment has regularly lagged behind announcements from the bioenergy industry. The estimated share of such technologies in this study probably lies on the optimistic side but any such predictions are prone to substantial potential error.

9 Conclusions, key messages and recommendations

Delivering both aspects of resource efficiency is a challenge for all renewable energy systems but a particular one for bioenergy. This arises from the relatively low energy conversion efficiency of bioenergy pathways and the considerable land use change often associated with biomass production, which results in complex direct and indirect impacts on ecosystem state and functioning.

This chapter presents the key conclusions and recommendations of the present study.

9.1 Improving resource efficiency in the bioenergy system

Resource efficiency in the energy system can be achieved in 2 major ways: a) in terms of creating more efficiency of the use of inputs for generating energy and reducing GHG emissions; and b) in terms of reducing negative ecosystem impacts from bioenergy production and enhancing the positive ones. In assessing either aspect, it is necessary to review the full life cycle of bioenergy production.

Use of waste and by-products

Wastes and by-products can contribute considerably to reaching the EU bioenergy targets. This report estimates that agricultural residues, organic wastes and forest residues contribute 43% of the total potential for meeting the NREAP targets in the Market First and this amounts to 55% and 59% respectively for the Climate Focus and Resource Efficiency storylines.

The advantages of waste- and residue-based bioenergy are that it will not add pressure on land and water resources and related ecosystem services, its GHG performance is considerably better than that of land-based resources, and it is a comparatively low-cost resource compared to cropped bioenergy.

In spite of this, there are still many hurdles in making the large waste and residue potentials accessible, particularly in the agricultural sector. The need for improvement in the technologies for collecting and processing all the residues efficiently is just one of many factors. Complex logistical arrangements are required to bring the usually bulky biomass sources together, and to increase the energy densities of the at-gate feedstock for further conversion into energy, through for example compaction, pelletisation, and possibly torrefaction. Furthermore, many stakeholders are involved in bringing the widely-spread biomass resources together. This requires joint and organised action at a regional level, including local policy support and planning permission. Another important aspect is that there are currently limited market mechanisms in place that stimulate the large scale and efficient collection of biomass residues. Finally, unlimited residue removal is not without environmental risks. Too much biomass removal from fields, as in the case of straw, may lead to a loss of soil fertility and increase the risk of soil degradation, with respective GHG implications from reduced soil carbon[43]. It may also have

[43] For a discussion of sustainable extraction rates of straw in Europe, see WWF (2012a).

negative effects for biodiversity, particularly soil biodiversity and for species that live off biomass residues, such as dead wood, crop roots, harvesting surplus etc[44].

While waste and residue biomass is the preferred biomass resource, the supply chains need to be improved significantly in the next years to make this huge potential accessible. The risk is that if these resources are not quickly utilised, preference will be given to the use of less sustainable biomass source such as cropped sources, having significant land use implications with related direct and indirect effects.

Favour the most resource-efficient pathways

Bioenergy is a renewable resource, but two specific features make it special, compared to all other energy sources – fossil, nuclear and renewable. First, bioenergy systems require significantly more land than any other energy system[45] which is a result of the comparatively low conversion efficiency of solar energy into chemical energy stored in plants, which is below 3%. Second, the land use associated with biomass production is closely related to environmental cycles and ecosystem functions, such as the carbon cycle, the productivity of soils or pollination, to name some.

The productivity of bioenergy feedstock cultivation and conversion into useful energy products such as gaseous, liquid or solid bioenergy carriers, expressed in terms of available bioenergy carriers per hectare of cultivated area per year, is very different between different bioenergy systems. Low-yielding cultivation systems combined with low-efficient conversion may provide 10-25 Giga-Joule per hectare per year (GJ/ha/yr) of useful output, while high-yielding options with high-efficient conversion could deliver 200-250 GJ/ha/yr (IFEU, CI, OEKO 2012). This represents a range of more than one order of magnitude, with the resource use of a given amount of land 20 times higher in the best case, compared to the least efficient case. Further, climate factors such as annual mean temperature, solar insolation, and water availability have a large influence on the net yield per hectare of land, with southern and especially equatorial latitudes favoring highly productive cultivation systems.

The GHG balance and biodiversity impacts of the most productive systems depend strongly on the land use change associated with their cultivation, meaning that it is important where these systems are used. In terms of resource-efficiency, this implies that the most productive bioenergy systems need “guidance” regarding which land should be used for their cultivation. Currently, though, the economic framework of markets does not deliver on that.

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[44] Sustainability requirements for bioenergy from forest residues are discussed in a series of “Joint Workshops” on the EU level (IINAS et al. 2012), and in a recent NGO position paper (WWF 2012b).

[45] For details on land use of electricity systems see Table 4.2: The overall life-cycle land use intensity of bioelectricity systems (using maize or short-rotation coppices as feedstock) is in the 2020 time horizon around 150 m^2/GJ_{el}, while direct solar systems need 2 (CSP in Spain) to 3 m^2/GJ_{el} (PV in Germany), and onshore wind parks require a maximum of 0.3 m^2/GJ_{el}. Fossil fuel and nuclear-based power plants need less land (0.02-0.1 m^2/GJ_{el}). Thus, the land use intensity of bioenergy from biomass cultivation is approx. 50 times higher than direct solar, 300 times higher than from onshore wind, and more than 1,000 times higher than for fossil or nuclear systems.

Bioenergy feedstocks need conversion into useful energy carriers, which causes losses. From a resource-efficiency perspective, it is decisive to stimulate the productive use of such losses, be it heat, or residues (such as fibres) to increase total output for a given input. In that regard, cogeneration is a key option to convert biomass feedstock efficiently, but also advanced biofuel technologies making use of (nearly) all biomass, and bio-refineries with "zero-waste" logics are longer-term relevant options.

Together with most productive cultivation systems (without LUC-related GHG emissions and biodiversity impacts), these conversion systems allow for more than 75% of GHG mitigation, compared to fossil-based systems.

Reaching such mitigation levels, while minimising direct and indirect adverse effects, requires significant efforts to speed up technological progress. Furthermore, the specific cost of reaching the NREAP targets would also be significantly higher in Storyline 2 and 3 than Storyline 1, because the investment cost of perennial crop cultivation, residue and waste collection and processing as well as advanced conversion systems are comparatively high.

This requires further analysis and assessment in follow-up work which should include the cost dynamics of technological innovations, and should be placed in the overall context of the European Union ambition to move to a carbon-neutral economy.

Minimise direct impacts

Both direct and indirect factors influence the overall GHG balance as well as other environmental effects of bioenergy production. This study developed a detailed analysis of direct environmental effects in Europe and integrated the potential impact of indirect land use effects in the estimation of life-cycle GHG balances for different bioenergy pathways (see Chapter 4).

This report underlines that there are more potentially adverse environmental effects connected to direct land uses, including changes in land management, which need to be addressed through policy incentives and safeguards that go beyond the current EU bioenergy policy framework. This particularly applies to the sustainable use of water resources and the prevention of effects on farmland biodiversity.

If demand for bioenergy leads to large scale plantation of perennial biomass crops, particularly on land released from arable and livestock farming and former abandoned farmland, this may increase the demand for irrigation water beyond available water resources. This is particularly a problem where large increases in high-yielding perennial plantations such as switchgrass and miscanthus occur, which require additional irrigation if produced in the more arid parts of Europe.

Although these crops are efficient in water use, their cultivation would still lead to additional water demand, if grown on land released from food and fodder production between 2003 and 2020 which was not under irrigation in 2003. This implies that most of the irrigation water needs for perennials are additional to the irrigation water demands for food and fodder crops for which the irrigation water demand may also increase towards 2020. An additional reason is that most of the land releases and abandoned land stock occur in the more arid regions of the EU, such as the Mediterranean and the eastern parts of the central Europe. The advantage of using these lands may be that they do not lead to any ILUC effect elsewhere. A disadvantage would be that they could increase irrigation water demand considerably if crops are chosen that require extra water during dry periods.

The results also show that policy intervention entirely driven by GHG mitigation targets for biofuels only (such as in Storyline 2) does not secure an overall positive environmental profile for European bioenergy production. The GHG mitigation focus comes at the expense of unsustainable water abstraction and further loss of farmland bird diversity in many EU regions.

The most environmentally beneficial bioenergy production is best secured by the package of measures belonging to Storyline 3. Emissions to air and water coming from European bioenergy crops will be lowest, loss of soil organic carbon and erosion are limited, water resources will not be affected by additional irrigation requirements and conservation of the farmland bird population is best secured.

Putting limits on irrigation water use in bioenergy cropping will not lead to a significant decline in total domestic bioenergy potential, but will rather prevent large-scale bioenergy development in arid regions where water resources are already over-used even without bioenergy targets.

Minimise indirect effects

ILUC effects have a significant impact on the GHG balance and mitigation capacity of land-based bioenergy chains if additional land is used for cultivating bioenergy feedstocks, as discussed in Chapter 2.

The current EU bioenergy policy framework does not include ILUC-GHG emissions in the mitigation requirement for biofuels of 50% to 2020 (60% for new installations), nor is there any mitigation requirement for solid or gaseous bioenergy used for heat and electricity production. This report, however, shows that absence of such mitigation requirements does significantly decrease the potential contribution of bioenergy sources to the realisation of EU GHG mitigation targets, particularly in the transport sector.

The inclusion of ILUC factors in the EU RED would have significant consequences for land-based bioenergy pathways resulting from the implementation of NREAP targets. It would, however, help to reach these targets in a more environmentally compatible way. Reaching these targets while including ILUC mitigation requirements in the policy framework will not be realistic if not accompanied by additional measures, though:

- First, significant financial incentives for increasing the collection and use of by-products and wastes and for the stimulation of dedicated cropping on low-ILUC-risk land are needed.

- Second, much more effort should be put into the development of advanced biofuel and other highly efficient conversion technologies to reduce biomass feedstock needs for a given demand (Fritsche, 2012).

Stimulation of the most resource efficient technologies and pathways
This report confirms that policies aimed at environmentally compatible upstream parts of the bioenergy chain cannot be successful unless accompanied by measures that stimulate improvements in other parts of the chain, particularly the downstream part involving the conversion steps, but also all logistics and the final end-use of bioenergy.

In this report, optimistic assumptions were made on the development and deployment of new, highly efficient technologies for bioenergy production by 2020, particularly in Storylines 2 and 3[46]. The relevance of implementing these optimistic expectations by 2020, however, becomes clear from the fact that it is exactly in the biofuel sector that enormous mitigation gains can be achieved and are needed most.

In the heat and electricity sectors, the overall increase in bioenergy even with application of less-advanced technologies is already leading to significant mitigation gain, certainly in countries where a large part of the heat and electricity is based on high-carbon lignite. But also in those countries efforts should be made to deploy more efficientl technologies. At the same time it is important to make progress in setting up the right infrastructure to bring together a sufficiently large and continuous amount of biomass feedstock to supply bioenergy systems operating at competitive cost levels, taken into account financial support schemes.

On the end-use side it is crucial to ensure that the grid infrastructure both for electricity and heat is able to distribute bioenergy and prioritise it above fossil energy. For bioenergy deployment this may become an important constraint, particularly because the natural gas grid capacity is not always where the agricultural and forest biomass is produced/available, which is often in remote rural locations.

In all storylines, to reach the heat targets, there is a need to deploy as much as possible waste heat from biogas electricity and solid biomass cogeneration plants. Since the feedstock for it will need to be derived from many wide-spread places, an optimal match between the production of heat and the consumption of it might be hard to achieve unless strong efforts are in place to synchronise the two.

Both the infrastructure for feedstock/biomethane and for cogenerated heat will require a great deal of investments and local co-operation as well as governmental guidance.

The 2020 technologies do not include bio-refinery and cascading use concepts, as those will be commercially introduced only later. Nonetheless, up to 2020 there are

[46] As compared to Storyline 1 it is expected that all NREAP biofuel targets can be reached using straw-based bioethanol, perennial-based biomass-to-liquid (BtL) diesel and large-scale deployment of liquid-gas fuel in public transport. Although the total amount of fuel produced in Storylines 2 and 3 will need to be half of what is needed in Storyline 1 (because of double counting), this is still an optimistic assumption when the recent history of bringing advanced biofuel technologies into the market is considered.

large efficiency improvements to be made in energy conversion technologies which are crucial components in the development of a more resource-efficient economy and should also be seen as crucial component for the market introduction of future bio-cascading and -refining.

However, in guiding technological development and policy it will be important that energy and material uses of biomass in bio-cascading applications are not dealt with separately. Energy and material uses are not to be developed as competing routes, but when setting up bioenergy technologies and infrastructure account should be taken of potential future synergies, even though biomaterial technologies are still in a pre-marketable stage, while the RED bioenergy targets are to be realised by 2020.

Develop environmentally-compatible bioenergy cropping systems

As already discussed in Section 3.3, current energy cropping trends do not correspond with the environmentally compatible future developed in the 2006 EEA bioenergy report, with arable crops for 1st generation biofuels dominating the current energy crop mix, and maize monoculture for biogas taking a prominent second place in Member States where biogas production is well-developed.

There are two main options for avoiding negative environmental impacts from energy cropping:

- avoiding the conversion of environmentally sensitive farming systems, in particular of high nature value (HNV) farmland areas; and
- developing environmentally compatible energy cropping systems.

The first option requires that the character of farming systems on HNV farmland land is not changed substantially while an exploitation of their biomass output for bioenergy purposes can be compatible with environmental objectives. An example of an environmentally compatible use would be the use of cuttings from olive grove management in bioenergy generation – if economically viable. In developing such uses, however, the character of HNV farming systems would have to be maintained, e.g. by keeping the share fallow land stable and not increasing the input use on, or cutting intensity of, permanent grasslands. In order to allow for this, there is a need to properly identify these farming categories, to monitor their status, and to provide for adequate revenue.

The 2nd option - development of environmentally compatible energy cropping systems - has been a focus of previous EEA analysis (see EEA, 2007, for example), and consists mainly in shifting from annual bioenergy crop production to perennial systems, and intercropping. Due to the economic approach of agricultural actors which is risk-averse, favours flexibility and using existing technologies and knowledge to reduce transaction costs, there is a significant barrier to investing in perennial cropping, as this implies capital being "locked up" for at least two rotations, and bringing forward higher investments than in the case of annual cropping. This can be attractive only if financial incentives for such shifts are available, and revenue from future perennial crop sales is both adequate and stable.

Furthermore, the establishment of perennial plantations needs to be developed carefully without too much soil disturbance and the associated loss of soil carbon, particularly on released and abandoned land categories where soil carbon resources have been building up for several years already. Practices such as ploughing and tilling should ideally be avoided and low-impact techniques (drilling or injection for planting and seeding) could be applied.

Bioenergy cropping, in particular of perennial crops, can be fitted in with the landscape and help to increase landscape diversity. This can support the creation of stepping stones for biodiversity through biomass production (see EEA, 2007).

9.2 Further issues that require attention

This report mainly explored the overall environmental performance of agricultural bioenergy pathways. Other issues that merit further attention include the following:

- The question of carbon debt is crucial in considering the GHG mitigation potential of bioenergy derived from forest biomass. This could only be discussed qualitatively in this study and requires further investigation.
- Indirect land use change not only affects the GHG balance of bioenergy pathways but also has substantial impacts on soil and water resources as well as biodiversity wherever it takes place. Such indirect effects have not yet been sufficiently studied.
- The monitoring of energy cropping trends is currently not sufficient to be able to analyse their environmental impact of the effectiveness of (environmental) policy measures in this regard. This has negative repercussions on our ability to improve policy design and implementation.
- It is recommended, therefore, that further investment in such monitoring systems at EU and country level is carefully considered.
- This report analyses only a part of all relevant questions and could be followed up with analysis of the economic implications of reaching the NREAP targets in the most environmentally-compatible and resource-efficient way (along the lines of Storyline 3).
- By focusing on the NREAPs, the analysis concentrates on the bioenergy sector and related technologies and development until 2020. Looking beyond this time horizon would, however, also be very important as emerging options, such as using biomass in bio-refineries and in 'cascading use' concepts, will only enter European markets after 2020 to a significant degree.
- The technologies involved in this report represent the technological development potential up to 2020. They exclude the co-production of biogenic materials and biochemicals with energy (bio-refineries), as until 2020 these technologies are not expected to become economic at a large scale[47]. There are, however, several technologies included that produce by-products for the chemical industry and livestock feed, and the calculation of the GHG mitigation potential of these downstream parts of the chain are included in the GHG allocation calculations of this study (based on GEMIS, see Section 5.3). Within this perspective, however, a follow-up study aiming at the time horizon of 2030- 2050 would be very useful, as important technologies for

[47] See Arnold et al. (2011); IEA BioT42 (2012); STAR-COLIBRI (2011a+b)

developing a resource-efficient (bio-)economy only become available from 2020 onwards.

9.3 Considerations for policy design

- Given that there is a limited (sustainable) volume of biomass it is important to ensure that the most resource-efficient bioenergy pathways are favoured.
- As land is a finite and increasingly scarce resource and non-bioenergy uses such as food, feed and fibre production are competing with bioenergy for land, a **minimum productivity** of cultivated feedstock could be considered taking account of type of feedstock crop and land. This would set a target for useful energy per hectare of land used for feedstock production and take into account environmental safeguards against negative impacts of intensification.
- Similarly, the efficiency of converting biogenic residues and wastes into bioenergy carriers could be considered in terms of percentage of useful energy per energy input, i.e. **minimum conversion efficiency**. These resource efficiency requirements would safeguard against developing bioenergy options which are efficient in reducing GHG emissions, but still inefficient in terms of resource use, e.g. co-firing solid bioenergy in old electricity-only power plants.
- The indirect land use change effects of European bioenergy production are very important for its overall environment profile. Hence it is important to consider what mechanisms are available for minimising potential negative impacts outside the European territory, including a reduction in the ambition levels for EU bioenergy targets, and introducing ILUC factors in the GHG balance of bioenergy.
- Only with strong economic incentives and regulatory action will it be possible to develop environmentally-compatible energy-cropping systems.
- With expected increases of using solid biomass for energy, and increasing imports of solid bioenergy carriers, the RED sustainability requirements need extension to solid bioenergy.
- Substantial technological progress needs to be achieved before a number of the most environmentally promising bioenergy pathways can become a reality. Hence, **substantial investment** in such technologies is required, and economic incentives for respective investors are needed, including a perspective for stable revenues.
- The choice of energy crops and cropping systems plays a key role in the wider environmental profile of energy-crop based bioenergy pathways. The development of environmentally compatible energy cropping systems has been a focus of previous EEA analysis (e.g. EEA, 2007), and builds on maintaining environmentally friendly agricultural land uses and on shifting from annual energy crops to perennial systems.
- Perennial plantations offer environmental benefits but need to be developed carefully, without excessive soil disturbance and associated loss of soil

carbon, particularly on land categories where soil carbon resources have built up for several years (e.g. on long-term set-aside or abandoned land). Practices such as ploughing and tilling should ideally be avoided and low-impact techniques (drilling or injection for planting and seeding) applied.

- Large-scale perennial biomass plantations potentially increase the demand for irrigation water beyond sustainable levels. This is particularly a problem for establishing high yielding perennial plantations such as switchgrass and miscanthus as these require additional irrigation if produced in the more arid parts of Europe. Other energy crops more adapted to the precipitation patterns in these regions are preferable, therefore, even if of somewhat lower productivity.
- The protection of farmland bird populations requires additional measures, particularly the prevention of the loss of fallow land. The results of this study show that unconstrained development of bioenergy (such as in the 'Market first' storyline) leads to farmland bird losses in a majority of EU regions while such negative impacts can in principle be avoided by favouring more efficient bioenergy pathways (see the example of the `Resource efficiency` storyline).
- In view of the expected increases in imports and use of solid biomass for energy it seems necessary to ensure that the use of biomass in the heat and power sectors is subject to clear environmental standards. Previous EEA work can provide useful background in that regard, such as in relation to biodiversity safeguards in forest ecosystems.
- Residue removal should not result in environmental risks. Too much biomass removal from fields or forests may reduce soil fertility and increase soil degradation, and release carbon from the soil. Indirect land use change not only affects the GHG balance of bioenergy pathways but also has substantial impacts on soil and water resources as well as biodiversity wherever it takes place. Such indirect effects have not yet been sufficiently studied and should be addressed in further research.
- Bioenergy feed stocks need to be converted into useful energy carriers, which causes energy losses. From a resource efficiency perspective, it is essential to minimise such losses and to use them productively where they are inevitable. This applies not just to material losses (e.g. residues such as fibres) but also to energy (e.g. heat), with the aim being to increase total output for a given input.
- Similarly, it is important to make progress in setting up the right infrastructure for bringing together a sufficiently large and continuous amount of biomass feedstock to supply bioenergy systems operating at competitive cost levels.
- Improving technology can help in collecting and processing residues efficiently. For example, the energy densities of feedstock delivered to bioenergy plants can be enhanced via prior compaction, pelletisation and other means at the point of collection
- Many stakeholders are involved in the complex logistical arrangements required to bring bulky biomass sources together. Success in this area requires joint and organised action at a regional level, including local policy support and planning permission.

- Finally, the interaction of the biomass demand for energy with other potential non-food uses of biomass, e.g. for replacing fossil fuels as feedstocks for plastics, needs to be investigated, as this could have serious land use and hence environmental implications.

9.4 Reflections on methodology and scope for further analysis

Developing a methodology to evaluate bioenergy's resource efficiency impacts is a complex task due to the variety and complexity of potential bioenergy pathways, the substantial range and complexity of required analytical tools, and the different spatial scales at which impacts occur. This section reflects on methodological and analytical questions associated with the present study, moving from a review of the approach used to potential analytical developments.

Advances and limits of the analytical approach employed:
In comparison with previous EEA work this study has aimed to develop several methodological improvements:

- the methodological approach incorporated an additional spatial scale, the global level, into the analysis by integrating indirect land use change as a key factor for the total GHG balance of bioenergy pathways;
- the efficiency of different bioenergy pathways was analysed with the help of updated life cycle databases and by using different storylines to explore how changing the relative role of different bioenergy pathways influences overall GHG efficiency;
- whereas ecosystem impacts were previously addressed via assumptions regarding 'environmental constraints', the current study also employed biophysical models to analyse the impact of land use patterns associated with the three storylines developed in the study on water, air emissions, soil erosion and biodiversity;
- the conceptual model allowed different resource efficiency aspects to be drawn together in an integrated analysis of developing bioenergy production.

While the sophistication of the analysis has advanced, there are nevertheless areas where the methodological approach could be enhanced. Areas for improvement relate to the quality of available input data and the suitability and limits of the modelling tools used.

- Key input data that were found to be of limited quality or missing include time series on energy cropping trends as well as cost estimates for biomass as input to bioenergy production. The latter had to be developed on very limited published information and expert based extrapolations of cost levels to all EU regions. Better field data could improve these estimates substantially but without extra data collection it will remain challenging to make good cost estimates of biomass resources which are not (yet) traded on existing markets.
- The more difficult the validation of input data, whether from statistical approaches or derived from modelling exercises, the higher the uncertainty of assessment results. The present study includes a sensitivity analysis regarding the impact of different ILUC factors but did not attempt to evaluate the potential influence of uncertainties arising from limited knowledge about yields

of different energy crops in Europe or associated biomass feedstock costs at gate. Improving such basic field data is often a resource-intensive exercise but should be a priority for future updates.

- Another key question that is not tackled in the present analysis is a consideration of the costs of the policy measures in the three storylines (e.g. price supports), which would obviously influence the desirability of expanding bioenergy compared to other renewable energy sources.

Analytical questions that were not tackled:

- quantifying how carbon debt influenced the GHG balance of the forest biomass used in the three storylines;
- comparing the GHG savings from using biomass for energy to the use of biomass as replacement of fossil fuel inputs in other processes, e.g. as an input to the chemical industry or as a building material;
- expanding the time horizon of the study to 2030, or even beyond;
- analysing the invasive potential of some of the new energy crops.

Expanding analytical boundaries

All types of integrated analysis need to set analytical boundaries in order to be manageable, respect the limitations of input data and modelling tools, and focus on key questions. This is obviously also true of the present study.

The list below sets out a number of analytical questions and developments that could be tackled in the future.

- Utilisation of biomass in different end uses: This study has only looked at the use of biomass for energy purposes. In this context it needs to be noted that the emerging discussion on a bio-economy — as part of the broader green economy paradigm (UNEP, 2012; EC, 2013a) — goes well beyond bioenergy. The bio-economy concept encompasses, inter alia, new biomaterials such as biopolymers, the re-introduction of biomass as basic material in construction and textile production etc.
- Reflections on changing consumption patterns: In the context of humankind's ever-increasing demand for energy and materials globally, more efficient resource use alone will not bring total demand down to sustainable levels of extraction or utilisation. Decreasing total demand via changing consumption and life style patterns therefore needs to be part of an integrated approach to resource management (EEA, 2012).
- Creating an effective policy framework: The three storylines were developed on the assumption that appropriate economic incentives and environmental rules would exist to bring about the depicted bioenergy future. In practice, more work and analysis has to be carried out to determine which kinds of legislative and economic incentives are most effective in stimulating the development of more resource-efficient bioenergy pathways and concepts (e.g. biorefinery and cascading use).
- Providing analytical standards for evaluating progress towards resource efficiency: This study has explored how to define resource-efficient bioenergy production. However, the analytical approach taken cannot necessarily be directly translated into the policy domain. Research challenges that are relevant in this context include the question whether one can develop a

composite measure of the ‘total resource efficiency impact’ of different potential bioenergy pathways; or whether it is feasible to determine certain thresholds or standards above which the use of bioenergy in different pathways or locations can be considered to be ‘resource-efficient’.

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11 Annexes

Annex 1 Global renewable energy targets

Most of the national renewable energy targets that are in place since 2010 aim for targets in 2020. Some refer to targets set for shares of electricity production, others for shares of total primary or final energy supply, specific installed capacities of various technologies, or total amounts of energy production from renewables, including heat. China for example aims for 15% of final energy consumption from renewables by 2020, in spite of the fact that total energy demand continues to grow at tremendous (double digit) rates. Brazil aims at renewable energy shares in total energy of 48% and in electricity of 85% by 2030. In Australia 20% of electricity should come from renewables by 2020 and South Korea aims for 11% renewables of primary energy by 2030.

It should however be mentioned that although targets are set for renewable energy, only few countries have also set targets for the specific contribution of bioenergy to these targets, as was done for the EU-27 (e.g. in the RED). In many countries targets also exist for biofuels. For these it is more likely, given the state of technology until 2020, that these will largely be based on bioenergy, often cropped agricultural biomass sources.

Mandates for blending biofuels into transport fuels have been enacted in at least 41 states/provinces and 24 countries at the national level. Brazil is the oldest and most well-known example which sets blending obligations ranging from 20-25% for biofuels. Other countries set targets for future levels of biofuels use. In the U.S. for example the "renewable fuels standard" (RFS) requires fuel distributors to increase the annual volume of biofuels blended to 36 billion gallons (136 billion litres/year) by 2022. Japan aims for an ethanol production of 6 billion litres per year by 2030 (estimated to represent 5% of transport energy). China targets to the equivalent of 13 billion litres of ethanol and 2.3 billion litres of biodiesel per year by 2020. South Africa's strategy targets 2% biofuels in total transport energy by 2020 (see Table 1).

***Table 1**. Use and blending share targets (T) and mandates (M) for liquid biofuels that can be met by either ethanol or biodiesel (based on Petersen (2008), updated on the basis of Renewables 2012 Global Status Report)*

Country	Type	Quantity or blending share	Comment
Argentina	M	5% ethanol share 7% biodiesel share*	
Australia, New South Wales*	M	6% ethanol share and 2% biodiesel share	*NSW postponed its mandate increase*
Belgium*	M	4% ethanol share 4% biodiesel share	
Brazil	M	18-20% ethanol blend* 5% biodiesel blend by 2013	*Reduced its mandated ethanol blend*
Canada	M	5% ethanol share 2% biodiesel share	*4 provinces enacted higher individual mandates**
China	M	10% ethanol share in 9 provinces*	
Colombia	T/M	8% ethanol share* 7% biodiesel share by 2012*	
Ethiopia*	M	10% ethanol share	
European Union	T	10% transport fuel share by 2020	*can also come from renewable energy sources*
Guatemala*	M	5% ethanol share	
India	M	10% ethanol blend	
Indonesia	M	3% ethanol share* 2,5% biodiesel blend*	
Jamaica*	M	10% ethanol share 5% biodiesel share	
Japan	T	6 billion litres by 2020	
Malawi*	M	20% ethanol share	
Malaysia	M	5% biodiesel blend	
Paraguay	M	24% ethanol share* 5% biodiesel share	
Peru	M	7.8% ethanol share 5% biodiesel share	
Philippines	M	10% ethanol share 2% biodiesel blend	
South Korea*	M	2,5% biodiesel share	
Thailand	M	5% ethanol share* 5% biodiesel share	
USA (federal)	M	136 billion litres by 2022*	
Uruguay	T/M	5% ethanol share by 2012 5% biodiesel share by 2012	
Zambia*	M	5% ethanol share by 2012 5% biodiesel share by 2012	

* new countries/targets compared to Petersen, 2008

Note: The figures above relate to different types of policy commitments or planning. They are not directly comparable but show the substantial scale of biofuel deployment that is foreseen over the next years / decade.

Stimulation policies to reach all these targets differ per country but include measures, such as tax reductions, investment support, feed-in tariff payments and the setting of renewable energy quotas. An overview of which measures are in place where is given in REN21 (2012). As in the EU some countries have also set additional sustainability criteria on the renewable energy production that can count towards the target. The California Low Carbon Fuel Standard (LCFS), for example, requires a minimum of 10% emissions reduction per unit of transport energy by 2020. The U.S. RFS requires that at least half of the biofuels production mandated by 2022 should reduce lifecycle emissions by 50% as compared to fossil fuels. California also plans to expand its policy to address other sustainability issues. Brazil also adopted new sustainability policies in 2009 for sugarcane ethanol, including zoning regulation of sugarcane expansion, social protocols and bans on burning the sugarcane. Beside these national obligations there are also several voluntary initiatives to stimulate the sustainable production of biofuels of which the most well-known examples are the Roundtable on Sustainable Biofuels, the Global Bioenergy Partnership (GBEP), Roundtable on Sustainable Palm Oil (RSPO), the Better Sugarcane Initiative (BSI), the Roundtable on Responsible Soy (RTRS), and the Forest Stewardship Council (FSC).

Annex 2 Differences between current and the EEA 2006-2007 study on the environmentally compatible biomass potential

The current study builds in many ways on the EEA work in 2006 and 2007 but shows nevertheless significant methodological differences. A systematic overview of the main differences is given in the Table 1 in this annex. First of all the policy assumptions are different for both studies. For the current study the policy arena has been developed much further. Clear targets are specified for renewable and bioenergy targets in the RED and the NREAPs and binding sustainability criteria for biofuels and bioliquids. These sustainability criteria specify 50% GHG reductions as compared to fossil fuels by 2017 but cover emissions related to direct land use changes only. However, the EU Parliament and the Council therefore asked the Commission to examine the question of indirect land use change (ILUC), the possible measures to avoid it and to report back at the end of 2010. In addition the CAP health check and sugar market reforms had not been decided at the time of the previous study.

The discussion on ILUC effects of bioenergy production on agricultural land has developed further since 2006 underpinned by several (worldwide) studies (e.g. Al-Riffai *et al.*, 2010; JRC-IE, 2010; Marelli 2011ab/2012ab; Van Oorschot *et al.*, 2010, Berndes *et al.*, 2011; Laborde, 2011) and policy communications (EC, 2011d). In this study much attention is paid to this issue. Firstly by providing an extensive discussion on the different recent studies in which estimates were produced of GHG emissions for ILUC (see Chapter 4). Secondly, by incorporation of ILUC factors in the environmental framework of the different storylines applied in this study, which leads to including them in a GHG emission-mitigation analysis covering the full life-cycle (primary production of biomass, transport, logistics, pre-treatment, conversion and by-product allocation).

The EEA 2006 study also included other environmental criteria for biomass cropping for the selection of land categories and cropping systems as well as general environmental criteria applied to the whole agricultural sector. In this study the additional environmental criteria are only applied to biomass cropping for bioenergy purposes. Furthermore, the environmental effects of the different environmental criteria applied in the three different storylines has also been estimated in a more quantitative manner showing effects on land based and total GHG emissions and mitigation targets, water quality and quantity, soil quality and biodiversity. In the EEA 2006 study the incorporation of environmental criteria was based largely on expert judgement and no quantified environmental impact assessment was carried on the results, with the exception of impacts on GHG emissions in the follow-up study in 2008 (EEA, 2008a).

Economic consideration were part of the assumptions in the storylines in the current study and were incorporated by setting a threshold on the maximum price to be paid per feedstock category, both from agriculture as from forest and waste potentials. In the EEA 2006 study no economic considerations were incorporated beforehand although in a follow-up study (EEA, 2008a) cost estimates of realising the potentials were calculated. The same applies to GHG emission effects.

In the 2006 study the simple assumption was made that the economic and regulatory policy framework would encompass all necessary measures to reach the potentials as estimated. Furthermore, as regards to competition with food and fodder it was assumed that this only applied to land used for production for (mostly subsidised) export of food products. Given the criticism of subsidised EU food exports from an international development perspective at that time these were considered dispensable. This meant that EU exports were phased out and the productive potential of the released land was assumed to be available for biomass cropping.

Table 1 *Overview of differences and similarities between the current study and EEA studies performed in 2006-2008*

Considerations:	**EEA 2006 study**	**2012 analytical approach**
Reference year	2010, 2020 and 2030	2020
Policy starting point	Biomass Action Plan (EC, 2005b), Kyoto protocol (2002) and Directive 2003/30/EC on the promotion of the use of biofuels or renewable fuels for transport.	'Directive on the promotion of energies from renewable sources' (Directive 2009/28/EC) (RED) and National Renewable Energy Action Plans (NREAPs)
Scenarios	One environmentally compatible future (for assumptions see environmental constraints) which were applicable to whole sectors rather than for bioenergy production only.	Three storylines: 1) Economy first 2) Climate first 3) Resource Efficiency
Environmental constraints for **agricultural** biomass	1) At least 30% of the agricultural land is dedicated to 'environmentally oriented farming' in 2030 2) Extensively cultivated agricultural areas are maintained 3) Approximately 3% of the intensively cultivated land is set-aside for establishing ecological compensation areas 4) Bioenergy crops with low environmental pressure are used	1. Depending on storyline: 1) All agricultural residues are used (e.g. straw, manure, cuttings) available below 3 €/GJ or 6 €/GJ (depending on storyline) 2) Minimal 50% mitigation target set to biofuels in storylines 2 and 3 including ILUC compensation. GHG mitigation applies to whole LCA calculation. 3) In storyline 3 minimal 50% mitigation target set to all bioenergies (biofuels for transport, solid and gaseous) 4) In storyline 2 and 3 use of biomass is always directed towards the most GHG efficient pathway. 5) In storylines 2 and 3 no use of biodiverse land or land of high carbon stock 6) Released agricultural land (between 2004 and 2020), fallow and (part of) abandoned lands can be used for dedicated bioenergy cropping provided mitigation requirements and other constraints (depending of storyline) are met. 7) In storyline 3 it is not allowed to reduce the total fallow land area of a region to less than 10% of totale arable land. 8) On released and fallow land crops with lowest GHG emissions (e.g. perennials) are used in storylines 2 and 3. In storyline 1 the crops are chosen according to the lowest costs (€/GJ). 9) In storyline 3) no irrigation for dedicated bioenergy cropping is allowed.
Environmental constraints for **forest** biomass	1) Current protected forest areas are maintained: residue removal or complementary felling are excluded in these areas 2) Forest residue rate is adapted to local site suitability (foliage and roots are not removed at all) 3) Complementary felling is restricted by an increased share of protected forest areas and minimum levels of deadwood.	Based on EEA (2006) forest potential estimates. But only the forest potential is used which was estimated to be available at 6 Euro/GJ and below.
Environmental constraints for **waste**	Ambitious waste minimisation strategies are applied.	Based on EEA (2006) waste potential estimates. Only the non-agricultural residue part of the EEA (2006) estimate was taken. It was

biomass		assumed that all waste potential would be used first before imports.
Economic considerations	Technical environmental potential. Costs have only been calculated in a follow-up study[48]	Economic environmental potential is estimated by setting maximum 'at-gate-price' paid for feedstock per storyline.
Inclusion of downstream conversion pathways	Not applied. The efficiency of the full pathway was considered in estimating the overall bioenergy potential from waste. However, this was not done in a quantified way, but only based on expert knowledge and expectations on technological learning. A quantified estimate of the GHG performance (and costs) of the full pathways using the different 2006 potentials was only developed in a later post-assessment (EEA, 2008a)[49].	The most efficient feedstock-conversion pathways were chosen on the basis of a full LCA. The full LCA of the feedstock-pathway combination was also taken to calculate the minimal mitigation requirement for inclusion of the feedstock in storylines 2 and 3.
Stimulation measures and assumptions	1) Further reform of the CAP towards further liberalisation 2) That the right policy measures are taken to avoid potential environmental drawbacks and increase potential environmental benefits of bioenergy production. 3) Competition between food/fodder and bioenergy production would only take place on land that produces food and feed output for exports.	1) Higher carbon credit payments in storylines 2 and 3 2) ILUC compensation is needed in storylines 2 and 3 for all biomass crops produced on land in competition with food/feed. 3) Double counting of 2nd generation and waste based biofuels and green gas used in public transport (only in storylines 2 and 3) 4) High support levels to technological research leading to faster introduction of 2nd generation biofuels in storylines 2 and 3
Impacts assessed	No quantified assessment of the potential impacts on environment of using the different identified biomass potentials. Only qualitative descriptions are given of the environmental risks involved when producing biomass feedstock on agricultural land.	Model-based impact assessments are used to estimate the implications for water quality and quantity, soil quality, biodiversity, GHG emissions and mitigation potential of the use of the biomass potentials in the three storyline situations.

[48] EEA (2008a).
[49] See footnote 9

Annex 3 Indirect effects

A systematic overview of potential indirect effects is given in Table 1 of this annex. Effects 'a' and 'b' are land use related and are discussed in Chapters 3 and 5 of this report. Another land use related effect is that a significant amount of by-products/co-products is produced in the conversion of biomass to biofuels. These enter the market and can reduce the demand for other fodder sources (effect 'c'). However, the net effect of this action chain is difficult to estimate. The contribution of biofuel production to additional fodder production will also lead to changes in the production of meat. The mechanism of price and demand for meat is very complicated, and may include several feedback loops. Lower fodder prices might reduce the price of meat which could increase demand, causing increases in meat prices again (effect 'd').

Table 1 *Potential indirect effects of bioenergy products*[50]

Indirect effect	Impact on GHG emissions	Impact on biodiversity
a. Indirect land use change (ILUC): conversion of land	Loss of carbon from vegetation and soils can be substantial, sometimes of the same order of magnitude as the environmental impacts from direct land use conversions	Immediate loss of natural area, more infrastructural barriers
b. Intensification of agricultural production	Emissions from nitrogen fertiliser use; these are very sensitive to management practices (worst case emissions equal ILUC emissions)	Emissions of nitrogen compounds and pesticides affect terrestrial and aquatic life
c. Substitution of traditional feedstock with by-products	Can considerably reduce potential ILUC-related environmental impacts,	Can reduce indirect land use change and loss in natural area, considerably
d. Excess in production of animal fodder	Effects unclear, both positive and negative; effects mainly via the land use system	Effects unclear, both positive and negative; effects mainly via the land use system
e. Impact on oil prices (leading to lower oil prices and higher oil consumption)	The indirect emissions can be of the order of 10-40% of the emissions from the fossil fuels replaced by bioenergy	Increase in environmental pressure of many economic activities
f. Impact of climate change on agricultural production	Regional differences: positive and negative effects on yields	Regional differences: positive and negative effects mainly via the land use and water systems

The impact of by-products from bioenergy production on land use can be included in model calculations on ILUC or in Life Cycle Analysis with allocation of land use based on substitution. It should be noted that if such an approach is part of an environmental assessment, the land use for soy meal, for example, is deduced from the land use for energy crops without considering the environmental impacts of soy production.

50 PBL, 2010a

Bioenergy production will also have an impact on the oil market (effect 'e'). Mandatory bio-energy production can lead to decreasing prices of crude oil, and thereby eventually lead to an increase in crude oil and total energy consumption. This so-called 'rebound' effect can reduce the possible gain from biofuels substantially, especially if not all sectors are facing some form of climate policy, or not all countries participate in climate change policies. The magnitude of this effect is rather uncertain, but could reach as much as 50% of potential gains (Barker *et al.*, 2009). Calculations with LEITAP/IMAGE resulted in an extra indirect emission of about 30% from the reduction in direct emissions. So these indirect emissions are in the order of 10-40% of the emissions of the substituted fossil fuels.

In some regions, climate change effects are already leading to agricultural productivity increases while in other regions the opposite is happening (effect 'f'). GHG emissions cause multiple feedbacks in biological systems, resulting in indirect effects on agricultural production. Higher CO_2 concentration leads to higher CO_2 uptake by the vegetation and therefore to higher plant productivity, and potentially to less deforestation. Emission of nitrogen compounds might have the same fertilising effect. Temperature increases and changing rainfall patterns are climate aspects with relevant potential impacts on agricultural productivity, positive in some regions and negative in others. Overall, a key climate change impact will be higher variability in rainfall and temperature patterns which is expected to lead to higher food production variability and increased food security risks.

Annex 4 HNV farmland

While the intensification of agriculture has been, and still is, a driver of biodiversity decline, low-input and traditional farming systems are important for the maintenance of biodiversity in many European landscapes (EEA, 2006). Biodiversity loss is associated with the decline in extensive farming systems, as documented in several studies, including Dunford and Feehan, 2001; Heath, *et al.*, 2000; Sirami, *et al.*, 2008; Peco, *et al.*, 2005, 2006; Bignal & McCracken, 1996 & 2000; MacDonald, *et al.*, 2000; Diemont, 1996; Schaminée and Meertens, 1992; Miles, 1981. For grassland systems in particular, Bunzel-Drüke, *et al.*, 2002; Dirkx, 2002 and others have shown that European native vegetation has adapted to grazing over millennia and that these habitats and all their functional components are best conserved by continuing traditional grazing practices. The importance of these grazed habitats is further underlined by the large number of species of different biota, that rely on them (e.g. Anger, *et al.*, 2002; Bignal and McCracken, 1996; Miguel, 1999; Nagy, 2002). It is because of the key role of extensive agriculture in maintaining species-rich habitats that the concept of High Nature Value (HNV) farmland has been developed (see Paracchini *et al*., 2008).

In the *6th Environmental Action Programme* (2001-2010), the *EU Biodiversity strategy towards 2010* and the *Pan-European Biological and landscape Diversity Strategy (PEBLS),* clear aims are formulated for conservation and restoration of the environmental state of natural habitats, landscapes, flora and fauna. The *European Sustainable Development Strategy (EU-SDS)* emphasises the importance of combatting a further decline of biodiversity and the need for sustainable management of natural resources and measures to mitigate climate change. The *Bern Convention, the European Landscape Convention*, and, at EU level, the *Habitats and Birds Directives* and *Rural Development Policy* (Community Strategic Guidelines for Rural Development, Programming Period 2007-2013) have also identified conservation of biodiversity on agricultural land as an explicit objective. This is in line with the Kyiv Resolution on Biodiversity, published in 2003, in which all European Environment Ministers declared that by 2008 a substantial proportion of HNV farmland should be under biodiversity-sensitive management, with rural development measures in place to support the ecological and economic viability of the associated farming systems (DG Agriculture and Rural Development, 2009).

The European Commission argues that the preservation of biodiversity associated with agricultural land outside protected areas (i.e. Natura 2000 sites) will also be essential to meet post-2010 targets for conservation of biodiversity. HNV farmland should therefore be protected and well managed, and policy support targeted at preserving agro-biodiversity is urgently needed.

All Member States have now committed themselves to the conservation and management of HNV farmland. The Council Decision on Community Strategic Guidelines for Rural development (for the 2007-2013 programming period) explicitly specifies that resources devoted to axis 2 should contribute to three EU-level priority areas, of which the first is ‘biodiversity and the preservation and development of high nature value farming and forestry systems and traditional agricultural landscapes’ (the other two are water and climate change). Consequently, EU Member States are now encouraged to explore the possibilities of integrating the concept of HNV farmland in their own rural development (incl. agri-environmental) programmes.

Annex 5 Biogas and other bioenergy technology options for straw: present and future

An effective strategy to mitigate indirect land use changes (ILUC) effects is the use of biomass residues (e.g. manure, forest thinnings, straw) and wastes (e.g. organic fractions in residential and industrial wastes). These could provide up to half of the bioenergy potential in some countries (EEA 2006; Smeets *et al.*, 2007), as confirmed by the present study. Straw in particular has high unused potential: out of a net straw availability in the EU27 of about 820 PJ, 230 PJ could be used economically in power plants of up to 2.5 GW (Edwards *et al.,* 2005) and the present study shows that this amount could be even higher by 2020.

Straw can be used for heat and electricity production, but also as feedstock for biogas and biofuels. Possible conversion technologies (details in Zeller *et al.*, 2011) are detailed below.

Thermo-chemical conversion
In a pyrolytic step (without oxygen), 85 % of the straw biomass is converted to gas. The solid residue is then turned to gas by adding oxygen. Finally the gas products are burned. Disadvantages/problems: straw has a relatively high ash content (high amount of potassium) and a low 'ash melting point' that can, in combination, lead to 'slagging' of the combustor. The combustion gas of straw also contains a relatively high amount of air pollutants (e.g., carbon monoxide, hydrogen chloride) which can cause corrosion of the combustor. Because of these problems, only a few straw-based thermo-chemical power plants have been installed in Europe. Further technological development is needed to develop a well-working conversion process.

Biogas from straw
Conversion of straw to biogas has relatively low biogas yields of 140-290 l_NCH_4/kg_{oTS} depending on its pre-treatment (compared with maize: about 340 l_NCH_4/kg_{oTS}; e.g., Bauer *et al.,* 2010). These low methane yields are mainly a result of the high amounts of lignin that cannot be digested under anaerobic conditions. Lignin surrounds cellulose and hemi-cellulose compartments making their digestion difficult. Also, the high C/N ratio of straw (about 80:1) is beyond the optimum of 10:1 to 30:1, inhibiting the activity of microbes. Straw tends to build up a floating layer in the digester, reducing digestion, and pumping straw is difficult. These problems can be reduced when straw is pre-treated (e.g. milling, steam, microwaves, chemicals, enzymes) and by co-fermentation with manure (high N-ratio) or other crops. Today, biogas production from straw is still under development and only a few research pilot plants are in place (see also Bauer *et al.*, 2010 and Wu *et al.*, 2010). In this study the use of straw in biogas plants is only included in Storylines 2 and 3 where investment in technologies is expected to be larger, making efficiency gains in conversion processes more likely to happen over a shorter time frame than in Storyline 1.

Ethanol production from straw
Microbes can convert glucose to ethanol under anaerobic conditions. Processing of feedstock rich in sugar or starch is well established, but processes that handle materials with a high amount of cellulose like straw are still under development. The main challenge is again the dissociation of ligno-cellulose, e.g. by heat and chemicals, and the hydrolysis of the cellulose to sugar monomers that can then easily be processed to ethanol. During recent years, some demonstration plants have been installed in the US and in Europe, but none is yet economically feasible. In this study it is assumed that this technology is economical by 2020 in all three Storylines. Regions with very high straw production are expected to be able to support a straw-based bioethanol plant, which is only expected to be economic at large scale (e.g. more than 200 000 GJ capacity, equivalent to at least 20 000 tonnes straw).

Bio Synthetic Natural Gas (SNG) from straw

The thermo-chemical Bio-SNG process offers the possibility of converting solid organic materials (e.g. wood or straw) to methane-rich gases that can be fed into gas pipelines or used as feedstock to convert further into a liquid fuel (see next under BtL). The Bio-SNG process has five steps: pre-conditioning (crushing and drying); gasification (partial oxidation to CO_2, CO, H_2O, H_2 and CH_4); cleaning of raw gas; catalytic methanisation (CO and H_2 to CH_4); and gas conditioning (high concentration of CH_4). Currently, Bio-SNG plants only process wood. The input of straw creates technical problems due to the high ash content and low melting-point (lower process temperatures are needed, resulting in more tar). Such problems can be solved by applying additives that increase the melting point of the ash, but these techniques are still under development. This pathway, based on straw, is included as an economic option by 2020 in all three Storylines. The same pathway based on wood chips, derived for example from agro-wastes (cuttings) and dedicated crops, is also included, but only when used to convert the gas further into a liquid biofuel as described next.

BtL production from straw

The BtL (Biomass-to-Liquid) concept covers the synthetic production of liquid biofuels (e.g., bio-methanol, di-methylether, Fischer-Tropsch-carbonhydrates (F-T)). The BtL process is based on the production of synthetic gas (gasification or a combination of pyrolysis and gasification) which is processed to liquid fuels with defined attributes. Again – as described above – the chemical composition of straw causes difficulties in BtL processes during gasification and pyrolysis. Currently, a concept producing a straw-pyrolysis slurry in decentralised plants followed by centralised gasification appears most promising. However, BtL plants are still under research and development. They are assumed to be economic in all Storylines by 2020.

Torrefaction of straw

Torrefication is a pyrolytic process under inert conditions that results in a material similar to coal. Torrefied biomass can be co-burned in coal-fired power plants. In general, straw can be torrefied, but the problems with straw described above can cause difficulties. Torrefication plants are still under development and the three Storylines to 2020 are all based on wood.

Final discussion

The optimal plant sizes for the technologies presented in the section above. Straw pellets can be burned in pellet heaters at the household level (30-50 kW_{th}) or in larger heating stations or combined heat and power (CHP) stations making use of bales of straw (about 500 kW_{th} up to 7 MW_{th}/2.3 MW_{el}). Biogas plants using straw as the main input together with manure may reach 500 kW_{el} to 2 MW_{el}. A feasible size for a straw-based Bio-SNG plant may be around 30 $MW_{firing\ thermal\ capacity}$, and bio-ethanol plants may be 10 times and BtL plants 100 times larger. These examples show clearly that some technologies are suitable for decentralised use (thermal and biogas) and others can only be applied on an industrial scale (Bio-SNG, Bio-ethanol, BtL). These, however, may face logistic problems to ensure straw supply which can be up to 4 Mio. tonnes of straw per year for a large BtL plant. Adequate straw availability is therefore assumed in all Storylines when used as a feedstock for the BtL pathway.

In summary, the use of straw for energy is still challenging and under development. However, recent publications show that further optimisation is likely and innovations can be expected in the near future. From an environmental point of view, a very promising pathway is the combined fermentation of straw and manure because it combines the use of two available residues and enables the return of fermentation residues (nutrients, non-digestible organic material) to the fields. Although details on the energy efficiency gain of combining straw with manure in a biogas conversion are still limited, this study assumes a 10 % gain.

Annex 6 Overview of effects on biodiversity resulting from potential shifts toward different types of bioenergy cropping

Type of land use changes	Present land use categories	Type of crops/use:	Typical biodiversity values	Negative impacts on habitat quality	Negative impacts on species	Positive impacts on habitat quality	Positive impacts on species
Shift from **very intensive land use** to bioenergy crops	Horticulture in Glasshouses Polytunnels	Flowers, vegetables	None, biodiversity values have already disappeared.	none	None	Inputs of fertilisers, herbicides and pesticides will be reduced. The same applies to tillage and irrigation practices. This will lead to improved soil and water quality, improved water availability for non-agricultural uses (e.g. biodiversity).	Higher landscape structural diversity improving connectivity and permeability of the landscape for birds and other invertebrate species. Soil biodiversity might benefit from less tillage and decline in inputs of pesticides, heavy metals etc.
	Horticulture	Strawberries, flower bulbs, flowers, vegetables					
	Root Crops	Potatoes, sugarbeet					
Shift from **intensive arable and permanent crops** to bioenergy crops	Sugar, starch and oil crops and intensive fodder crops	Winter wheat, barley, maize, rice, rye, rape, sunflower, temporary grass etc.	None, biodiversity values have practically already disappeared, except for some more common farmland birds and mammals using these crops for shelter and breeding (e.g. maize) and soil biodiversity.	If a shift takes place to a more intensive crop (e.g. winter cereal to sugarbeet) this may lead to higher input use and tillage. This will have negative implications for water (pollution and eutrophication) and soil quality (pollution, erosion and compaction)	If a shift takes place from permanent crops to rotational arable the tillage increases which will have major impacts on soil and water quality and subsequently soil organisms. A shift from maize to rotational arable will diminish shelter and breeding opportunities for mammals and birds.	If shifts take place from rotational arable and permanent crops to perennials this may lead to lower inputs of fertilisers, pesticides, herbicides and water use which will have positive impacts on soil and water quality and water availability.	Shifts from arable to perennials crops will lead to lower mechanisation (tillage) which will be beneficial to soil biodiversity. It will also create greater diversity in landscape structure and provide pockets to support connectivity and permeability of the landscape for birds and mammals.
	Permanent Crops (Intensive)	Fruit orchards, citrus, nuts, olive groves and vineyards					

Shift from **medium to low intensive land uses**	Permanent Grass (Intensive)	Grass, silage production, grazing	Some HNV farmland areas are found in this category, certainly those supporting meadow and steppic birds (e.g. lapwing, partridge, great bustard). Practically no Annex I habitat types occurring here.	If a shift takes place from these categories to more intensive crops (e.g. to sugarbeet, OSR) and a tightening of rotations this may lead to higher input use and mechanisation (tillage). This will have negative implications for water (pollution and eutrophication) and soil quality (pollution, erosion and compaction). In steppic areas with cereal cropping a shift to biofuel crops may encourage increase in irrigation with potential water depletion effects.	Conversion to bioenergy crops may lead to loss of fallow lands, which are an important habitat for species from a range of biota. If permanent grasslands are converted to arable this will have negative impacts on biodiversity and especially ground nesting birds. Further introduction of rotational arable crops in this category will destroy extensive farmland habitats of importance for common birds, cereal weeds and included in the HNV farmland category. When extensive permanent crops are exchanged biodiversity loss will be severe as there are many mammals and birds, but also weeds depending on low intensity olive groves, nut tree plantations and vineyards. Also open steppic agricultural landscapes, which are the typical habitat for steppic birds of prey, may be destroyed by introduction of perennial crops.	If perennials are exchanged for intensive permanent grassland this may lower input of fertilisers which will have positive effect on water quality, but increased tillage (although limited) may encourage soil erosion.	Some species (certain birds and small mammals) might profit from introduction of perennial crops in typical open monotonous permanent grassland or arable landscapes as they provide shelter and nesting opportunities.
	Fodder Crops - with Short term fallow	triticale, alfalfa etc.					
	Extensive arable	Summer wheat, barley, rye, etc.					

Shift from **low intensive land uses** to bioenergy crops	Agro-forestry (incl. Dehesas, Montados)	(Cork) oak, olives, chesnuts, trees-grass, trees-cereals, sometimes grazed with pigs, goats, cows	This type most strongly coincides with HNV farmland. Many Annex I habitat and species types occur in this group. Examples of Annex I: Fennoscandian wooded meadows & wooded pastures; Sclerophellous grazed forests (Dehesas) with evergreen Quercus suber and/or Quercus ilex; Dry sand and wet heath types; Endemic oro-mediterranean heath with gorse; Salt meadows and marshes; Machairs; 2330 Inland dunes with open Corynephorus and	Any shift to bioenergy cropping will entail changes in traditional management, and will generally leasd to increases in input uses, more mechanisation and disturbance of landscape structure. This will have negative implications for potentially water quality (pollution and eutrophication) and quantity and soil quality (pollution, erosion and compaction).	Any shift to bioenergy crops will have an adverse effect on farmland biodiversity as it leads to direct loss of farmland habitats and specific landscape structural composition in which a careful equilibrium exists between low intensity agricultural management disturbance and a mix of species of different biota.	If cuttings of grasslands and other agricultural residues are harvested this may have positive impacts on the quality of semi-natural habitats which on human interference through low intensive management (biomass removal). Biomass demand could be an economic stimulus to continue managing these	Extensive management of semi-natural grasslands creates more opportunities for a wider diversity of farmland birds, invertebrates and small mammals.
	Traditional + long-term fallow	fallow					
	(Mediterranean) scrub, moors and heathlands	some very extensive grazing					
	Permanent grass (extensive)	Extensively grazed					

	Wetlands	Sometimes very extensively grazed	Agrostis grasslands; 2340 Pannonic inland dunes; 5130 Juniperus communis formations on calcareous grasslands; Calcareous grassland; Selicious alpine and boreal grasslands; Semi-natural dry and wet grasslands; Pseudo-steppes with grasses and annuals; Species rich Nardus grasslands; steppic grasslands; Nordic alvars; Molinia meadows on calcareous or peaty soils; Alluvial meadows, Lowland and mountain hay meadows			areas instead of completely abandoning them.	

Annex 7 Overview of environmental risks and opportunities of bioenergy cropping systems

Increased demand for agricultural products is met in part by expanding the areas of land used and in part by intensifying the use of existing land (Tilman *et al.*, 2002; 2009). There is a clear risk that energy crop introduction will exacerbate the trend towards intensification with adverse effects for farmland biodiversity and overall habitat quality. However, the final effect is strongly determined by the type of energy crop introduced, and the type of cropping management that is applied. An overview of possible risks and positive externalities from bioenergy cropping is given below.

• *Destruction and fragmentation of natural ecosystems:*
The transition to large-scale agricultural monocultures often involves the destruction of areas (which may in themselves be small) of high conservation value (e.g. field borders and structural elements of the agricultural landscape, protected area buffer zones and natural ecosystems); this poses an additional threat to biological diversity (MA, 2005).

• *Risks arising from inadequate crop choice:*
Agricultural biomass comprises dedicated bioenergy crops. These can be 'conventional' bioenergy crops such as starch crops (e.g. cereals, sugar beets) or oil crops (e.g. rapeseed, sunflower) as well as perennial grasses or short rotation forests on agricultural land.

At present there are no specific energy varieties among the annual crops grown for bioenergy production. Amongst conventional annual crops, cereals (rye and barley) and sunflowers usually have a better environmental profile (EEA, 2006), whereas wheat, grain maize, potatoes, sugar beet and oilseed rape have a relatively high negative impact on the environment. Nutrient input is generally high for these crops but varies strongly between countries and farming practices (EEA, 2006).

As a general rule, crops are less beneficial for biological diversity and carbon stocking in the soil than forests, grasslands or pastures. Perennial crops such as *Jatropha*, oil palm and short rotation plantations of for example willow and poplar rate better on these factors than one- to three-year crops such as rape, cereals or maize. Once the plantations are established, not when they come in the place of natural or semi-natural vegetation.

Woody SRC crops have a rotation time of at least 15 years; harvest of the biomass will only start after 2 to 5 years. Also, input use and machinery requirements are much more limited than with arable crops. Further they have deep roots and there is less need to dig or plough soil, so these crops, should reduce nitrate leakage into water supplies – a common problem for agricultural land treated with nitrogen-based fertiliser. Further weed control is required for short rotation coppice before cultivation and shortly after planting (Tubby and Armstrong, 2002).

Similarly, miscanthus only requires pesticide application during the early establishment phase to keep out competitors (Bullard and Metcalfe, 2001). For most of the growing cycle, therefore, no additional pesticide is required, resulting in lower probability of contamination of groundwater sources through pesticide than with annual food crops.

Many perennials are also shown to improve soil quality, increase the amount of carbon sequestered in the soil, and reduce soil erosion. SRC crops for example have the potential to increase biodiversity, although they are less beneficial to ecosystems than natural habitats such as woodlands and natural grassland and intense management of such crops can interfere with wildlife. However, measures such as carefully planned planting density and location, and the introduction of crop types that are preferred by nesting birds, could help to maximise the benefits and provide greater biodiversity than is found on traditional arable land (Rowe *et al.*, 2007)

• *Risks arising from inappropriate crop rotations:*
Every crop is grown in a certain rotation with other crops, which often differ significantly between regions or even between single farmer practices. There are substantive differences in terms of biodiversity between varied crop rotations and mono-cropping practices. As we can observe in Germany the rising demand for maize and rape for biogas and biodiesel increase their portion of crop rotation. From the biodiversity perspective structural variety is lost and besides new problems occur e.g. resistance problems of the rape gloss beetle, increased occurrence of the European corn borer, whereby the demand for genetically modified organisms (Bt-corn) or pesticides increases.

• *Risks arising from the loss of agrobiodiversity:*
Agrobiodiversity provides important ecosystem services for sustainable agriculture (pollination, nutrient recycling, erosion protection etc.), but agrobiodiversity may be lost in the conversion of small-scale, biodiverse farming systems into large scale monocultures. This form of intensification is linked with the genetic erosion of varietal diversity (Phillips and Stolton, 2008).

• *Risks arising from over-fertilization and eutrophication:*
Increased tillage, erosion and sediment removal can pose a risk to natural ecosystems even at a considerable distance (WGBU, 2008; 2009).

• *Risks arising from pesticide pollution:*
The input and accumulation of pollutants can pose a significant risk to biological diversity unless limits are set to pesticide use and integrated plant protection is pursued within a framework of sustainable agricultural practice.

• *Risks arising from the overuse of water resources:*
Beyond the risk of increasing diffuse pollution, water availability might prove another key concern. Agriculture is already a significant user of water resources in the EU, in particular for irrigation. The impact of irrigation differs between countries and regions, due to climatic conditions and land uses, but there are concerns that bioenergy cropping will increase this water stress in several areas due to increasing irrigation which often comes additional to the water demand of agricultural crops that are already grown in a region or which is a new irrigation water demand in the case of newly converted land cover changes from (semi-)natural to bioenergy crops. High water demand from fast-growing perennial energy crops was identified as a key environmental risk in an expert workshop on short rotation coppice and energy grasses (JRC-EEA, 2006). Overuse of local water resources for agriculture often goes hand in hand with the loss of wetlands. Wetlands harbour above-average diversity but at the same time they are at particular risk from conversion and degradation (IWMI, 2007).

• *Risks arising from invasive alien species:*
An underestimated problem concerns the introduction of new energy crop species. Several perennial species or hybrids with high biomass yield and high tolerance to different environmental conditions may be attractive for cultivation. However, usage and distribution of these species may become uncontrolled causing these species to invade natural habitats which would result in the loss of natural biodiversity (Eppler *et al.*, 2007).

• *Risks arising from the spread of genetically modified material:*
The use of genetically modified organisms entails the risk that genetically modified material will spread in wild populations (WBGU, 2009).

These effects of intensification apply both to energy crop cultivation systems and to other intensive farming systems. However, there is a difference between the bioenergy farming systems in use today, which have ecological impacts very similar to those arising from the intensive production of food (e.g. cereals), feed (e.g. soya) or feed stocks (e.g. cotton) (SCBD, 2008), and the energy crop cultivation systems that are expected to proliferate in the future which will enable the whole plant to be used (Doyle *et al.*, 2007). In terms of some of these ecological impacts the latter type score more positively if perennial, biodiverse cultivation systems are used in which only above-ground biomass is harvested and little tillage takes place.

The yields obtained from these cultivation systems will also be improved if the crops are well supplied with nutrients and water through fertilization and irrigation; much will depend on whether these additional inputs are economically feasible and applied in a sustainable manner. For the moment, however, these considerations remain theoretical. Since use of these new farming systems is not yet widespread, there is as yet little concrete evidence of their positive or negative impacts on biological diversity (SCBD, 2008).

Annex 8 Bioenergy cropping data sources used for EU-27 countries

Introductory note: *This annex aims to provide a comprehensive and up-to-date picture as far as possible. Complete and recent data are difficult to obtain but an update of this annex will be attempted over the summer 2012. The review of this annex will probably then also include the elimination of unnecessary or too detailed information.*

In 2007 the European Commission tendered a study with the specific objective to analyse the different water needs and distribution of bioenergy crops grown or potentially grown in the next decades in the EU. The resulting report (Dworak *et al.*, 2009a) contains an overview of the dedicated bioenergy cropping area which has been used for this study and which has been updated with additional (more recent) sources from AEBIOM (2009). The reference year for the data ranges between 2006 and 2008. The main sources used to produce Table 1 are listed below per country.

Table 1 *Dedicated bioenergy cropping area in 2008* (hectares)*

	Oilseed rape	Sun-flower	Wheat	Barley	Sugar beet	Maize (biogas and bio-ethanol)	Other arables (e.g. sorghum)	Reed Canary Grass (RCG)	Willow	Poplar	Miscan-thus	Hemp
Belgium	959		1173	191	0	660	0	0				
Bulgaria		258094	0		0	0	0	0				
Czech Republic	104000		0		0	0	0	0				
Denmark			51300	42750	0	0	0	0	2500			
Germany	1105000		78080	49920	3000	295000	0	0		500	300	
Ireland											2000	
Greece		11220	0		0	0	0					
Spain		150223	11902	21159	0	0	104			18		
France	885687	66665	225000	75000	50000	50000	0		500		1500	
Italy	5200	59800	0		0	0	0	0	0	6000	7500	
Hungary	10175	8325	0		0	0	0					
Netherlands	2500		0		0	500	0					
Austria	10200	4800	855	645	0	40000	0					300
Poland	740740		0		0	0	0		7000		13500	
Romania	22746	545912	0		0	0	0					
Finland	821		119	320	0	0	0	18700				
Sweden	50000		19600	15400	0	0	0	780	13000			390
United Kingdom	320542		10824	5093	0	0	0		5500		13500	
Total	**3258571**	**1105038**	**398852**	**210479**	**53000**	**386160**	**104**	**19480**	**28500**	**6518**	**38300**	**690**

Source: Dworak et al. (2009b) and AEBIOM. For detailed information on data sources used see overview in this Annex.
** Figures are only given for countries for which information was found on energy cropping areas.*

Austria

Bioenergy production in 2006 (Brainbows Informationsmanagement GmbH (2007) and Raab (2007)):
SRC (Miscanthus und others): some 100 ha
Cereals for heating: more than 1,500 ha
Biogas (Silage Maize and fodder: around 40,000 ha
Bioethanol: no production ha
Rape seed (biodiesel): about 15,000 ha

Belgium (only Flanders)
Information was received from Linda Meiresonne working for the Linda Research Institute for Nature and Forest. The underneath figures were derived from the Ministry of Agriculture. Arable crops: inventory based on applications for energy subsidy (45 €/ha) or set aside subsidy.
Energy – Situation 2007:
Rapeseed: 507 ha
Wheat: 200 ha
Mais: 521 ha
Energy – Situation 2008:
Rapeseed: 116 ha
Mais: 508 ha
Set aside – Situation 2007:
Rapeseed: 452 ha
Wheat: 1,164 ha
Mais: 139 ha
Tricale: 2 ha
The Flemish region had 622,133 ha of agricultural land in 2007 (normal arable land and set-aside). So 0.45% of the agricultural area was occupied with targeted energy crops.

Bulgaria
A rough indication on oil cropping area for biodiesel purposes were derived from a European Biodiesel Board (EEB) report.
In this report it is stated biodiesel production first started in Bulgaria as early as 2001, and was mainly based on used cooking oils collected from restaurants, as developed by the company SAMPO in Brussartzi (North-Western Bulgaria). However, there has been a rapid increase in production of sunflower and rapeseed-based biodiesel. Today indeed, the energy crops used as raw material for biodiesel are mainly rapeseed and sunflower, although it should be noted that some climatic restrictions exist for rapeseed cultivation' (Garofalo, 2007).
Based on this statement the present area of rape and oil seeds was taken from the FSS 2007 and then it was assumed that 1/3 of the production coming from this area was used for biodiesel production.
This leads to the following cropping area:
Oil seed rape: 335 ha
Sunflower: 257,759 ha
Total: 258,094 ha

Cyprus
The hectares in agriculture used for bioenergy cropping in Cyprus is zero. In general the main reasons for not having such a RES in Cyprus is a) the requirements in high level technological knowledge (planning of installation, treatment of raw material). b) Lack of previous experience, c) Increased water requirement of energy crops in relation to the water stressed agriculture (Personal communication Ayis I. Iacovides).

Denmark:
Information on the cropping area was derived the Danish Ministry of Food, Agriculture and Fisheries, which specifies a total area of 95,000 hectares of oil seed rape. Leppiman (2005) also specifies that in Denmark biomass (mainly straw, wood and manure) accounts for nearly 10% of the total energy production.

Estonia
Today energy crops (mainly rapeseed) are grown within an area that does not exceed 50 thousand hectares. The harvest is about 70 – 80 thousand tonnes, which is not sufficient to produce biodiesel. Cereal production (approximately 600-760 thousand tonnes) does not currently cover domestic demand for fodder, foodstuff, seed and

industrial needs. Therefore additional cereal is being imported to cover demand (not for conversion into ethanol) (Barz and Ahlhaus, 2005).

France

Until 2005 bioethanol in France was produced primarily from sugarbeet and secondarily from wheat: most bioethanol production is likely to be derived from wheat in 2008, at the expense of sugarbeet. According to the French Ministry of Agriculture, 300,000 hectares of wheat, 50,000 hectares of corn and 50,000 hectares of sugar beet are expected to produce bioethanol by 2008. For wheat and corn, this will represent less than 5% of the total grain acreage (Hénard and Audran, 2007).
France: Situation 2007/2008:
OSR: 872,352 ha
Sunflower: 80,000 ha
Corn maize: 50,000 ha
Starch (cereals): 300,000 ha
Sugerbeet: 50,000 ha
Total: 1,352,352 ha

Germany

There is significant increase in biomass cultivation for bioenergy purpose in Germany. The biggest production is focused on biodiesel. The oil seed crop cover already over 1,100,000 hectares, which is almost 10% of the arable land (Table 1). Germany as a large central European country has 11.8 mill. hectares of arable land. Future biomass potentials in Germany for energy crops are stipulated to be even up to 2 mill. hectares or 17% of the arable land on medium to long terms.

Rapid growth in interest in biogas has been noticed recently in Germany. Between 2004 and 2005 the area dedicated for biogas energy crops increased over six times. Around 80% of the applied crops is maize, harvested for maize silage. Further growth is expected. In 2007 Germany had the highest number of biogas plants in Europe (around 3000). Biogas is produced from manure, industrial organic waste but especially from cultivated energy crops. Energy crops state for over 46% of the substrates. Share of animal manure is around 24% of feedstock applied for biogas in Germany. The biogas potential in Germany was calculated as 24 bill. m3 biogas per year. The amount will increase rapidly and boost the number of biogas plants.

__Table 2__ Cultivation of non-food crops in Germany in 2006

Table VIII: Cultivation of non-food crops in Germany in 2006 [28]

Raw materials	Surface area in ha			Total
	Base areas*		Set aside	
	without energy crop premium	with energy crop premium		
Rapeseed	610,000	172,000	318,000	1,100,000
Oilseed lin	3,000			3,000
Sunflower	4,000		1,000	5,000
Other energy crops(incl.maize)	30,000	188,000	77,000	295,000
Starch	128,000			128,000
Sugar	18,000			18,000
Fibres	2,000			2,000
Pharmaceutical crops	10,000			10,000
Total	805,000	360,000	396,000	1,561,000

*estimate, as no detailed data and trade statistics available

Source: http://websrv5.sdu.dk/bio/JHN_paper_07.pdf

Energy Maize production Germany 2008-2009:

Maisanbaufläche Deutschland in ha, 2008 und 2009 (vorläufig)
nach Bundesländern und Nutzungsrichtung in ha

Bundesland	Körnermais inkl. CCM		Silomais		Futter- oder Energiemais*		Energiemais		Anbaufläche gesamt	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
Baden-Württemberg	71.625	67.325	63.236	69.989	1.464	0	30.076	25.707	166.401	163.021
Bayern	95.821	64.822	322.767	319.860	5.737	10.780	49.474	53.029	473.799	448.490
Brandenburg	9.279	9.109	142.892	145.055	0	0	4.327	4.839	156.498	159.003
Hessen	4.413	2.180	26.476	27.481	1.503	1.181	4.609	4.655	37.001	35.497
Mecklenburg-Vorpommern	7.404	1.033	91.980	66.463	413	10.228	16.702	21.867	116.499	99.591
Niedersachsen	110.136	102.575	243.977	242.651	82.962	93.432	37.724	50.672	474.799	489.329
Nordrhein-Westfalen	111.823	111.326	126.325	121.201	4.731	9.347	16.521	16.374	259.400	258.249
Rheinland-Pfalz	741	741	19.995	21.264	2.645	2.645	11.320	11.320	34.700	35.970
Saarland	.	.	.	.	.	.	.	.	.	.
Sachsen	39.203	40.585	40.563	38.722	0	0			83.200	82.741
Sachsen-Anhalt	21.817	22.752	69.828	65.599	0	0	9.355	15.941	101.000	104.293
Schleswig-Holstein	0	0	106.753	118.676	4.323	3.603	24.346	34.742	131.099	153.418
Thüringen	120	120	44.456	47.074	3.434	3.434	600	985	49.500	51.782
Bundesgebiet	472.382	422.568	1.299.249	1.284.035	107.212	134.648	205.053	240.132	2.083.896	2.081.382

Quelle: DMK, Kleffmann, Stand Mai 2009
. = kein Wert vorhanden
* = Verwendung als Energie- oder Futtermais noch offen, großenteils Energiemais

DMK

Greece
The Hellenic Ministry of Rural Development and Food has outlined that during 2007 (Panoutsou, 2008):
Approximately 73,000 tonnes of indigenous oil seeds (mainly comprising of 69,000 tonnes cotton seeds) would be used for biodiesel production,
In addition, 11,200 hectares of agricultural land would be cultivated with energy crops, under contractual schemes, for biodiesel production.
Hellenic Sugar Industry announced in 2006 that two sugar mills in north (Xanthi) and central (Larisa) Greece will be converted to bioethanol plants. This fact is expected to provide robust incentives for energy farming, since the annual resource requirements of the two plants are expected to be in the range of 600,000 tonnes of sugar beets and 600,000 tonnes of cereals (since these were estimates and no confirmation was found for the plants already being in production these areas were not taken into account in this study).
Situation 2004:
Maize crop: 10,628 ha
Total crop cultivation for biogas: 13,603 ha
Situation 2005:
Maize crop: 66,988 ha
Total crop cultivation for biogas: 86,912 ha

Hungary
In Hungary on 18,500 hectares energy crops were grown in 2008 (Doran, 2008).

Ireland
At present, biomass provides over half of Ireland's renewable energy - mainly through wood used for heating in the domestic and wood processing industry sectors (Bruton and McDermott, 2006).

Italy
Biodiesel in Italy is mainly produced from rapeseed oil (about 70% of the total) and soybean oil (20%), with the remainder coming from both sun and palm oils. Rapeseed oil is imported from other EU countries, while soybean oil is either imported from the EU or domestically produced from imported beans (oil from domestic beans, being GM free, is used for food consumption). According to industry sources, this year (2007) some 65,000 hectares have been or will be planted to oilseeds (50,000 hectares to sunflower seeds and 15,000 hectares to rapeseeds) under cultivation contracts between growers and the processing industry for the production of biodiesel. In 2006 bioethanol production rose to 1,280,000 hectoliters, obtained from alcohol produced from both the distillation of wine surpluses and molasses (Perini, 2007).

Poland
With plantations of about 2,000 hectares (2006) willows are mostly used as energy crop. Secondly, straw is becoming more popular for energy use, but it is currently only marginal in relation to overall production. Poland has set a target for expanding the area used for energy crops up to 160-200 thousand hectares in 2010 representing 1.2 – 1.4% of whole arable land in Poland. It may be an alternative sources of income for farmers. Now cultivation area of energetic willow is only 5.4 thousand hectares (Wesolowski, 2005).

Portugal
9,000 hectares area under energy crops in 2008 (Doran, 2008)

Romania
Romania has a significant potential for production of bioethanol from sweet sorghum and biodiesel from rape oil and sunflower oil. It also has very good prospects as a net exporter within the EU. In Romania, in 2004, almost all of 100,000 tonnes of rapeseed, 70,000 tonnes of sunflower and 408,000 tonnes of sunflower seeds were exported possibly for bioenergy production (Kondilia and Kaldellis, 2007).

UK
Final data used were derived from www.nnfcc.co.uk (National non-food crops website). The data on this website specify the following (in hectares):

England: SRC-willow: 3,083 ha SRC-poplar: 5 ha Miscanthus: 5,772 ha	Wales: SRC-willow: 7 ha	Scotland: SRC-willow: 289 ha	N-Ireland: SRC-willow: 289 ha	UK *(region unknown)*: SRC-willow: 2,486 ha Miscanthus: 1,960 ha	Total: OSR: 320,542 ha Wheat; 14,614 ha Barley: 1,303 ha SRC-willow: 5,865 ha SRC-poplar: 5 ha Miscanthus: 7,732 ha

In addition other information was also provided on: http://www.rcep.org.uk/biomass/chapter2.pdf

It specified that willow (Salix spp.) has already been used in commercial or near commercial operations in the UK. Investment in developing new varieties with increased yield stability and improved crop management has made willow increasingly competitive as an energy source. Willow chips are a reliable source of fuel of a consistent quality, suitable for firing in CHP and district heating plants. Willow has been grown extensively in Scandinavia for fuel, and in Sweden some 15,000 hectares of land are dedicated to its production for renewable energy. Consequently, much more information about cultivation, harvesting and yields is available for willow than for the other potential energy crops.
The grass miscanthus (Miscanthus spp.) is attracting an increasing amount of interest but it is still largely at trial stage in the UK. Among other potential candidate species, poplar (Populus spp.) is closest to providing an alternative source of fuel. Poplar is being trialled in short rotation coppice (SRC) plantations, as well as being tried in silvoarable agro-forestry where it is intercropped with arable species.
There are currently 1,795 hectares of land under cultivation of commercial willow SRC and miscanthus in the UK; at least 1,500 hectares of this is willow. The land dedicated to energy crops totals less than 0.01% of the total arable land in the UK. The Defra Non- Food Crops Strategy states that domestically grown crops should meet a significant part of the demand for energy and raw materials in the UK. The National Farmers' Union suggests that up to 20% of crops grown in the UK could be made available for non-food uses (i.e. for fuels or industrial materials), by 2020; hence, there is scope for a significant expansion of energy crop production in the UK. Planning crops in order to achieve the maximum environmental benefits and yields in areas close to demand is the challenge to be met by the farmers and energy generating companies.
http://www.defra.gov.uk/farm/crops/industrial/research/reports/biofuels_prospects.pdf

In 2001, over 23,000 hectares of oilseed rape was grown on UK farms for biodiesel production, though virtually all was processed in mainland Europe on an .equivalence trade basis.. Until recently UK biodiesel production was limited to 200 tonnes. The reduction in duty from April 2002 is likely to increase this significantly. However, currently no crops are registered for bioethanol production on set-aside and no bioethanol is currently being produced.

Annex 9 Loss of grassland in Germany

Permanent grassland habitats are often characterised by high biodiversity value, mainly in terms of the species composition and richness, the relative abundance of species as well as the vegetative structure (Hopkins and Holz, 2006). Due to their biodiversity value many grassland-habitats are included in the High Nature Value farmland category in the EU. In European countries like Germany, the loss of semi-natural and extensive grassland is a major driver for the loss of biodiversity (Lind *et al.*, 2009). During the period from 2003 to 2009, the threshold of 5 % for loss of permanent grassland under the EU cross-compliance policy was already exceeded by five federal states (combined with two largely urban states) in Germany: Mecklenburg-West Pomerania; Lower Saxony & Bremen; North Rhine-Westphalia; Rhineland-Palatinate and Schleswig-Holstein & Hamburg (Table 1). The other federal states experienced grassland losses of 2.7 to 4.2 %. Only Hesse showed a slight increase of its grassland area (+0.83 %). The total average loss of grassland in Germany amounts to 4.5 % (-226,000 ha) in the time period (Table 1).

Table 1 *Grassland (GL) area share and change in Germany between 2003 and 2009*

	Area 2003		Area 2009		Change of area 2003-2009	
	1000 ha	Proportion	1000 ha	Proportion	1000 ha	Proportion
GRASSLAND						
Baden-Württemberg	567	39.7%	549	38.8%	-18	-3.1%
Bavaria	1,151	35.7%	1,111	34.7%	-40	-3.5%
Brandenburg & Berlin	295	22.0%	286	21.5%	-9	-3.23%
Hesse	299	36.9%	302	37.9%	3	+0.83%
Mecklenburg-West Pomerania	278	20.3%	260	19.2%	-18	-6.4%
Lower Saxony & Bremen	764	29.0%	708	27.2%	-56	-7.3%
North Rhine-Westphalia	463	29.9%	436	28.5%	-27	-5.8%
Rhineland-Palatinate	251	37.6%	235	35.8%	-16	-6.3%
Saarland	42	51.1%	40	51.3%	-2	-3.8%
Saxony	192	20.9%	187	20.6%	-5	-2.7%
Saxony-Anhalt	179	14.8%	171	14.3%	-8	-4.2%
Schleswig-Holstein & Hamburg	363	35.0%	338	32.7%	-25	-6.9%
Thuringia	181	22.4%	174	21.7%	-7	-3.7%
Germany (total)	**5,024**	**29.4%**	**4,798**	**28.4 %**	**-226**	**-4,50%**
ARABLE LAND						
Arable land (total)	**11,827**	**69.2%**	**11,933**	**70.6%**	**106**	**0,10%**
SETTLEMENTS/STREETS						
Settlements/ streets	**4,514**	**--**	**4,742**	**--**	**228**	**2,30%**

Source: Grassland data from Behm (2009), up-date from Behm (2008, cited in Lind *et al.*, 2009); arable land and settlements/streets from Statistisches Bundesamt Deutschland www.destatis.de

During the same period, the amount of arable land increased and urban areas (settlements and streets) increased about 106,000 ha and 228,000 ha, respectively (see Table 1). This seems to suggest that grasslands have been directly converted to arable land and urban areas and additional land not covered before in the statistics has been taken into use again. In-depth analysis of the turn-over of grassland and arable land based on small scale InVeKoS data for three federal states (NABU, 2009) reveals that the turn-over may be about 3-6 times higher than the balance sum (balance sum is the difference of registered arable land and grassland; compare Figure 1). This means from a nature protection view point that an even higher proportion of grassland with biodiversity value may have been destroyed than indicated by the balance sum.

Regarding an increased need of land for agriculture, bioenergy production may have put further pressure on grassland, both through direct and indirect land use changes (dLUC and ILUC) (Lind *et al.* 2008). Beside loss of grassland there are also cases reported of further intensification of grasslands in recent years which also cause additional biodiversity losses. These changes are not directly visible in statistical data on land use changes but can only be illustrated in monitoring studies (e.g. Osterburg *et al.*, 2008).

Although hard evidence is difficult to get, there seems to be a causal relationship between increased dedicated biomass cropping, especially the increase of maize cultivation, and the loss and intensification of permanent grassland area: the area used to cultivate crops for non-food purposes increased from about 850,000 ha in to 2003 to about 2 Mio ha in 2009 (FNR, 2010; total arable land in Germany in 2009: 11.9 Mio ha). Maize cultivation was probably the most important driver for grassland change (NABU, 2009, see Figure 1 and Table 1), which is used as sole feedstock source or in combination with manure in biogas installations. These installations are more often found on livestock farms, where most of the permanent grassland resource is concentrated, than on arable farms.

Figure 1 *Analysis of InVeKoS (Integriertes Verwaltungs- und Kontrollsystem) data from 2005 to 2007 (sum for MV, NI, NW, RP). a) Visualisation of analysis; b) Changes in grassland areas. Source: NABU (2009)*

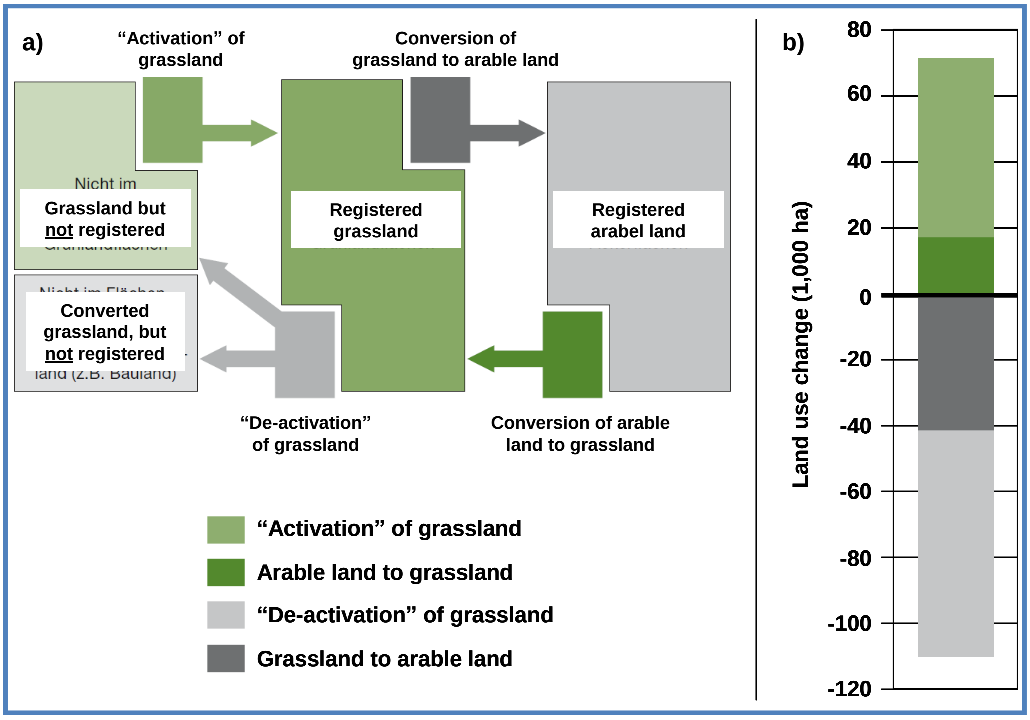


Figure 2 *Change of grassland and maize area. Net-calculation based on InVeKoS-Data of Mecklenburg-West Pomerania, Lower Saxony, North Rhine-Westphalia and Rhineland-Palatinate from 2005 to 2007.*

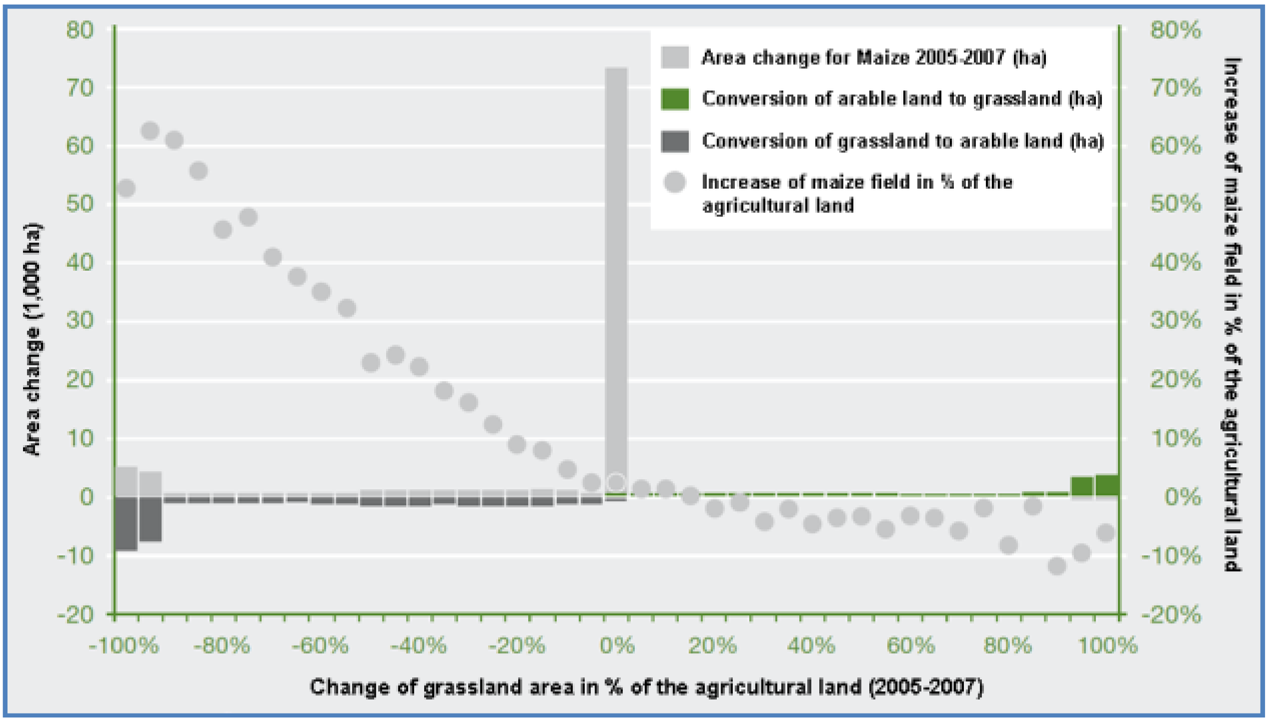


Table 2 *Change in energy and total maize area in Germany (2005-2009).*

	2009	**2005**	**2009**	**Change (2005-2009)%**	**% energy maize total**
Baden-Württemberg	163021	4054	25707	534%	15.8%
Bayern	448490	18167	53029	192%	11.8%
Berlin		0	.	0%	.
Brandenburg	159003	1994	4839	143%	3.0%
Bremen	.	0	0	0%	.
Hamburg	.	0	0	0%	.
Hessen	35497	778	4655	498%	13.1%
Mecklenburg-Vorpommern	99591	2287	21867	856%	22.0%
Niedersachsen	489329	27419	50672	85%	10.4%
Nordrhein-Westfalen	258329	7592	16374	116%	6.3%
Rheinland-Pfalz	35970	1277	11320	786%	31.5%
Saarland	.	0	.	.	.
Sachsen	82741	482	.	.	.
Sachsen-Anhalt	104293	1260	15941	1165%	15.3%
Schleswig-Holstein	153418	4108	34742	746%	22.6%
Thüringen	51782	256	985	285%	1.9%
Total	**2081382**	**69674**	**240131**	**245%**	**11.5%**

Source: Data from BLE, DMK, Kleffman

Annex 10 Price estimates of biomass sources in 2020

In order to determine the availability of different biomass feedstock types to be included in the total biomass potential per storyline estimates were made of 2020 cost levels as a proxy for at gate prices. This implies that for every feedstock type a cost level is estimated including an average cost estimate for transport of the feedstock per ton to the plant gate. For perennials, this was estimated to be an extra 10 €/t_{DM} for pre-treatment (chipping etc.) and transport to the gate.

These cost levels were estimated to determine which feedstock potentials could be included in the potential per storyline. In Storyline 1, the maximum at-gate price levels for biomass feedstocks for bio-heat and bioelectricity was set to 3 €/GJ. In Storylines 2 and 3, this level was set at 6€/GJ which allows for the use of more expensive feedstock, e.g. from less fertile land.

Different information sources were used to derive these cost estimates, with data from the Biomass Futures project being a key input (http://www.biomassfutures.eu/ [51]). An overview of the sources used and the way final cost levels were calculated is given in Table 1 for agro-biomass sources. These costs were used to estimate which part of the domestic biomass potentials from the forest and waste sectors were available in the three storylines, and were used as a price proxy. Table 2 gives an overview of the national average costs per biomass feedstock type used for the calculations of available biomass per feedstock. However, as the perennials were estimated at regional levels. Tables 3 and 4 provide cost and yield level estimates in the different management systems.

[51] See http://www.biomassfutures.eu. Although the potential estimates in the Biomass Futures project were made taking other scenario assumptions as a start, the cost level estimates followed a similar methodology. Further detail on this is given in the Biomass Futures report (Elbersen *et al.*, 2012: www.biomassfutures.eu/public_docs/final_deliverables/WP3/D3.3%20%20Atlas%20of%20technical%20and%20economic%20biomass%20potential.pdf.

Table 1 *Approach and sources used for estimating price levels for agro-biomass sources in 2020*

	Reference(s) used	**Elaboration/assumptions**
Dry manure Wet manure	Lensink *et al.*, 2010, Conceptadvies basisbedragen 2011 voor electriciteit en groen gas in het kader van de SDE regeling. ECN-E--10-053	It is assumed that in regions with large (excess) manure production there is more incentive and likeliness for occurrence of economies of scale that will lead to conversion into biogas. The threshold taken above which manure is expected to become a potential is 100 kg N/ha. The price of manure in regions with a large manure excess is assumed to be 0 Euro/ton. In regions with limited or no excess a price is expected to be paid to compete with use of fertilisers which ranges between 40 and 80 Euro/ton manure.
Straw	Trhän *et al.* 2011	The price level of 50 € /t was taken from Thrän *et al*, (2011) for regions with an excess straw potential (total straw production minus straw denand from competing uses), and a level of 80 €/t was assumed in regions where there is limited straw availability, and, hence, more competition.
Prunings from fruit trees, nuts, vineyards, olives and citrus.	National cost levels for supply costs for agricultural residues derived from Siemons *et al.*, 2004, extrapolated to 2020 taking account of inflation levels.	
Rotational crops	EC. 2010f *Prospects for agricultural markets and income in the EU 2010-2020.* Blanco Fonseca, M. *et al.*, 2010, Impacts of the EU biofuel target on agricultural markets and land use: a comparative modeling assessment. JRC 58484	Price levels at regional level were taken from the CAPRI model for the baseline scenario for 2020.
Perennials 2008	1) Carrasco & Sixto, expert consultation Rothamsted, 2007. In: Eppler *et al.*, 2007. and Mitchell, 1999 2) Schweinle, 2007, Erricson, 2006 and Dudly and Riche *et al.*, 2007. 3) Christian and Riche, 1999. Monti *et al.*, 2007, Kanna *et al.* 2008. 4) Dudly and Riche *et al.*, 2007.	Production cost estimates were made for poplar 1), Willow 2), Miscanthus and Switchgrass 3) and Reed Canary grass 4) based on different publications (see left column with references per corresponding number). In these references a detailed overview was provided of types of cost-yield level and management combinations. In order to extrapolate the cost to other EU regions the yield level in every region was used as a distribution factor. The yield levels for perennials were estimated according to the methodology described in Annex 12 of this report. A distinction is made in cost for high yield, medium yield and low yield cropping systems.

For the rotation biomass crops the ,modelled Capri price levels in 2020 were taken.
For the perennial biomass crops this information was not available in Capri so other information sources had to be used and own calculations were made. In order to calculate the average cost per ton dry matter (DM) of a perennials crop in every EU NUTS 2 region, the yield levels per hectare per crop in a high, medium and low input

system were matched with published cost levels per hectare. High input systems were matched with published cost levels for a high input system, preferably estimated for a similar climate region (if available, otherwise data from a bordering climatic zone were applied). The cost levels per hectare could then be re-calculated to cost per ton dry mass by dividing the per hectare costs by the yield levels reached for every perennial crop per region. Crop level estimates were made using the GWSI crop growth models as explained in Annex 12.

Table 2 *Overview of average prices for agro-biomass feedstocks in 2020 (feedstock costs, dry matter, at gate price in €/GJ (LHV))*

2020	Dry manure	Wet manure	Straw	Prunings (fruit trees, vineyards, olives, citrus, nuts)	Maize/corn (bioethanol)	Forrage maize (biogas)	Rape	Sugarbeet	Sunflower	Cereals (wheat+ barley)	Grassland cuttings abandoned grasslands
AT	2.9	26.2	3.9	2.5	29.9	4.9	17.7	25.4	20.0	9.8	3.9
BG	2.9	26.2	3.3	1.0	29.8	5.1	15.9	21.7	16.2	7.9	3.3
BE/LU	0.9	7.9	4.4	2.1	32.3	4.0	21.3	24.2		10.5	4.4
CY	2.9	26.2		0.9		137.0				24.5	3.4
CZ	2.9	26.2	3.8	0.8	28.6	12.6	18.3	25.8	24.9	10.1	3.8
DE	2.0	18.3	3.5	2.1	31.4	5.3	20.2	27.6	24.1	10.3	3.5
DK	0.0	0.0	2.3	2.1	19.6	6.0	24.0	26.7		11.0	2.3
EE	2.9	26.2	3.8	1.1			20.6	21.4		7.3	3.8
EL	2.9	26.2	3.9	1.8	47.1	7.9		23.7	39.0	15.6	3.9
ES	2.4	21.3	2.9	0.8	38.7	1.1	18.9	30.8	25.4	11.7	3.4
FI	2.9	26.2	3.8	1.5	19.6		21.3	30.2	20.7	10.3	3.8
FR	2.5	22.7	2.8	2.3	30.8	3.6	20.7	20.4	22.4	10.5	2.8
HU	1.3	11.2	2.8	0.8	23.0	4.9	18.3	28.6	24.1	9.0	2.8
IE	2.9	26.2		2.9	19.6		20.7	30.7	14.8	9.2	2.9
IT	2.3	21.0	3.6	1.2	35.7	32.5	16.7	22.1	19.6	14.0	3.6
LT	2.9	26.2	2.3	1.0	39.4	33.3	17.8	24.8		8.3	2.3
LV	2.9	26.2	3.1	1.0		13.9	18.0	26.7		7.9	3.4
MT	2.9	26.2		0.8						16.5	3.4
NL	1.2	10.9	5.9	2.4	43.2	4.2	13.7	26.2	14.8	10.2	5.9
PL	1.6	14.8	3.7	0.9	4.1	2.9	8.9	14.2	10.0	8.1	3.7
PT	2.1	18.7	3.1	1.8	5.4	8.7	0.0	10.1	14.9	10.4	3.4
RO	2.9	26.2	2.5	1.2	6.7	26.6	6.8	2.7	11.5	10.3	3.4
SE	2.2	19.7	3.9	2.1	0.0	9.9	9.9	6.8		8.1	3.9
SI	2.9	26.2	3.8	1.2	4.6		11.2	15.6	13.7	11.9	3.8
SK	2.2	19.7	3.8	1.2	4.2	0.5	7.6	13.7	13.8	8.6	3.8
UK	2.9	26.2	3.1	1.3	0.0	2.9	11.1	11.8	14.5	10.0	3.1

As to perennials we relied on published cost specifications derived from cropping trials and experiments in several regions in the EU. In Table 3 an overview is given of the cost level estimates found in the literature per perennial type.

Table 3 *Yield and cost levels for perennials (Yields calculated according to methodology described in Annex 12).*

		Yield in tn/ha									Cost estimate (€/t_{DM})								
		RCG			miscanthus			switchgrass			RCG			miscanthus			switchgrass		
Code	NUTS_NAAM	high	medium	low	high	medium	low	high	medium	low	high	medium	low	high	medium	low	high	medium	low
AT110000	Burgenland (A)	17	15	8	18	15	8	13	12	8	38	42	65	81	64	83	94	66	77
AT120000	Nieder÷sterreich	15	15	8	15	15	8	11	12	8	41	42	65	94	64	83	110	66	77
AT210000	KΣrnten	12	12	7	10	10	6	7	8	5	49	49	80	136	91	119	160	95	111
AT220000	Steiermark	14	14	8	13	13	7	9	11	7	43	43	69	105	71	92	123	74	86
AT310000	Ober÷sterreich	13	13	7	12	12	7	8	10	6	45	45	73	116	79	102	136	82	95
AT320000	Salzburg	11	11	6	9	9	5	6	7	4	51	51	84	154	103	135	181	107	126
AT330000	Tirol	10	10	6	7	7	4	5	5	3	57	57	94	203	135	178	240	140	165
AT340000	Vorarlberg	10	10	5	6	6	3	4	5	3	58	58	96	220	146	192	260	152	179
BG010000	Severozapaden	18	16	10	20	18	11	14	15	10	36	39	57	72	63	78	98	65	73
BG020000	Severen tsentralen	19	15	10	22	18	12	15	14	11	35	40	55	68	63	73	92	66	69
BG030000	Severoiztochen	19	14	11	23	16	13	16	13	11	34	44	53	66	69	71	90	72	67
BG040000	Yugoiztochen	20	14	11	23	16	13	16	13	11	34	44	53	66	72	71	89	74	67
BG050000	Yugozapaden	17	14	10	19	15	11	13	12	10	37	44	59	76	74	82	103	76	76
BG060000	Yuzhen tsentralen	19	14	10	21	16	12	15	13	11	35	43	55	70	70	75	95	73	70
BL210000	Prov. Antwerpen	15	15	8	13	13	7	9	11	7	42	42	67	107	72	94	125	75	88
BL220000	Prov. Limburg (B)	15	15	8	13	13	7	9	11	7	42	42	68	106	72	94	125	75	88
BL230000	Prov. Oost-Vlaanderen	15	15	8	13	13	7	9	10	7	42	42	67	108	73	95	126	76	88
BL240000	Prov. Vlaams Brabant	15	15	8	13	13	7	9	11	7	42	42	67	107	73	94	125	75	88
BL250000	Prov. West-Vlaanderen	15	15	8	13	13	7	9	10	6	41	41	67	109	74	96	127	76	89
BL310000	Prov. Brabant Wallon	15	15	8	13	13	7	9	11	7	42	42	67	107	73	94	125	75	88
BL320000	Prov. Hainaut	15	15	8	13	13	7	9	11	7	42	42	67	105	72	93	124	74	87
BL330000	Prov. LiΦge	14	14	8	13	13	7	9	10	6	42	42	68	109	74	96	127	76	89
BL340000	Prov. Luxembourg (B)	14	14	8	13	13	7	9	10	6	43	43	69	110	75	97	129	77	90
BL350000	Prov. Namur	14	14	8	13	13	7	9	10	7	42	42	68	107	73	95	126	76	88
CZ010000	Praha	14	14	8	13	13	7	9	11	7	43	44	70	105	72	93	124	74	87
CZ020000	Strednφ Cechy	14	14	8	13	13	7	9	11	7	43	43	69	105	71	92	123	74	86
CZ030000	Jihozßpad	14	14	8	13	13	7	9	10	6	44	44	71	109	74	96	127	76	89
CZ040000	Severozßpad	14	13	8	13	13	7	9	10	6	44	45	71	109	74	96	128	77	89
CZ050000	Severov?chod	14	14	8	14	14	8	9	11	7	43	43	69	104	71	91	122	73	85
CZ060000	Jihov?chod	15	15	8	15	15	8	10	12	7	41	42	66	95	65	84	111	67	78

		Yield in tn/ha									Cost estimate (€/t_{DM})								
		RCG			miscanthus			switchgrass			RCG			miscanthus			switchgrass		
CZ070000	Strednφ Morava	15	15	8	15	15	8	10	12	7	42	42	67	97	66	85	113	68	80
CZ080000	Moravskoslezsko	14	14	8	14	14	8	10	11	7	42	42	68	101	69	89	119	72	83
DE110000	Baden-W^{n}rttemberg	14	14	8	13	13	7	9	10	7	43	43	69	107	73	94	126	75	88
DE120000		14	14	8	13	13	7	9	10	7	43	43	69	107	73	94	126	75	88
DE130000		14	14	8	13	13	7	9	10	7	43	43	69	107	73	94	126	75	88
DE140000		14	14	8	13	13	7	9	10	7	43	43	69	107	73	94	126	75	88
DE210000	Bayern	14	14	8	12	12	7	8	10	6	44	44	72	115	78	101	135	81	94
DE220000	Berlin, Bremen, Hamburg	14	14	8	13	13	7	9	10	7	43	43	69	108	73	95	126	76	89
DE230000		14	14	8	13	13	7	9	10	7	43	43	69	108	73	95	126	76	89
DE240000		14	14	8	13	13	7	9	10	7	43	43	69	108	73	95	126	76	89
DE250000		14	14	8	13	13	7	9	10	7	43	43	69	108	73	95	126	76	89
DE260000		14	14	8	13	13	7	9	10	7	43	43	69	108	73	95	126	76	89
DE270000		14	14	8	13	13	7	9	10	7	43	43	69	108	73	95	126	76	89
DE400000	Brandenburg	15	14	8	14	14	8	10	12	7	42	44	67	98	67	86	115	69	81
DE710000	Hessen	14	13	8	13	13	7	9	10	7	43	45	69	108	73	95	126	76	88
DE720000		14	13	8	13	13	7	9	10	7	43	45	69	108	73	95	126	76	88
DE730000		14	13	8	13	13	7	9	10	7	43	45	69	108	73	95	126	76	88
DE800000	Mecklenburg-Vorpommern	14	13	8	12	12	7	9	10	6	44	47	72	112	76	98	131	79	92
DE910000	Niedersachsen	14	14	8	12	12	7	9	10	6	44	44	70	112	76	98	131	79	92
DE920000		14	14	8	12	12	7	9	10	6	44	44	70	112	76	98	131	79	92
DE930000		14	14	8	12	12	7	9	10	6	44	44	70	112	76	98	131	79	92
DE940000		14	14	8	12	12	7	9	10	6	44	44	70	112	76	98	131	79	92
DEA10000	Nordrhein-Westfalen	14	14	8	13	13	7	9	10	6	43	43	70	110	75	97	129	77	90
DEA20000		14	14	8	13	13	7	9	10	6	43	43	70	110	75	97	129	77	90
DEA30000		14	14	8	13	13	7	9	10	6	43	43	70	110	75	97	129	77	90
DEA40000		14	14	8	13	13	7	9	10	6	43	43	70	110	75	97	129	77	90
DEA50000		14	14	8	13	13	7	9	10	6	43	43	70	110	75	97	129	77	90
DEB10000	Rheinland-Pfalz	15	14	8	14	14	8	10	11	7	42	44	68	104	71	91	121	73	85
DEB20000		15	14	8	14	14	8	10	11	7	42	44	68	104	71	91	121	73	85
DEB30000		15	14	8	14	14	8	10	11	7	42	44	68	104	71	91	121	73	85
DEC00000	Saarland	15	14	8	14	14	8	10	11	7	41	43	67	100	68	88	117	71	83
DED00000	Sachsen	14	14	8	13	13	7	9	11	7	43	43	69	105	71	92	123	74	86

		Yield in tn/ha									Cost estimate (€/t_{DM})								
		RCG			miscanthus			switchgrass			RCG			miscanthus			switchgrass		
DEE00000	Sachsen-Anhalt	14	14	8	14	14	8	10	11	7	42	44	68	103	70	91	120	73	85
DEF00000	Schleswig-Holstein	13	13	7	11	11	6	8	9	6	46	46	75	124	84	109	146	87	102
DEG00000	Thⁿringen	14	13	8	13	13	7	9	10	6	44	46	71	112	76	98	131	78	92
DK000000	Hovedstaden	12	12	6	10	10	5	7	8	5	50	50	82	141	95	124	166	98	115
EE000000	Estonia	11	11	6	9	9	5	7	7	5	52	53	86	146	98	128	172	102	119
EL110000	Anatoliki Makedonia, Thraki	22	12	10	25	14	11	18	11	10	31	48	57	69	78	77	81	80	72
EL120000	Kentriki Makedonia	21	12	9	25	13	11	17	11	10	32	50	60	71	83	83	82	86	77
EL130000	Dytiki Makedonia	20	10	8	22	11	9	16	9	8	34	55	66	77	96	96	90	100	90
EL140000	Thessalia	22	10	8	26	11	9	18	9	8	31	57	68	69	98	98	80	102	91
EL210000	Ipeiros	21	10	8	24	11	9	17	9	8	32	55	66	72	98	98	84	102	91
EL220000	Ionia Nisia	25	11	9	29	11	9	20	9	8	29	52	63	63	97	96	73	100	90
EL230000	Dytiki Ellada	23	10	8	27	10	8	19	8	7	30	57	69	66	105	105	76	109	98
EL240000	Sterea Ellada	24	9	7	28	10	8	20	8	7	29	60	73	63	112	111	74	116	104
EL250000	Peloponnisos	26	9	7	30	9	7	21	7	7	28	60	72	60	114	113	69	118	106
EL300000	Attiki	29	10	8	33	9	7	23	7	7	26	58	70	55	113	112	64	117	105
EL410000	Voreio Aigaio	31	10	8	36	9	7	25	7	7	25	57	68	52	114	114	60	119	106
EL420000	Notio Aigaio	34	11	9	41	11	9	28	9	8	24	53	64	47	100	100	54	104	93
EL430000	Kriti	35	10	8	41	11	9	29	9	8	23	58	70	47	99	99	54	103	92
ES110000	Galicia	18	14	10	18	13	10	12	10	9	36	43	57	95	85	88	112	88	82
ES120000	Principado de Asturias	16	12	9	15	11	8	10	9	7	39	48	62	112	97	103	131	101	96
ES130000	Cantabria	18	13	10	17	13	9	12	10	8	37	45	58	100	86	92	117	89	86
ES210000	Pais Vasco	18	14	10	19	14	10	13	11	9	35	44	55	91	81	85	107	83	79
ES220000	Comunidad Foral de Navarra	19	13	10	19	13	11	13	11	10	35	45	55	89	82	82	104	85	77
ES230000	La Rioja	19	12	9	19	12	9	14	9	8	35	50	60	88	93	92	103	96	86
ES240000	Arag≤n	21	12	9	22	12	10	15	10	9	33	49	59	78	88	88	91	92	82
ES300000	Comunidad de Madrid	23	10	8	25	10	8	17	8	7	31	56	68	70	104	103	82	108	97
ES410000	Castilla y Le≤n	19	11	9	20	11	9	14	9	8	34	52	62	85	100	100	99	104	93
ES420000	Castilla-la Mancha	24	10	8	26	11	9	19	9	8	30	55	67	67	99	99	78	103	92
ES430000	Extremadura	25	11	9	29	11	9	20	9	8	29	53	64	63	96	96	73	100	90
ES510000	Catalu±a	21	12	10	23	13	10	16	10	9	32	49	58	75	84	84	88	87	78
ES520000	Comunidad Valenciana	25	11	9	28	12	10	20	10	9	29	52	63	64	88	88	74	91	82
ES530000	Illes Balears	30	12	10	34	14	11	24	11	10	26	48	57	55	77	77	63	80	72
ES610000	Andalucia	27	11	8	31	12	9	22	9	8	27	54	65	59	93	92	68	96	86

		Yield in tn/ha									Cost estimate (€/t_{DM})								
		RCG			miscanthus			switchgrass			RCG			miscanthus			switchgrass		
ES620000	Regi≤n de Murcia	27	10	8	31	11	9	22	9	8	27	57	69	59	95	94	68	98	88
ES700000	Regi≤n de Murcia	27	10	8	31	11	9	22	9	8	27	57	69	59	95	94	68	98	88
FI130000	Pohjois-Suomi	7	7	4	5	5	3	3	4	2	76	76	130	276	182	241	327	190	224
FI180000	ItΣ-Suomi	9	9	5	7	7	4	5	6	3	64	64	106	194	129	169	229	134	158
FI190000	EtelΣ-Suomi	10	10	6	8	8	5	6	7	4	56	56	93	162	108	142	191	112	132
FI1A0000	LΣnsi-Suomi	9	9	5	8	8	4	5	6	4	59	59	99	179	119	156	211	124	146
FI200000	┼land	9	8	5	8	7	4	5	5	4	59	70	99	179	133	157	211	138	146
FR100000	?le de France	16	14	9	16	15	9	11	12	8	39	43	62	90	65	80	106	68	75
FR210000	Champagne-Ardenne	16	14	9	15	15	9	11	12	8	39	43	63	93	67	82	109	69	77
FR220000	Picardie	15	15	9	14	14	8	10	12	7	40	42	64	98	67	87	115	70	81
FR230000	Haute-Normandie	15	15	9	14	14	8	10	11	7	40	42	64	101	69	89	119	72	83
FR240000	Centre	17	15	10	17	15	10	12	12	9	37	42	58	83	64	73	97	66	69
FR250000	Basse-Normandie	16	15	9	14	14	8	10	11	7	39	41	63	101	69	89	118	71	83
FR260000	Bourgogne	17	15	9	17	16	9	12	12	9	37	41	59	85	63	75	99	65	70
FR300000	Nord - Pas-de-Calais	15	15	8	13	13	7	9	11	7	41	42	66	105	72	93	124	74	87
FR410000	Lorraine	15	15	8	15	15	8	10	12	7	41	42	65	98	67	86	114	69	80
FR420000	Alsace	15	15	8	14	14	8	10	11	7	42	42	67	100	68	88	117	71	82
FR430000	Franche-ComtΘ	15	15	8	15	15	8	10	12	7	41	41	65	97	67	86	114	69	80
FR510000	Pays de la Loire	18	15	10	17	16	10	12	12	9	36	41	58	83	63	74	97	65	69
FR520000	Bretagne	16	16	9	14	14	8	10	12	7	38	39	61	98	67	86	115	69	81
FR530000	Poitou-Charentes	19	14	11	20	15	11	14	12	10	35	43	54	87	74	81	102	77	75
FR610000	Aquitaine	19	15	11	20	16	11	14	13	10	35	40	54	85	69	79	99	71	74
FR620000	Midi-PyrΘnΘes	18	14	10	18	15	10	13	12	9	37	43	58	92	76	85	108	79	80
FR630000	Limousin	18	15	10	18	16	10	12	13	9	36	40	58	96	72	88	112	74	83
FR710000	Rh⌠ne-Alpes	16	13	9	15	13	8	11	11	8	40	45	63	110	83	101	128	86	94
FR720000	Auvergne	17	15	9	17	15	9	12	12	8	37	41	59	100	74	93	117	76	87
FR810000	Languedoc-Roussillon	20	13	10	21	13	10	15	10	9	33	46	55	80	84	84	94	87	78
FR820000	Provence-Alpes-C⌠te d'Azur	18	11	9	19	11	9	13	9	8	36	52	62	90	98	98	105	102	91
FR830000	Corse	23	11	9	25	11	9	18	9	8	31	53	64	70	96	95	81	99	89
HU000000	K÷zΘp-Magyarorszßg	18	14	10	21	16	11	14	13	10	36	42	56	83	69	77	97	71	72
HU100000	K÷zΘp-Dunßnt·l	18	14	10	20	16	11	14	13	10	36	42	56	84	69	78	98	72	73
HU210000	Nyugat-Dunßnt·l	18	15	10	19	17	11	14	14	10	36	41	57	88	67	81	103	69	76

		Yield in tn/ha									Cost estimate (€/t_{DM})								
		RCG			miscanthus			switchgrass			RCG			miscanthus			switchgrass		
HU220000	DΘl-Dunßnt·l	19	14	10	21	16	12	15	13	11	35	43	55	82	70	76	95	72	71
HU230000	╔szak-Magyarorszßg	17	15	9	19	17	10	13	14	9	38	40	60	91	65	84	107	68	79
HU310000	╔szak-Alf÷ld	18	16	10	20	18	11	14	14	10	37	40	58	87	65	80	101	67	75
HU320000	DΘl-Alf÷ld	19	15	11	22	17	12	15	14	11	34	41	54	79	67	73	92	69	69
IR000000	Ireland	11	11	6	6	6	3	4	5	3	51	51	83	213	142	186	252	147	173
IT000000	Piemonte	15	12	8	15	12	8	11	10	8	41	48	65	109	89	101	128	92	94
IT110000	Valle d'Aosta/VallΘe d'Aoste	11	10	6	8	8	4	5	6	4	53	55	88	173	116	152	204	120	141
IT120000	Liguria	20	13	11	22	14	11	15	11	10	33	45	54	78	80	79	91	83	74
IT130000	Lombardia	16	13	9	16	14	9	11	11	8	40	45	64	91	70	80	106	73	75
IT200000	Provincia Autonoma Trento	13	13	7	12	12	6	8	9	6	46	47	75	119	81	105	140	84	98
IT310000	Veneto	16	15	9	16	15	9	11	12	8	40	41	64	89	65	79	104	67	74
IT320000	Friuli-Venezia Giulia	15	15	8	15	15	8	11	12	8	41	41	66	94	64	82	109	66	77
IT330000	Emilia-Romagna	20	15	11	23	17	13	16	13	11	34	41	53	77	68	71	89	71	67
IT400000	Toscana	21	14	11	24	15	12	17	12	11	33	44	52	74	74	74	86	77	69
IT510000	Umbria	20	14	11	23	15	12	16	12	11	34	44	53	76	76	76	89	79	71
IT520000	Marche	21	14	11	24	16	13	17	13	11	33	42	51	74	71	71	86	74	67
IT530000	Lazio	21	14	11	25	15	12	17	12	11	32	44	52	71	76	76	83	79	71
IT600000	Abruzzo	20	13	11	23	14	12	16	12	10	33	45	53	76	77	76	89	80	72
IT710000	Molise	21	14	11	25	15	12	17	12	11	32	44	52	71	75	75	83	78	70
IT720000	Campania	23	14	11	26	15	12	18	12	11	31	44	52	69	75	75	80	78	70
IT800000	Puglia	26	15	12	30	16	13	21	13	12	28	41	49	61	70	69	70	72	65
IT910000	Basilicata	24	14	11	27	15	12	19	12	11	30	43	51	65	73	73	76	76	68
IT920000	Calabria	26	14	11	29	15	12	21	12	11	28	43	52	61	73	73	71	76	68
IT930000	Sicilia	28	14	11	32	15	12	22	12	11	27	44	52	57	72	72	66	75	67
ITA00000	Sardegna	26	12	9	30	13	10	21	10	9	28	49	59	60	84	83	69	87	78
LT000000		13	13	7	12	12	6	8	8	5	47	76	50	120	138	129	141	143	120
LV000000		12	12	7	11	11	6	7	7	5	49	80	54	131	151	141	154	157	132
NL110000	Groningen	14	14	8	12	12	7	8	9	6	44	44	71	118	80	103	138	83	97
NL120000	Friesland (NL)	14	14	8	12	12	6	8	9	6	44	44	72	120	81	105	141	84	98
NL130000	Drenthe	14	14	8	12	12	7	8	9	6	44	44	71	118	80	104	138	83	97
NL210000	Overijssel	14	14	8	13	13	7	9	10	6	43	43	69	111	75	98	130	78	91
NL220000	Gelderland	14	14	8	13	13	7	9	10	7	42	42	68	107	73	94	126	76	88

		Yield in tn/ha									Cost estimate (€/t_{DM})								
		RCG			miscanthus			switchgrass			RCG			miscanthus			switchgrass		
NL230000	Flevoland	14	14	8	12	12	7	8	10	6	44	44	70	116	79	102	136	81	95
NL310000	Utrecht	14	14	8	13	13	7	9	10	6	42	42	68	109	74	96	128	77	90
NL320000	Noord-Holland	14	14	8	12	12	7	8	9	6	44	44	71	117	80	103	138	82	96
NL330000	Zuid-Holland	14	14	8	12	12	7	9	10	6	43	43	69	112	76	98	131	79	92
NL340000	Zeeland	14	14	8	13	13	7	9	10	6	42	42	68	110	75	97	129	77	90
NL410000	Noord-Brabant	14	14	8	13	13	7	9	10	6	42	42	68	108	74	95	127	76	89
NL420000	Limburg (NL)	14	14	8	13	13	7	9	11	7	42	42	68	107	73	94	125	75	88
PL110000	L≤dzkie	15	14	8	15	15	8	10	12	7	42	42	68	98	67	86	114	69	80
PL120000	Mazowieckie	14	14	8	14	14	8	10	11	7	42	43	68	99	68	87	116	70	82
PL210000	Malopolskie	14	14	8	14	14	8	10	11	7	43	43	70	104	71	91	121	73	85
PL220000	Slaskie	14	14	8	14	14	8	10	11	7	43	43	69	103	70	91	121	73	85
PL310000	Lubelskie	15	15	8	15	15	8	10	12	7	42	42	67	95	65	84	111	67	78
PL320000	Podkarpackie	15	15	8	15	15	8	10	12	7	42	42	68	96	66	85	113	68	79
PL330000	Swietokrzyskie	14	14	8	14	14	8	10	12	7	42	42	68	98	67	87	115	70	81
PL340000	Podlaskie	14	14	8	13	13	7	9	11	7	44	44	71	106	72	93	124	75	87
PL410000	Wielkopolskie	14	14	8	14	14	8	10	11	7	42	43	68	99	67	87	115	70	81
PL420000	Zachodniopomorskie	14	13	8	13	13	7	9	10	6	44	45	71	109	74	96	128	77	90
PL430000	Lubuskie	15	13	8	15	14	8	10	12	7	41	45	67	96	67	85	113	70	79
PL510000	Dolnoslaskie	14	14	8	14	14	8	10	11	7	43	43	69	101	69	89	118	71	83
PL520000	Opolskie	15	15	8	14	14	8	10	12	7	42	42	67	98	67	87	115	70	81
PL610000	Kujawsko-Pomorskie	14	14	8	13	13	7	9	11	7	43	44	70	105	71	92	123	74	86
PL620000	Warminsko-Mazurskie	13	13	7	13	13	7	9	10	6	45	46	73	112	76	98	131	79	92
PL630000	Pomorskie	13	13	7	11	11	6	8	9	6	47	47	76	122	82	107	143	85	100
PT110000	Norte	19	12	10	20	11	9	14	9	8	34	48	57	85	94	94	99	98	88
PT150000	Algarve	30	10	8	35	11	9	25	9	8	26	57	69	53	99	98	61	103	92
PT160000	Centro (PT)	23	12	10	25	12	10	17	10	9	31	48	57	71	89	88	82	92	82
PT170000	Lisboa	26	13	11	29	15	12	21	12	11	28	45	53	61	75	75	71	78	70
PT180000	Alentejo	27	11	9	31	12	10	22	10	9	28	51	61	59	88	88	68	91	82
RO010000	Nord-Vest	16	15	9	18	17	10	12	14	9	39	40	61	95	67	88	111	69	82
RO020000	Centru	19	15	11	22	18	12	16	14	11	34	41	53	78	65	72	91	67	67
RO030000	Nord-Est	18	16	10	21	18	12	15	15	10	36	40	56	82	63	76	96	65	71
RO040000	Sud-Est	18	16	10	20	18	11	14	15	10	37	39	58	86	63	79	100	65	74
RO050000	Sud - Muntenia	18	16	10	20	18	11	14	14	10	37	39	58	87	63	81	102	66	76

	Yield in tn/ha										Cost estimate (€/t_{DM})								
		RCG			miscanthus			switchgrass			RCG			miscanthus			switchgrass		
RO060000	Bucuresti - Ilfov	15	15	9	16	16	9	11	13	8	40	40	65	103	70	95	121	72	89
RO070000	Sud-Vest Oltenia	15	15	8	16	16	9	11	12	8	41	41	66	107	72	99	125	74	92
RO080000	Vest	19	16	10	21	18	12	15	15	11	35	39	55	81	62	75	94	64	70
SE010000	Stockholm	10	10	6	8	8	5	6	7	4	55	55	91	162	108	142	190	112	132
SE020000	╓stra Mellansverige	11	11	6	8	8	5	6	7	4	54	54	90	163	109	143	192	113	133
SE040000	Smɑland med ÷arna	11	11	6	8	8	5	6	7	4	53	53	87	160	107	140	188	111	130
SE060000	Sydsverige	11	11	6	9	9	5	6	7	5	51	51	84	151	101	132	178	105	123
SE070000	VΣstsverige	11	11	6	8	8	5	6	7	4	53	53	88	163	109	142	192	113	133
SE080000	Norra Mellansverige	9	9	5	6	6	3	4	5	3	61	61	102	214	142	187	253	148	174
SE090000	Mellersta Norrland	7	7	4	4	4	2	3	3	2	75	75	128	330	217	288	391	226	267
SE0A0000	╓vre Norrland	6	6	3	4	4	2	3	3	2	84	84	143	359	236	313	426	245	290
SI000000	Vzhodna Slovenija	16	16	9	17	17	10	12	14	9	38	40	61	83	58	73	97	60	69
SK010000	Bratislavsk? kraj	17	14	10	19	16	10	13	13	9	37	43	59	79	62	70	92	64	65
SK020000	ZßpadnΘ Slovensko	16	14	9	17	16	10	12	13	9	38	42	61	83	62	73	97	64	69
SK030000	StrednΘ Slovensko	15	14	8	15	15	8	10	12	7	42	43	67	96	66	84	112	69	79
SK040000	V?chodnΘ Slovensko	15	15	8	15	15	8	11	12	8	42	42	67	94	64	83	110	67	77
UKC00000	Tees Valley and Durham	11	11	6	6	6	4	4	5	3	52	52	86	210	140	184	248	145	171
UKD00000	Cumbria	11	11	6	17	13	8	12	10	7	53	53	87	85	74	85	100	77	79
UKE00000	East Yorkshire and Northern Lincolnshire	12	12	7	17	13	8	12	10	7	48	48	79	85	74	84	99	77	79
UKF00000	Derbyshire and Nottinghamshire	13	13	7	17	13	8	12	10	7	46	46	75	84	74	84	98	76	78
UKG00000	Herefordshire, Worcestershire and Warks	13	13	7	17	13	8	12	10	7	45	45	73	84	74	84	98	76	78
UKH00000	East Anglia	14	14	8	17	13	8	12	10	8	43	44	70	84	74	84	98	76	78
UKJ00000	Berkshire, Bucks and Oxfordshire	14	14	8	17	13	8	12	10	8	44	44	70	83	74	83	97	76	78
UKK00000	Gloucestershire, Wiltshire and Bristol/Bath area	14	14	8	17	13	8	12	10	7	44	44	71	84	74	84	98	77	79
UKL00000	West Wales and The Valleys	12	12	7	17	13	8	12	10	7	48	48	79	84	74	84	98	77	79
UKM0000 0	South Western Scotland	10	10	5	17	13	8	12	10	7	58	58	96	83	74	84	97	77	79
UKN00000	Northern Ireland	11	11	6	17	13	8	12	10	7	51	51	84	83	74	84	97	77	79

Table 4 Yield and cost levels for willow and poplar (yields based on GLOBIOM model, IIASA).

		Yield in t/ha				Cost estimate (€/t_{DM})			
		Willow		Poplar		Willow		Poplar	
Code	**NUTS_NAME**	**high**	**low**	**High**	**Low**	**high**	**low**	**high**	**low**
AT110000	Burgenland (A)	11	7	12	8	48	63	30	40
AT120000	Niederösterreich	10	7	7	4	64	69	32	49
AT210000	Kärnten	11	7	5	3	50	64	45	69
AT220000	Steiermark	11	7	5	3	51	66	47	72
AT310000	Oberösterreich	10	6	5	3	57	75	43	66
AT320000	Salzburg	12	8	3	2	47	61	70	107
AT330000	Tirol	10	6	4	3	57	74	56	87
AT340000	Vorarlberg	10	7	4	3	53	70	52	81
BG010000	Severozapaden	12	8	9	6	44	58	24	36
BG020000	Severen tsentralen	12	8	10	6	48	62	22	34
BG030000	Severoiztochen	12	8	10	6	45	59	23	36
BG040000	Yugoiztochen	11	7	9	6	52	67	26	40
BG050000	Yugozapaden	11	7	9	6	50	65	25	38
BG060000	Yuzhen tsentralen	11	7	9	6	48	63	25	39
BL210000	Prov. Antwerpen	10	6	10	6	56	73		
BL220000	Prov. Limburg (B)	12	8	6	4	47	61	39	60
BL230000	Prov. Oost-Vlaanderen	11	7	11	7	51	66		
BL240000	Prov. Vlaams Brabant	13	9	13	9	42	55		
BL250000	Prov. West-Vlaanderen	11	7	11	7	49	64		
BL310000	Prov. Brabant Wallon	13	8	13	8	42	55		
BL320000	Prov. Hainaut	13	9	13	9	42	55		
BL330000	Prov. LiΦge	12	8	9	6	46	60	24	37
BL340000	Prov. Luxembourg (B)	12	8	9	6	47	61	24	36
BL350000	Prov. Namur	13	8	10	7	43	55	22	34
CZ010000	Praha	9	6	8	5	63	82	26	41
CZ020000	Strednφ Cechy	9	6	7	5	64	83	30	47
CZ030000	Jihozßpad	9	6	6	4	64	83	37	58
CZ040000	Severozßpad	9	6	6	4	63	82	35	54
CZ050000	Severov?chod	9	6	6	4	61	79	35	54
CZ060000	Jihov?chod	9	6	6	4	62	80	36	56
CZ070000	Strednφ Morava	10	7	8	5	53	69	27	41
CZ080000	Moravskoslezsko	10	6	8	5	56	72	26	40
DE110000	Baden-Württemberg	11	7	8	5	52	67	26	41
DE120000		12	8	6	4	46	60	34	53

DE130000		11	7	6	4	51	67	37	57
DE140000		10	7	8	5	55	71	28	43
DE210000	Bayern	11	7	6	4	51	66	38	59
DE220000	Berlin, Bremen, Hamburg	10	7	6	4	53	70	39	60
DE230000		9	6	6	4	61	80	35	53
DE240000		8	5	7	4	69	89	34	52
DE250000		9	6	7	4	61	79	34	52
DE260000		10	7	8	5	53	69	29	45
DE270000		11	7	6	4	52	68	38	58
DE400000	Brandenburg	8	5	6	4	73	95	38	59
DE710000	Hessen	12	8	8	5	48	62	27	41
DE720000		12	8	8	5	48	62	27	42
DE730000		10	6	7	5	58	75	31	47
DE800000	Mecklenburg-Vorpommern	7	5	5	4	74	96	41	62
DE910000	Niedersachsen	9	6	7	5	59	77	30	47
DE920000		9	6	8	5	61	80	28	44
DE930000		7	5	5	4	76	100	41	63
DE940000		8	5	5	4	73	96	41	63
DEA10000	Nordrhein-Westfalen	12	8	12	8	46	60		
DEA20000		11	7	8	5	50	65	26	40
DEA30000		8	5	6	4	69	90	39	60
DEA40000		8	6	8	5	65	85	27	42
DEA50000		10	6	5	4	56	73	41	62
DEB10000	Rheinland-Pfalz	11	7	8	5	49	64	28	43
DEB20000		10	7	9	6	53	69	26	39
DEB30000		11	7	7	5	48	63	30	46
DEC00000	Saarland	12	8	9	6	46	60	25	38
DED00000	Sachsen	9	6	7	4	59	77	33	51
DEE00000	Sachsen-Anhalt	9	6	7	4	65	84	34	52
DEF00000	Schleswig-Holstein	7	5	5	4	77	100	41	63
DEG00000	Th^{n}ringen	9	6	7	5	62	81	30	46
DK000000	Hovedstaden	7	5	4	3	78	101	57	88
EE000000	Estonia	7	5	7	4	79	103	32	49
EL110000	Anatoliki Makedonia, Thraki	0	0	9	6			24	37
EL120000	Kentriki Makedonia	0	0	8	5			28	43
EL130000	Dytiki Makedonia	0	0	10	6			22	34
EL140000	Thessalia	0	0	9	6			24	37
EL210000	Ipeiros	0	0	11	7			20	31
EL220000	Ionia Nisia	0	0	14	9			16	25
EL230000	Dytiki Ellada	0	0	10	6			23	35

EL240000	Sterea Ellada	0	0	9	6			24	37
EL250000	Peloponnisos	0	0	10	7			22	33
EL300000	Attiki	0	0	10	6			23	35
EL410000	Voreio Aigaio	0	0	9	6			24	38
EL420000	Notio Aigaio	0	0	9	6			24	37
EL430000	Kriti	0	0	10	7			21	33
ES110000	Galicia	13	8	10	6	43	56	22	34
ES120000	Principado de Asturias	12	8	6	4	45	59	37	56
ES130000	Cantabria	12	8	8	5	44	58	26	41
ES210000	Pais Vasco	13	8	12	7	43	56	19	30
ES220000	Comunidad Foral de Navarra	0	0	11	7			21	32
ES230000	La Rioja	0	0	9	6			24	37
ES240000	Arag≤n	0	0	8	5			28	44
ES300000	Comunidad de Madrid	0	0	7	4			33	51
ES410000	Castilla y Le≤n	0	0	7	5			31	48
ES420000	Castilla-la Mancha	0	0	7	5			30	46
ES430000	Extremadura	0	0	10	7			22	33
ES510000	Catalu±a	0	0	8	5			26	41
ES520000	Comunidad Valenciana	0	0	9	6			25	38
ES530000	Illes Balears	0	0	11	7			20	31
ES610000	Andalucia	0	0	10	7			21	33
ES620000	Region de Murcia	0	0	8	5			27	42
ES700000	Region de Murcia	0	0	0	0				
FI130000	Pohjois-Suomi	4	3	3	2	129	168	85	132
FI180000	ItΣ-Suomi	5	3	3	2	122	158	71	109
FI190000	EtelΣ-Suomi	4	2	3	2	156	203	79	122
FI1A0000	LΣnsi-Suomi	0	0	0	0			1068	1644
FI200000	┼land	1	1	2	1	618	805	122	187
FR100000	Ile de France	13	9	9	6	42	55	25	38
FR210000	Champagne-Ardenne	12	8	7	5	48	62	31	47
FR220000	Picardie	11	7	8	5	49	63	29	44
FR230000	Haute-Normandie	13	8	8	5	43	56	27	42
FR240000	Centre	12	8	10	6	44	58	23	35
FR250000	Basse-Normandie	14	9	9	6	39	50	25	38
FR260000	Bourgogne	13	8	9	6	43	56	23	36
FR300000	Nord - Pas-de-Calais	12	8	7	4	45	59	34	52
FR410000	Lorraine	12	8	6	4	47	62	40	61
FR420000	Alsace	11	7	5	3	48	63	46	72
FR430000	Franche-ComtΘ	13	8	6	4	43	56	37	56

FR510000	Pays de la Loire	14	9	10	7	40	52	22	33
FR520000	Bretagne	13	8	12	7	43	55	19	30
FR530000	Poitou-Charentes	14	9	11	7	39	50	20	30
FR610000	Aquitaine	14	9	10	7	39	50	22	33
FR620000	Midi-PyrΘnΘes	0	0	11	7			20	30
FR630000	Limousin	14	9	5	3	39	51	48	73
FR710000	Rh⌠ne-Alpes	0	0	9	6			25	38
FR720000	Auvergne	12	8	7	4	47	61	34	52
FR810000	Languedoc-Roussillon	0	0	9	6			26	39
FR820000	Provence-Alpes-C⌠te d'Azur	0	0	9	6			25	39
FR830000	Corse	0	0	12	8			18	27
HU000000	Közép-Magyarország	0	0	0	0				
HU100000	Közép-Dunántúl	12	8	10	6	47	61	23	35
HU210000	Nyugat-Dunántúl	11	7	11	7	52	68	21	32
HU220000	Dél-Dunántúl	12	8	12	8	47	61	19	29
HU230000	Észak-Magyarország	12	8	11	7	46	60	20	30
HU310000	Észak-Alföld	12	8	10	7	45	58	22	33
HU320000	Dél-Alföld	10	7	8	5	53	69	29	45
IR000000	Ireland	0	0	0	0				
IT000000	Piemonte	0	0	0	0				
IT110000	Valle d'Aosta/VallΘe d'Aoste	0	0	10	6			23	35
IT120000	Liguria	0	0	2	1			114	175
IT130000	Lombardia	0	0	10	6			23	35
IT200000	Provincia Autonoma Trento	0	0	7	4			33	51
IT310000	Veneto	0	0	3	2			66	101
IT320000	Friuli-Venezia Giulia	0	0	6	4			36	56
IT330000	Emilia-Romagna	0	0	4	3			55	84
IT400000	Toscana	0	0	8	5			28	43
IT510000	Umbria	0	0	10	7			21	33
IT520000	Marche	0	0	10	6			23	36
IT530000	Lazio	0	0	9	6			26	40
IT600000	Abruzzo	0	0	11	7			20	31
IT710000	Molise	0	0	9	6			24	37
IT720000	Campania	0	0	9	6			23	36
IT800000	Puglia	0	0	9	6			25	38
IT910000	Basilicata	0	0	9	6			24	36
IT920000	Calabria	0	0	9	6			25	39
IT930000	Sicilia	0	0	10	7			22	34
ITA00000	Sardegna	0	0	8	5			28	44

LT000000		9	6	0	0	63	82		
LV000000		8	5	7	5	66	86	31	47
NL110000	Groningen	7	5	6	4	76	99	39	59
NL120000	Friesland (NL)	8	5	7	4	68	88	33	50
NL130000	Drenthe	7	5	6	4	75	97	36	55
NL210000	Overijssel	8	5	7	5	66	86	32	49
NL220000	Gelderland	11	7	6	4	52	68	40	61
NL230000	Flevoland	8	5	0	0	68	88		
NL310000	Utrecht	11	7	0	0	49	64		
NL320000	Noord-Holland	9	6	7	4	61	79	32	50
NL330000	Zuid-Holland	10	6	0	0	57	74		
NL340000	Zeeland	8	5	0	0	66	86		
NL410000	Noord-Brabant	9	6	6	4	60	79	35	54
NL420000	Limburg (NL)	11	7	0	0	49	64		
PL110000	L≤dzkie	9	6	6	4	63	82	38	59
PL120000	Mazowieckie	8	5	6	4	67	88	38	59
PL210000	Malopolskie	9	6	5	3	60	78	42	65
PL220000	Slaskie	10	6	6	4	56	73	39	60
PL310000	Lubelskie	10	6	6	4	57	74	39	60
PL320000	Podkarpackie	10	6	7	5	57	74	31	47
PL330000	Swietokrzyskie	10	7	6	4	53	69	37	57
PL340000	Podlaskie	8	5	6	4	66	86	40	62
PL410000	Wielkopolskie	8	5	6	4	70	91	36	55
PL420000	Zachodniopomorskie	9	6	6	4	63	82	36	56
PL430000	Lubuskie	8	5	7	4	66	85	33	50
PL510000	Dolnoslaskie	9	6	5	3	62	81	48	73
PL520000	Opolskie	9	6	10	7	59	77	22	34
PL610000	Kujawsko-Pomorskie	8	5	6	4	67	87	39	59
PL620000	Warminsko-Mazurskie	8	6	5	4	65	85	40	62
PL630000	Pomorskie	8	5	6	4	69	90	35	53
PT110000	Norte	15	10	9	6	38	49	24	37
PT150000	Algarve	0	0	11	7			20	31
PT160000	Centro (PT)	15	10	9	6	37	48	24	37
PT170000	Lisboa	0	0	0	0				
PT180000	Alentejo	0	0	10	6			22	34
RO010000	Nord-Vest	11	7	8	5	48	63	28	43
RO020000	Centru	11	7	7	4	48	63	33	51
RO030000	Nord-Est	12	8	8	5	47	61	28	42
RO040000	Sud-Est	12	8	9	6	46	60	25	39
RO050000	Sud - Muntenia	12	8	8	5	48	62	27	42
RO060000	Bucuresti - Ilfov	12	8	6	4	46	59	35	54
RO070000	Sud-Vest Oltenia	12	8	5	4	47	62	41	62
RO080000	Vest	13	8	10	6	43	56	23	35

SE010000	Stockholm	9	6	0	0	65	84		
SE020000	╓stra Mellansverige	8	5	6	4	70	91	40	62
SE040000	Smσland med ÷arna	9	6	7	4	62	81	33	51
SE060000	Sydsverige	5	3	3	2	115	150	64	99
SE070000	VΣstsverige	1	0	1	1	917	1194	152	234
SE080000	Norra Mellansverige	0	0	0	0			459	707
SE090000	Mellersta Norrland	8	5	5	4	67	87	41	62
SE0A0000	╓vre Norrland	8	5	5	4	68	89	41	62
SI000000	Vzhodna Slovenija	0	0	6	4			40	61
SK010000	Bratislavsk? kraj	11	7	11	7	51	66	21	32
SK020000	ZßpadnΘ Slovensko	11	7	10	6	51	67	23	35
SK030000	StrednΘ Slovensko	11	7	5	3	51	66	48	74
SK040000	V?chodnΘ Slovensko	11	7	6	4	49	63	37	58
UKC00000	Tees Valley and Durham	0	0	3	2			64	98
UKD00000	Cumbria	7	4	5	3	81	106	42	65
UKE00000	East Yorkshire and Northern Lincolnshire	7	5	5	3	76	100	44	68
UKF00000	Derbyshire and Nottinghamshire	8	5	7	4	68	88	34	52
UKG00000	Herefordshire, Worcestershire and Warks	10	7	7	4	54	70	34	52
UKH00000	East Anglia	10	6	7	5	56	73	32	49
UKJ00000	Berkshire, Bucks and Oxfordshire	11	7	10	6	48	63	23	35
UKK00000	Gloucestershire, Wiltshire and Bristol/Bath area	11	7	7	5	49	64	30	46
UKL00000	West Wales and The Valleys	9	6	6	4	60	78	37	57
UKM00000	South Western Scotland	0	0	3	2			82	126
UKN00000	Northern Ireland	1	0	5	3	48	74	48	74

Annex 11 Definition and identification of no-go areas

Highly biodiverse areas and areas of high carbon stock are not to be used for biomass cropping in Storylines 2 and 3. It is difficult to capture spatially all of these areas in Europe because of the lack of spatially detailed information and lack of a clear definition. However, there are several categories of land (and of habitats and species) officially acknowledged in EU directives and policies as important to be managed for nature conservation objectives. These categories have also been (partly or fully) mapped:

Natura 2000 sites: The ultimate objective is to restore and/or maintain the Favourable Conservation Status (FCS) of the habitats types and the species covered by the two Nature Directives (Birds Directive and Habitats Directive). This objective is also an integral part of the overall post-2010 EU biodiversity target. Most of the EU countries have now mapped the Natura 2000 sites and within these sites there is also some (but incomplete) spatial indication of the agricultural areas.

HNV farmland areas: This concept recognises the causality between certain types of farming activity and 'natural values' related to high levels of biodiversity and/or the presence of species and habitats of conservation concern. The conservation of these High Nature Value (HNV) farmland areas is an explicit objective of EU's environment and rural development policies (e.g. Kiev Resolution on Biodiversity). More importantly the HNV farmland areas have now also become an important policy target in the new Rural Development Programme (EAFRD) (Council Regulation 1698/2005). In response to this, the Community's Strategic Guidelines for rural development, 2007 –2013, encourage Member States to put in place measures to preserve and develop HNV farming systems. In order to meet the objective of preserving and enhancing HNV farming, MS are asked to apply the baseline indicator 18 on HNV farmland area (as part of the Common Monitoring and Evaluation Framework) at the start of the Rural Development Programme and to introduce own indicators to measure the extent and quality of their HNV farmland annually as from 2010 onwards. Mapped information from MS is not available yet, but mapping of HNV farmland has been carried out at European scale by EEA and JRC. The most recent data sets are described in Paracchini *et al.* (2008) where HNV farmland has been identified using four categories of information:

- Land cover (Corine LC) (e.g. semi-natural vegetation classes such as semi-natural grasslands, agro-forestry, scrub, woodland-pastures, land use mosaics etc.) [Note that an up-date is currently underway on the basis of the newest CLC data set.]
- Natura 2000 sites that contain species and habitats associated with agricultural land use; these were overlaid with a farmland mask based on land cover data.
- Important Bird Areas and Prime Butterfly Areas overlaid with a farmland mask based on land cover data.
- National data that document the distribution of species of European conservation concern on farmland and that are available in a spatially-referenced format.

This spatial database of HNV farmland (Paracchini, *et al.*, 2008) is available and can be used as an EU wide database for the farmland areas of high biodiversity.

Areas of high carbon stock are not part of any official designations. However, they show in most if not all cases a complete overlap with highly biodiverse farmland areas. More specifically they are mostly overlapping with permanent grassland areas, especially the wetter ones on peaty soils.

Both the NATURA 2000 (farmland) and the HNV farmland areas are regarded as good proxies for high biodiverse and high carbon stock areas and will be taken as no-go areas for biomass cropping in both Storylines 2 and 3. Their area share per region (NUTS 2) is applied to the released land area and the result is then subtracted from the total released land potential that is available for dedicated cropping in these 2 Storylines. To give a sense for the range in area share an overview of the HNV area share at national level is provided in the table underneath.

Table 1 *HNV area share (national averages, for the analysis the NUTS 2 area shares were used).*

	col 1	col 2	col 3	col 4	col 5
COUNTRY	HNV farmland area according to this study	Agricultural land (CLC agricultural classes + HNV areas)	Utilised Agricultural Area (official figures from EUROSTAT FSS)	Discrepancy (col2/col3)*100	Area share of HNV farmland (col1 / col2)
Austria	*2,447,292*	*3,578,621*	*3,266,250*	*109.6%*	*68.4%*
Belgium	347,960	1,786,942	1,385,580	129.0%	19.5%
Bulgaria	2,509,989	6,734,217	2,729,390	246.7%	37.3%
Cyprus	*342,045*	*637,043*	*151,500*	*420.5%*	*53.7%*
Czech Republic	1,043,973	4,950,869	3,557,770	139.2%	21.1%
Germany	3,162,699	21,607,362	17,127,350	126.2%	14.6%
Denmark	172,267	3,446,150	2,707,690	127.3%	5.0%
Estonia	380,879	1,695,820	828,930	204.6%	22.5%
Spain	18,986,960	34,038,906	26,085,390	130.5%	55.8%
Finland	*1,330,797*	*2,967,068*	*2,215,970*	*133.9%*	*44.9%*
France	7,797,145	35,311,870	27,856,320	126.8%	22.1%
Greece	5,349,572	9,122,263	3,583,180	254.6%	58.6%
Hungary	1,906,124	6,822,877	4,555,110	149.8%	27.9%
Ireland	1,162,594	5,777,390	4,443,970	130.0%	20.1%
Italy	6,127,030	18,359,587	13,062,260	140.6%	33.4%
Lithuania	627,202	4,159,700	2,792,040	149.0%	15.1%
Luxembourg	12,871	142,632	127,510	111.9%	9.0%
Latvia	568,400	2,853,680	1,432,680	199.2%	19.9%
Netherlands	368,788	2,621,717	1,958,050	133.9%	14.1%
Poland	4,813,243	20,231,887	14,754,880	137.1%	23.8%
Portugal	2,900,462	5,035,890	3,736,140	134.8%	57.6%
Romania	4,860,372	14,433,920	13,906,700	103.8%	33.7%
Slovenija	591,314	754,255	485,880	155.2%	78.4%
Slovakia	547,582	2,485,476	2,159,900	115.1%	22.0%
Sweden	1,136,030	4,759,869	3,192,440	149.1%	23.9%
United Kingdom	5,165,466	19,368,468	13,174,690	147.0%	26.7%
Total	74,659,056	233,684,479	171,277,570	136.4%	31.9%

(*) Malta not included

Source: Paracchini et al., 2008

Annex 12 Modelling yields and irrigation water needs for rotational arable crops (CGMS) and for perennial crops (GWSI)

To determine the irrigation water requirements of the rotational arable crops also used as feedstock for biofuels, the potential and water-limited yield and the amount of water directly used by the crops for transpiration under potential conditions were obtained from the data base of the Crop Growth Monitoring System (CGMS) (MARS project of the Joint Research Centre). The data have been collected for the six crops at NUTS-2 level. The six crops are winter wheat, spring barley, grain maize, oil seed rape, sunflower and sugar beet[52].

CGMS uses grid cells of 50x50 km as basic climatic grid on which daily weather data are available as time series over many years. In this study the five-year period of 2003-2007 has been used as input for the simulation of crop growth and water use with CGMS. The simulations have been carried out for all regions where the agricultural statistics mention that the crop is grown. In addition to weather data the simulation model requires as input soil data and crop parameters for each given crop. The final simulated values of yield and water use at the end of the season have been averaged over the five years, and aggregated over NUTS-2 regions.

The yield data include the total biomass and the amount of storage organs (grains or roots) accumulated at the end of the growing season. In addition the water used for transpiration under potential crop growth conditions has been quantified. The net amount of water needed to produce one Tonne of crop biomass has been determined by dividing potential crop water use by amount of biomass. This is the crop water use efficiency (WUE), expressed in cubic meter (m3) water per ton dry matter. It has been determined for each crop in each NUTS-2 region.

The following values for crop water use efficiency (WUE) (transpiration based) have been used (see Table 1).

Table 1 *WUE expressed in m3 water/Ton dry matter biomass*

Crop	WUE mean	Stdev	min	max
Winter wheat	163	13	126	197
Spring barley	152	18	113	197
Oilseed rape	166	13	134	205
Sunflower	333	56	245	482
Sugar beet	156	32	126	248
Grain maize	164	23	130	224

**Note: average WUE over 2003-2007 and all NUTS-2 regions in EU-27 where the crop is cultivated*

52 The water use requirements and rainfall deficiency could have also be determined from the Global Water Satisfaction Index (GWSI) system of JRC for the same crops of interest: Spring barley, grain maize, spring wheat, grain sorghum, soybean. However, the administrative subdivision of Europe applied in GWSI is based on FAO's global administrative maps which does not correspond to the NUTS-2 level subdivision over Europe, and requires manual recoding. Since the CGMS provided data at NUTS-2 which were easier to convert into the River Basin Districts (RBD) boundaries we made a choice for the CGMS based modelling runs.

Irrigation is needed to increase the yield from the water-limited level to the potential yield level.

The net amount of required irrigation water has been quantified as the biomass yield difference multiplied by the WUE, or

Net crop irrigation water requirement = (potential biomass yield – water-limited biomass yield) * WUE

The net crop irrigation requirement has been calculated for all NUTS-2 where the crop occurs. The crop water requirement is based on crop transpiration only and assumes a maximum efficiency of 100%. When taking into account within field water evaporation from the soil surface, the net irrigation requirements may be 10 to 20% higher.

The water requirements at field level take into account the field water application efficiency which depends on the irrigation technique, timing, and weather conditions and within field water losses due to irregular distribution involving excess applications.

The field water application efficiency has been taken from NUTS-2 level data compiled by (Wriedt *et al.*, 2008). These however only refer to the field level efficiency. It would be better to use efficiency data covering the whole trajectory from river and groundwater extraction to field level application. If this would be the case an additional water transport loss above field level application loss should be accounted for (e.g another 70% water transport efficiency). However, since neither national nor regional specific information on this is not available at all, we only took account of the field water application efficiency.

The per hectare irrigation water requirements were then calculated and multiplied by the total irrigated area every biomass crop was estimated to use (based on irrigation shares per crop per NUTS-2 from Wriedt *et al.*, 2008). This multiplication resulted in a total irrigation water requirements per NUTS-2 region.

Modelling irrigation water requirements and yields for perennial bioenergy crops with the GWSI model:
The FAO method of modelling crop water use and crop yield response allows taking account of the effects of suboptimum temperatures and water deficits on the length of the growing season, on crop water use and crop yield (Doorenbos and Kassam, 1979; Allen *et al.*, 1998). In the present study, two separate assessments have been made, one for a typical C3 grass and another one for a typical C4 grass. For each reference crop the water use and crop yield have been assessed for two theoretical reference situations, one for completely irrigated conditions (potential production situation) and one for purely rainfed conditions (water-limited production situation). This allows to identify a zonation across Europe for the climatic suitability for each crop type and to analyze the differences in climatic suitability between C3 and C4 (Table 2).

Table 2 *Examples of C3 and C4 perennial biomass grasses already grown in EU countries and to which the presented modelling approach is assumed to be applicable*

Crop	C3	C4
Reed Canary Grass (Phalaris arundinacea L.)	X	
Miscanthus (Miscanthus spp.)		X
Switchgrass (Panicum virgatum L)		X
Giant Reed (Arundo donax L.)	X	

The basic assumption on the length of growing season for grass is that grass starts growing (and thus, using water) as soon as the average temperature (over 10 days) exceeds a threshold, and that it stops growing as soon as the temperature drops below this threshold. However, the full evapotranspiration rate (and therefore full growth rate) are reached when the temperature exceeds a second threshold at a higher temperature, above which the temperature is optimum for realizing the full potential in terms of evapotranspiration and related crop growth. In between the lower and higher threshold temperatures the evapotranspiration is reduced linearly from a complete reduction (reduction factor = 1) at the lower threshold to no reduction (reduction factor = 0) at the second threshold.

The values for the two temperature thresholds chosen in the present study are:
C3 grass, 5 and 10 degree Celcius
C4 grass, 10 and 18 degrees Celcius

A full green cover is assumed all year, so Kc = 1 during 36 dekades (10 days periods) of the year.

The progress index increases from 0 to 100 over 1 + 35 periods of 10-days
The rooting depth of the grass is 1,000 mm, so it is rather deep and this makes that the soil-limited maximum rooting depth plays a role in the modelling of the soil water balance in all soils shallower than 100 cm.

Climate and soil data

The results have been obtained by applying the FAO-method within the European part of the Global Water Satisfaction Index system (GWSI) JRC-Agri4Cast for the two grass crops. The GWSI system contains the soil and climatic data and calculation modules. The two grasses have been defined especially for the present study. The climatic data are a time series of 10 years (1996-2005) 10-daily weather data of the ECMWF model on a 1x1 degree longitude-latitude grid. The European land area counts 1,088 of such major grid cells. The European soil map has been overlaid with a much finer grid at 0.1x0.1 degree resolution. This full grid counts 79,607 cells over Europe. Within each fine grid the soil map distinguishes up to 50 different Soil Typological Units. The soil data used in GWSI is a result of grouping these soil typological units (STUs) of the European soil map into physical soil types with identical agro-hydrological properties (rooting depth, water holding capacity). These physical soil types have been mapped on a 0.1x0.1 degree grid, where each grid cell has one or more soil types, known by their percentage are occupation, of which the total amounts to 100%. Combining climate grid and soil types resulted in 17,912 calculation units (unique combinations of climate and soil type). For each calculation unit five water related output variables have been stored for each crop assessment, namely the cumulative values over the growing season of the water surplus, the water deficit, the maximum evapotranspiration ETm (irrigated situation), the actual evapotranspiration ETa (rainfed situation) and precipitation. Each variable is expressed in mm/season.

Spatial aggregation

The calculations have been made for the complete European area (all calculation units), without considering a land use mask. The water output variables are mapped to the full grid of 0.1x0.1 degree by assignment of the values from the calculation units. Several aggregation options are possible to assign a value from the calculation units to a fine grid cell. In the present study we have chosen for the area weighted average value over each grid cell as the area weighted value is the most unbiased value in a postprocessing, e.g., in order to combine these results with a land use mask and to distinguish regional yield patterns in relation with current agricultural areas.
The fine grid data are a basis for aggregation to NUTS-2 or national values, or to values at River Basin.

Translating water use into biomass potential yields
The maximum grass yield has been calculated by assuming characteristic water use efficiency values from the literature for C3 and C4 grasses. WUE is expressed in gram dry matter per kg used water. The range in WUE values is from 1 to 5 gr DM per kg ET. (Note that its inverse value is used as well. The corresponding range is expressed as between 1,000 and 200 kg ET per kg DM).
As the basic conversion is 1 mm water = 10 m3 per hectare = 10,000 kg/ha, another expression of the range in WUE is from 10 to 50 kg DM per mm ET. We have chosen the WUE values as follows:
WUE for C3 crops 30 kg DM per mm water use
WUE for C4 crops 40 kg DM per mm water use

nil (zero percent) harvest losses

With a range in ETa values of 200 to 1,300 mm over Europe , this leads to a range in theoretically maximum yield levels of 6,000 – 40,000 kg/hectare for C3 grasses, and 7000- 50,000 kg/hectare for C4 grasses. Note that on the same location the modelled ETa value for C3 and C4 are often different, due to differences in temperature response. These maximum yield levels are not attainable in reality for reasons explained earlier. A fraction of 70% of these maximum yields is a more realistic biomass yield ceiling, and 50% of these maximum yields is probably a fair target under intensive management.

When the choice is for extensive management and low external inputs, the value of the maximum yield maps is that it shows zones with relatively high and relatively low potential, and the differences in potential between typical C3 and C4 crops.

Results of the biomass assessment for C3 and C4 grasses
The assessment of the maximum yields leads to a set of four European yield maps, of which as an example only the two for C3 are displayed, showing a regional yield pattern for the reference situations in Table 3.

Table 3 *Assessment of the maximum yields*

Grass yield kg/ha	C3	C4
Potential	<5,000 to 40,000 (see Map 1)	<5,000 to >45,000
Water limited	<5000 to 20000 (See Map 2)	<5,000 to 20,000

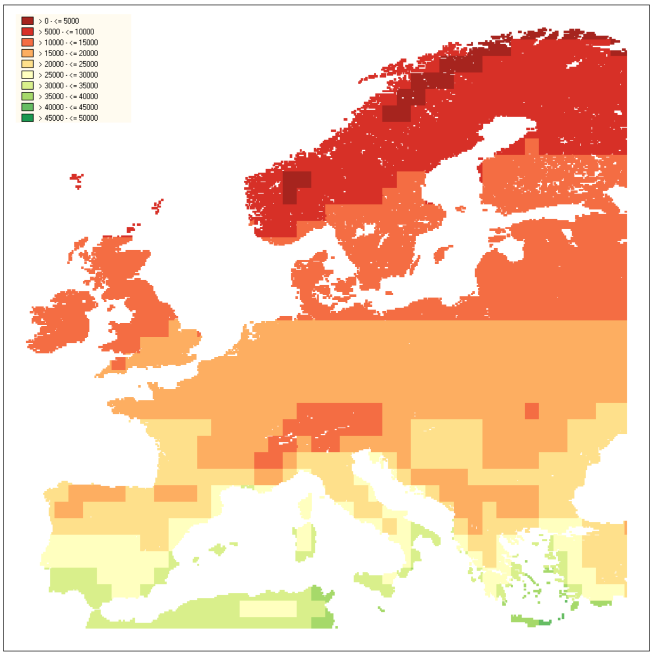
In the next step the difference between C3 and C4 and potential and water limited yield levels can be analyzed, which results in four additional yield difference maps as displayed in Table 4.

Table 4: *Difference between C3 and C4 and potential and water limited yield levels*

Grass yield kg/ha	C3 grass	C3-C4 difference	C4 grass
Potential grass yield	<5,000 to 40,000	Up to + 8,000 in northwest Europe Up to – 8,000 in south Europe (Map 3)	<5,000 to >45,000
Pot – watlim difference	0-30,000		0-35,000
Water limited grass yield	<5,000 to 20,000	Up to + 8,000 in northwest Europe Up to – 4,000 in south and SE Europe (Map 4)	<5,000 to 20,000

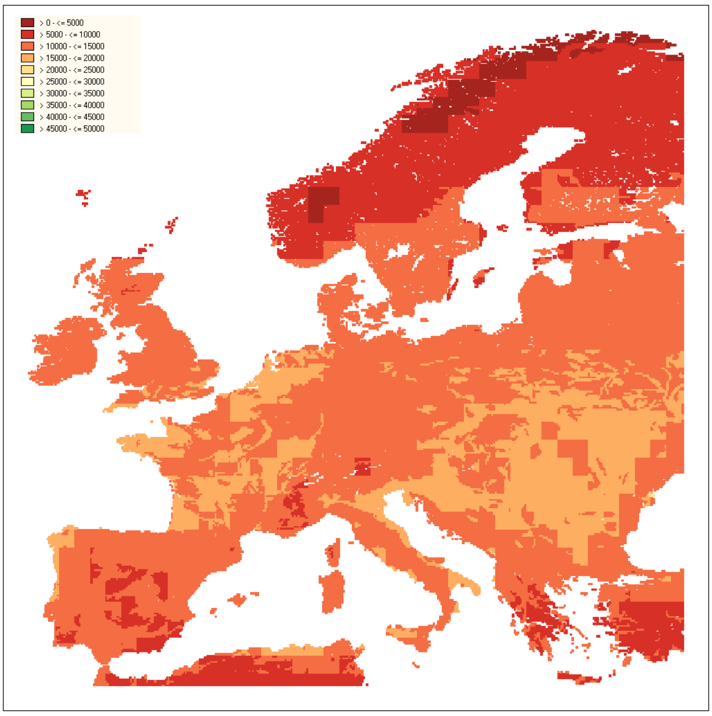
Map 1 C3 Potential grass production

qryC3Pot.bmp : C3 Potential grass production (kg / ha)



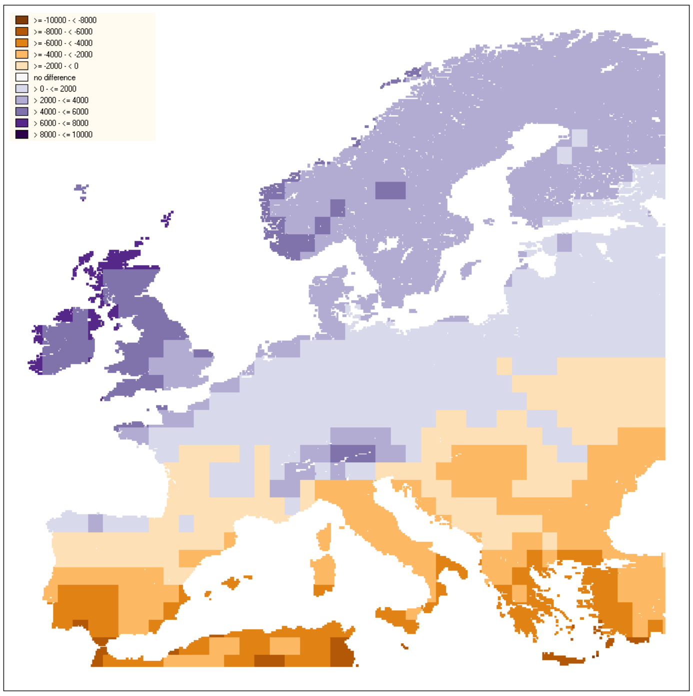
Map 2 *C3 water limited grass production*

qryC3WL.bmp : C3 Water limited grass production (kg / ha)



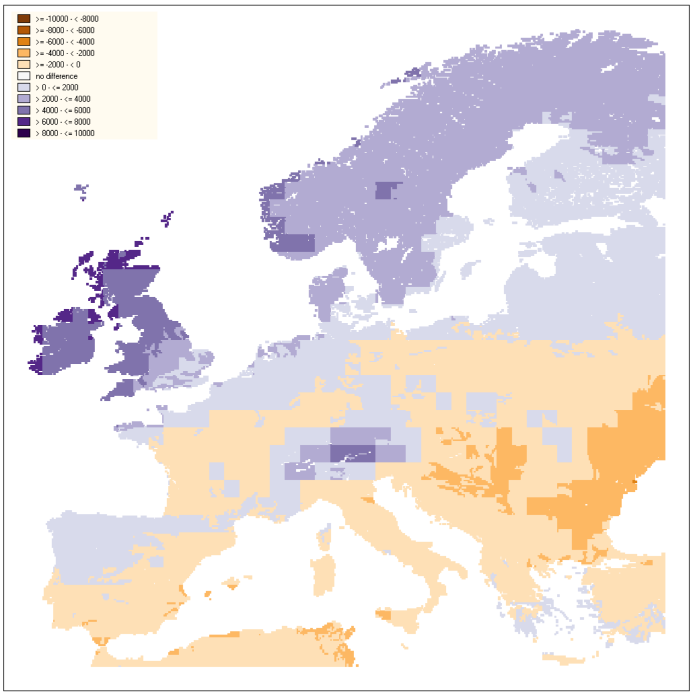
Map 3 C3/C4 Potential difference in yield

qryDiffC3C4Pot.bmp : C3 / C4 Potential difference (kg / ha)



Map 4 C3/C4 water limited difference in yields

qryDiffC3C4WL.bmp : C3 / C4 Water limited difference (kg / ha)



The analysis presented above shows that the potential yield of C3 grass exceeds the C4 yields in the northern half of Europe and in the mountainous areas. The dividing line runs in the direction SWW-NEE. Just north of the dividing line are the Spanish Atlantic north coast, Brittany, Massif central and Alps in France, the Alpine and Carpathian regions, Poland and Bielorussia. The highest differences are in the areas with long cool summers, especially in Ireland and western UK, in the Alps and in a few areas in Norway. A second area with somewhat smaller differences in yield are Scandinavia and Finland, which have a short cool summer, and in the coastal strips along the Channel and in the North Sea region, which have slightly warmer summer than western UK. In the whole area of the northern European low plain from Brussels to Moscow the C3 grass has a slight advantage above the C4 grass. However, under water limited conditions the C4 grass has a relative advantage in those parts of the European plain where drought periods occur regularly in the summer, especially in soil regions with a lot of sandy soils, such as eastern Germany and Poland, except the coastal strip along the Baltic Sea. In northern European regions without water stress in the growing season the C3 grass maintains its advantage over C4 crops.

In the southern half of Europe potential grass yields of both C3 and C4 grasses increase southwards, but the C4 grass out-yields the C3 grass. The difference is largest under potential (irrigated) conditions in the far south. Under water-limited conditions C4 grass also out-yields the C3 grass. But the difference is levelled of by the increasing drought stress in the most southern regions.

The highest water-limited grass yields for C4 grasses are southern France, but not in the Mediterranean part, in northern Italy and all the area east of Warschau-Vienna, down to the west coast of the Black Sea, and West-Ukraine. The highest water-limited yields of C3 grass are slightly below the C4 yields and occur in the same regions as for C4 grass and for the Benelux countries. In all these areas a rather favourable balance exists between rainfall and evapotranspiration, during the entire growing season between the onset of spring and late autumn.

Conclusions for mapping of yield and water need levels:
Via the above exercise we have derived a database specifying per 0.1x0.1 degree grid the total attainable and water limited yield for C3 and C4 crops and the related water need to arrive to this potential. From the latter we can also specify the irrigation water need per grid by subtracting the water need under total attainable yield with the under a water limited yield. The yields per location also provide the basis for the calculation of the potential energy yield from the C3 and C4 crops per location.

Translating biomass yield of perennial grasses over Europe into obtainable biomass volumes under current farming conditions for the scenario assessments
The estimated theoretical maximum biomass productions for C3 and C4 perennial grasses assume optimum management conditions, which implies that a full green cover is reached soon after the start of the growing season, and sufficient nutrient availability from soil and fertilizer during the entire growing period. Two separate yield estimates have been made, one under full irrigation and one under purely rainfed conditions. These two production levels, potential and water-limited, should correspond with the highest yields observed in field experiments. In reality, the yields are often lower, due to suboptimum conditions such as nutrient shortage or incomplete plant cover.

For example, Consentino *et al.* (2007) report for a Miscanthus (a C4 grass) field experiment in Catania, Sicily, where the combined irrigation and nitrogen effects were studied, a maximum biomass yield of 27 T/ha dry matter under full nitrogen and water supply, 19 T/ha under full irrigation and low nitrogen level, and 17 T/ha under limited irrigation and nitrogen conditions. For the second year in the same multi-year experiment, the biomass yields were 18, 14.6 and 14.5 T/ha dry matter respectively. Note that there was not a purely rainfed situation in this trial. This shows inter-year yield variability, and important yield reductions due to limiting soil and water conditions. The annual biomass production for the same region (Sicily, NUTS itg1) according to to GWSI model was 35 tonnes DM ha-1 year-1 under potential conditions and 15 tonnes under water-limited conditions. In this case the maximum observed yield is 77% of the potential yield.

Table 5 *Comparison of observed and simulated biomass yield in some European countries for C3 and C4 grasses*

Country	C4 grass observed	C3 grass observed	C4 simulated	C3 simulated
Biomass yields are in tonnes DM ha-1 year-1	sw switch gra mi Miscanthus	gr giant reed rcg reed canary	pot potential wl water-lim	Pot potential wl water- lim
Finland		5-12 (rcg)		8-11 (pot)
				8-10 (wl)
Sweden		5-12 (rcg)		7-12 (pot)
				7-12 (wl)
Denmark	5-15 (mi)		10-11 (pot)	
			10-10 (wl)	
Britain	11 (sw)	6-12 (rcg)	5-13 (pot)	10-16 (pot)
	10-15 (mi)		5-13 (wl)	10-14 (wl)
Germany	4-30 (mi)	15-20 (gr)	12-16 (pot)	14-16 (pot)
			12-15 (wl)	13-14 (wl)
Switzerland	13-19 (mi)		9-13 (pot)	
			9-12 (wl)	
Austria	22 (mi)		7-20 (pot)	
			7-17 (wl)	
North Italy		3-32 (gr)		11-22 (pot)
				10-15 (wl)
Italy	30-32 (mi)		8-35 (pot)	
			8-16 (wl)	
South Italy		15-34 (gr)		25-30 (pot)
				12-15 (wl)
North Greece		5-17 (gr)		21-26 (pot)
				10-12 (wl)
Greece	26-44 (mi)		28-46 (pot)	
			9-14 (wl)	
South Greece		7-31 (gr)		29-38 (pot)
				9-11 (wl)
Turkey	28 (mi)		23-33	
			8-16	
Spain	14-34 (mi)	8-37 (gr)	16-40 (pot)	18-34 (pot)
			10-14 (wl)	10-14 (wl)

* For both observed and simulated data the range in yields is given: for the observed data the range within a country, for the simulated data the lowest and highest regional yields (NUTS-2) within a country.

Lewandowski *et al.* (2003) provide a review of perennial grasses for use as energy crops in the US and Europe, and provide reported yield ranges from literature, per grass species and country. It is not clear under what kind of conditions these grasses were grown but we may assume that the highest yields are related to intensive crop management and our estimates of potential and water-limited biomass yields should

correspond to these observed yields, while the lowest yields are probably below our water-limited yields, unless the reported yields are from irrigated fields.
Table 5 provides the comparison of yields reported by Lewandowski *et al.* (2003) and our yield estimates, per crop type and country.

Analysis of the figures in the table shows that in general:
The highest simulated biomass yields for perennial C4 grasses vary from 11 tonnes DM/ ha/year in Denmark, 13 tonnes DM/ ha/year in Britain to 40 tonnes DM/ ha/year in Spain and even 46 tonnes DM/ ha/year in Greece.

The picture for C4 grasses over all countries with data shows that the highest observed biomass yields are between 80 and 120% of the highest potential yields. For C3 grasses the highest observed yields are between 85 and 95% of the highest potential yields.

This leads to the assumption that under modern intensive fully irrigated farming all (C3 and C4) perennial grasses could reach 90% of the potential biomass yield. Comment: this assumption (introduction of modern intensive farming practices, including irrigation when drought occurs), may not be very realistic as a scenario that will be applicable over large regions, because water availability will be a real constraint in southern Europe.

In situations where no irrigation water is available, but which are otherwise under modern farm management and have good soils, the biomass yields will show more regional variation. For regions in southern Europe it may yet be necessary to apply one irrigation at the start of the growth cycle to ensure crop establishment. A good crop cover is necessary for reaching the full water-limited yield. The assumption of modern farm technology is justified, as large scale biomass cropping will be organized as a new agricultural business which will not evolve from traditional farming.

The basic set of assumptions for the yield level is that the production ceiling is set at 90% of the potential production, but will not exceed the water-limited production. This can be assessed easily by taking the lowest value of the following two yield levels: (90% of potential yield) and (100% of the water-limited yield).

Note 1: This assumption means that in areas with sufficient rainfall (northern half of Europe) the attainable production will be close to 90% of the potential yield, but especially in southern Europe the rainfed biomass production will be down to 50 or 25% of the maximum irrigated production.

Note 2: It appears from the observed yield data however, that for the southern European countries the lowest observed yields are above the water-limited yields, implying that the bio-energy grasses are irrigated at least partly. Yet the assumption that the large scale introduction of new biomass crops should rely largely on rainfed cropping seems justified.

In a situation of extensive arable farming and low soil quality (shallow, or otherwise marginally productive soils) the biomass production will be lower than under intensive farming. We assume that the range of yield levels for these situations can be found in the tail of the observed yields, e.g. below the midyield in the range of observed yields per region (or per country). In reality the variability in biomass yields under extensive farming systems will be high. A reasonable first guess would be to assess the obtainable biomass yield under extensive arable farming as the lowest yield of the following two: (50% of the potential yield) and (80% of the water limited yield).

Summary on assessment in three yield levels:

In summary we can derive from the set of regional mean potential and water-limited yields for C3 and C4 perennial grasses three attainable biomass yield levels, according to the type of cropping:

High yield: Modern fully irrigated cropping: all grasses could reach 90% of the potential biomass yield.

Medium yield: Modern rainfed cropping (apart from crop establishment irrigation): attainable grass yield equals the lowest value of the following two yield levels: (90% of potential yield) and (100% of the water-limited yield).

Low yield: Extensive cropping: the lowest yield of the following two: (50% of the potential yield) and (80% of the water limited yield).

These 3 yield levels have been used in the storyline studies to estimate the final total yield levels of Miscanthus, Switchgrass and Reed Canary Grass (RCG) (see Table 5).

Annex 13 Estimating the abandoned land resource in the EU-27

In this study a rough estimate was made per NUTS 2 region of the area potentially abandoned and available for bioenergy production. 3. In regions/countries for which statistical or published evidence is given of high passed land abandonment figures (based on Pointereau *et al.*, 2008) an extra 5% or 10% of the utilised agricultural area (according to the CAPRI 2020 baseline scenario) is expected to be potentially abandoned. From this abandoned potential only a maximum of 5% can be used for dedicated cropping with perennials provided the environmental constraints per storyline are met. Underneath an overview is given of the potential abandoned land surface estimated in this study. It becomes clear that abandoned land is mostly found in most central and eastern European countries as well as some Scandinavian and Mediterranean countries..

Table 1 *Overview of abandoned land potential per region (only 5% of this land resource is assumed to be available to be converted into dedicated energy cropping).*

Country	Potentially abandoned land (in 1000 ha)
Austria	0
Bulgaria	250
Belgium	0
Cyprus	3
Czech Republic	93
Germany	62
Denmark	0
Estonia	18
Greece	149
Spain	567
Finland	13
France	162
Hungary	132
Ireland	38
Italy	263
Lithuania	65
Latvia	72
Malta	0
Netherlands	0
Poland	806
Portugal	88
Romania	723
Sweden	7
Slovenia	23
Slovakia	103
UK	0

Annex 14 Detailed ILUC factors and scenario descriptions for studies compared in Chapter 4

***Table 1**: Indirect land use change emissions for various feedstocks*

	Reported avg. value	Range	Annualization period
	gCO2e/MJ	gCO2e/MJ	years
CARB			
Corn ethanol	30	18-44	30
Sugar cane ethanol	46	32-57	30
Soy biodiesel (preliminary)	42	27-51	30
Cellulosic ethanol (preliminary)	18	n.d.	30
E4tech			
Rapeseed biodiesel	4.2	n.d.	n.d
Palm oil biodiesel	74	n.d.	n.d
Sugar cane ethanol	n.d.	3.5-10.2	n.d
ADEME			
Soy biodiesel, Brazil direct LUC, USA indirect LUC		17-1380	20
Soy biodiesel, Brazil direct LUC		21-419	20
Sugarbeet ethanol, ILUC		13-181	20
Rapeseed biodiesel, ILUC		-33-187	20
Palm oil biodiesel, direct LUC		10-160	20
Sugar cane ethanol, direct LUC		19-190	20
IFPRI (marginal ILUC emissions**)			
Sugar beet ethanol		16.07-65.48	20
Sugar cane ethanol		17.78-18.86	20
Maize ethanol		54.11-79.15	20
Wheat ethanol		16.12-37.26	20
Palm oil biodiesel		44.63-50.13	20
Rapeseed biodiesel		50.60-53.68	20
Soy biodiesel		67.01-75.40	20
Sunflower biodiesel		56.27-60.53	20
PBL			
Wheat ethanol, EU	73	24-144	20
Sugar beet ethanol, EU	85	33-151	20
Sugar cane ethanol, Brazil	111	41-195	20
Sugar cane ethanol, Pakistan	41	14-83	20
Rapeseed biodiesel, EU	106	38-198	20
Soy biodiesel, USA	87	0-273	20
Soy biodiesel, Argentina	169	64-293	20
Palm oil biodiesel, Indonesia	96	23-214	20

Palm oil biodiesel, Malaysia	96	23-214	20
JRC			
Biodiesel scenarios			
LEITAP Biod EU-Deu	337	80-800	20
FAPRI Biod EU	76	19-180	20
AGLINK Biod EU	40	10-95	20
AGLINK Biod US	42	11-100	20
GTAP Biod mix EU	66	16-156	20
LEITAP Biod INDO	74	19-176	20
GTAP Biod Ind/Mal	14	14-34	20
Ethanol scenarios			
LEITAP Wht Eth EU-Fra	128	32-303	20
FAPRI Wht Eth EU	69	17-163	20
AGLINK Wht Eth EU	100	25-238	20
IMPACT Wht Eth EU	39	10-92	20
GTAP Wht Eth EU	139	35-329	20
IMPACT Wht Eth US	39	10-92	20
LEITAP Maize Eth US	151	38-358	20
AGLINK Coarse grains Eth US	89	22-211	20
GTAP Coarse grains Eth US	29	7-68	20
IMPACT Maize Eth US	19	5-44	20
IMPACT Coarse grains Eth EU	20	5-48	20
AGLINK Sugar cane Eth Bra	23	6-56	20

CARB

The scenarios for biofuels in the CARB study build on the base year 2001 (with, in some of the cases, adjustments for a yield increase). On this baseline, an additional increase in biofuels production was imposed. The model then calculates a new equilibrium. Comparison of the results of this scenario with the baseline scenario is used to derive ILUC. The shocks of additional biofuels are as follows. The production increase in the corn ethanol case was 13.25 billion gallons (from 1.75 in 2001). Sensitivity analyses were also conducted with an 8.75 billion gallon increase. Similarly, a sugar cane scenario was calculated with a production increase of 2 billion gallons (from 3.61 in 2001). The soy biodiesel scenarios include an increase from 0.0005 billion gallons of biodiesel in 2001 to 0.3 and to 0.7 billion gallons in 2020. Other model settings included in the sensitivity analysis are elasticity of crop yield with respect to area expansion, crop yield elasticity, elasticity of land transformation and trade elasticity of crops.

The CARB study does not report explicitly on the total amounts of biofuels included in the scenarios. One can assume that 2001 biofuel production, which was relatively low, was included in the baseline. The global increase projected for 2010 or 2020 based on current policies was not included in the scenarios. This is important because it is likely that the total global production of biofuels will influence the final ILUC factor. This means the higher the global background demand for biomass for energy the less likely is any potential compensation of a given extra biofuels demand via agricultural intensification, as the current land potential is already largely exploited.

E4tech

In this study the scenarios are not a source of exogenous model inputs, but provide the context in which the ILUC calculations should be interpreted. The baseline is the 2020 projection for the demand for crops, with the 2008 demand for biofuels. The biofuels scenario includes world targets for biofuels in 2020. Both scenarios include all crops and are based on projections by the FAPRI model. The calculated ILUC factors for soybean and palm oil were based on the global demand for these products, while the data for ethanol and rapeseed were based on European demands. In the scenarios, these demands are translated into demand for feedstock. The difference in demand for these feedstocks in the two scenarios is the basis of the ILUC calculations. US corn was not modelled explicitly and was assumed not to influence the production of the other feedstocks. From this additional demand for a certain crop, the ILUC effects are determined using a causal descriptive approach (including market responses, yield and area changes).

The E4tech study also includes various scenario options within the causal descriptive approach for each biofuel. For palm biodiesel these include assumptions on yields, deforestation, peat lands and plantation lifetime. For rapeseed these include the amount produced in Europe, the amount imported from Ukraine, deforestation rates in Indonesia and Malaysia, use of rapeseed meal as fodder, and co-product substitution ratios. Soy biodiesel scenarios include assumptions on substitution of soy oil in China by rapeseed and palm oil and assumptions on the ILUC of this palm oil. For wheat, the European wheat trade balance, yield increase due to biofuel demand, deforestation rates in Indonesia and Malaysia, deforestation rates in Argentina and Brazil, and share of DDGS used as fodder are included. For sugar cane the scenarios include assumptions on EU and US bioethanol consumption, production and export in US and Republic of South Africa, yield increase in sugar cane, pasture displacement due to additional sugar cane demand, pasture intensification including differences in developed and developing countries, displacement to Brazil and Argentina, and deforestation rates in Brazil. All these assumptions add to the uncertainty ranges presented in this study.

ADEME

The ADEME study is mainly a life cycle assessment with a sensitivity analysis for ILUC. No modelling tools for the global system are used. The analysis is simply based on assumptions. Direct land use change in Europe is assumed to be zero and in the other continents this is highly uncertain. Indirect land use changes are uncertain for all continents. The sensitivity analysis includes estimates for different variables at four levels: a maximum, intermediate, moderate and optimistic scenario. The maximum includes conversion of tropical forest with a smoothing period of 20 years (soy is compensated for its production of by-products). The intermediate scenario considers the conversion of degraded forest (or a mix of tropical forests with partial peatland and crops). In the moderate scenario only 80 % of the oil is actually substituted and of this, half is cultivated on current croplands through yield increase, without any effect on GHG emissions. Of the corresponding CO_2 emissions, only half is attributed to palm oil production. In the optimistic scenario the cultivation of degraded land may lead to negative emissions. Cultivating soy on 'cleared land' may reduce land conversion elsewhere because the by-products reduce the demand for fodder crops, according to the report. For example, the emissions for direct land use were estimated as between -4 and 27 ton/ha/yr (optimistic and maximum estimates for sugar cane), -6 to 23 ton/ha/yr (optimistic and maximum estimates for palm oil), and 0 to 32 ton/ha/yr (optimistic and maximum estimates for Brazilian soy bean).

For the ILUC (of EU crops) a similar range of scenarios with similar set-ups was used. An important difference here is that for methyl esters (diesel) the values for ILUC are much lower than those of the direct land use changes. This is because with direct land use changes 1 ha forest is cropped with one hectare of a biofuel feedstock crop.

However, with regard to ILUC the starting point of potential impacts is not the land use but the production. The effect of ILUC is therefore determined by the amount of land expansion or the intensification of existing land that is needed to compensate for this loss in production (and not necessarily this loss in land). Since the assumption on oil yield per hectare is five times higher for palm than for rape, the ILUC for EU oil crops is considered to be relatively low (1 ha of (food) rapeseed oil could be replaced by only 0.2 ha of palm oil). For the ethanol this effect is not as marked. The emissions for ILUC were estimated at between -6 and 7.5 ton/ha/yr (optimistic and maximum estimates for methyl esters), -4 to 27 ton/ha/yr (optimistic and maximum estimates for ethanols). The study reports the direct LUC for palm oil-derived biodiesel, sugar cane ethanol, Brazilian soybean –derived biodiesel and Brazilian soybean fame with ILUC from US soybean biodiesel. ILUC is practically equal to direct land use using the above assumptions on land use. ILUC was estimated for EU rapeseed biodiesel and sugar beet ethanol.

IFPRI 2010 study

This modelling exercise used the GTAP database. First, the reference year was updated from 2004 to 2008. Scenario assumptions were based on the literature and include an oil price of $109 per barrel and EU road transport energy demand of 316 Mtoe in 2020. Some exogenous yield increase was assumed (5 % in the EU and up to 30 % in Brazil), except for palm oil. Trade policies are kept as in 2008. Anti-dumping duties for US biodiesel are incorporated. EU policies on sugar reform and the end of set-aside are included. The baseline includes the 3.3 % blending level of 2008 throughout the period until 2020 and the 5.75 % blending target is not implemented. This results in a situation in 2020 with 9.75 Mtoe consumption with a 90 % share of biodiesel. Expected cropland expansion is 36 % in Brazil and 5 % in Europe (9 % globally).

Against this baseline, three trade scenarios are evaluated: business as usual, full multilateral trade liberalisation in biofuels, and EU bilateral trade liberalisation with Mercosur. These scenarios assume 5.6 % blending in 2020. This is a 70 % EU increase and an 8 % increase globally. The model uses a target ratio between biodiesel and bioethanol of 45 to 55 %, as a function of vehicle fleet composition. The scenario set-up has some drawbacks, as stated in the study itself: 'Due to the potential non-linearity in our analytical framework …, this policy design will also explain the relatively low per unit cost (CO_2 and economic inefficiency) of such a mandate. … the effects of trade liberalisation will be very strong, and may be overestimated'. A sensitivity analysis was therefore performed: using a range of mandate biofuels targets (4.6 to 8.6 %), parameter uncertainties were included and fertiliser modelling and interaction between pasture and croplands was evaluated.

PBL

The PBL study is based on EU biofuel consumption in 2007. Scenario assumptions on how demand, population, yields etc. develop are therefore not necessary. Where possible this information is used directly from monitored data, however direct data on ILUC is not available. To construct this from the available data several assumptions have to be made. The data also often has a high and a low estimate. These data ranges, combined with the assumptions, result in the uncertainty range presented in the study. The assumptions include the share of imports consumed and the share of production exported, the share of by-product used as fodder, and the fate of the displaced production on land now used for biofuels. For the last of these, two different assumptions are made: one that all displaced production is produced elsewhere on the same continent, the other that that the displaced consumption is spread all over the world. The data ranges in the conversion emissions included in the study are also a source of uncertainty.

JRC

The JRC study is a collective modelling exercise of several modelling groups, asked to run the same scenarios (including LEITAP, GTAP, FAPRI, AGLINK, IMPACT). In the time frame of the study it was not possible to align all model assumptions. For example, the original baselines of the various models were not replaced. Details on the baselines of the different models can be found in the original report (JRC-IE, 2010). The scenarios calculated in the context of the study are the so-called marginal scenarios. A small shock of 1 Mtoe of additional biofuel demand is added to the baseline. The study includes four variants:

- marginal extra ethanol demand in the EU
- marginal extra biodiesel demand in the EU
- marginal extra ethanol demand in the US
- marginal extra palm oil demand in the EU (for biodiesel or pure plant oil use).

The study assumes that the marginal effect on top of the baseline is similar to a scenario with a variety of biofuels (and with higher targets). The model therefore assumes the ILUC factor to be independent of biofuel demand. One average result was calculated and no separate calculations are made for the feedstock types and regions. The uncertainty range presented is based solely on differences in conversion emissions.

Oeko Institut study
This approach uses a 'world mix' of land use implied by agricultural exports and explicit assumptions on respective land use change in each country/region which can be projected over time to derive future ILUC values for given risk levels. For this, the yield data of biofuel feedstocks was projected from 2005 to 2030, and the IPCC emission factors for direct land use change were held constant. Next, the trade shares for 2010 were estimated based on FAOSTAT data trends from 2000 to 2008, and the possible changes in LUC due to national/regional land use policies were factored in. For 2030, a range of land use change figures was derived in three scenarios to reflect possible longer-term developments:

- the 'HIGH' case assumes that conversion of carbon-rich land, especially in Argentina, Brazil and Indonesia, cannot be stopped, so this scenario indicates the maximum (upper) range of possible LUC emissions;
- the 'LOW' case assumes that policies to ban conversion of carbon-rich land are successful, and also that degraded land is increasingly used for feedstock production. Thus, this scenario describes the 'optimistic' (lower) range of possible GHG emissions from LUC;
- the 'REF' case is the middle path between HIGH and LOW, but leaves out the use of degraded land.

The high, low and reference levels of land conversion are then combined with a risk level (the amount of land that is actually converted) of 25 and 50 % to arrive at the ILUC levels.

Annex 15 Conversion pathways for domestic forest and waste biomass supply and imports

Table 1 *Biomass to bioenergy pathways for imports in economic storyline expressed in PJ and related emissions (land based, transport and conversion emissions included)**

		Import type	total amount (PJ)	emission kg CO2eq	Average kg CO2/GJ
Heat	Pellets from SRC wood and residues from forests	BR eucalyptus-SRC-pellets Boiler district heat	0		
		BR eucalyptus-SRC-marginal-pellets Boiler dis	0		
		CA wood residues pellets Boiler district heat	721.8	25566805411	35.4
		CA round wood pellets Boiler district heat	0.0		
		US wood residues pellets Boiler district heat	721.8	15787347842	21.9
		US round wood pellets Boiler district heat	0.0		
		RU wood residues pellets Boiler district heat	721.8	22385567872	31.0
		RU round wood pellets Boiler district heat	0.0		
Biofuels	Agricultural biofuels	EtOH sugarcane 1G Brazil	123.6	10848682745	87.8
		EtOH sugarcane 1G Brazil sustain	0.0		
		palmoil-biodiesel Indonesia	247.1	25549987907	103.4
		palmoil-biodiesel Indonesia sustain	0.0		
		soybean-biodiesel Argentina	123.6	19604751225	158.6
		BR eucalyptus-SRC-pellets SNG-BTL			
		BR eucalyptus-SRC-marginal-pellets SNG-BTL			
		CA wood residues pelletsSNG-BTL			
		CA round wood pellets SNG-BTL			
		US wood residues pelletsSNG-BTL			
		US round wood pellets SNG-BTL			
		RU wood residues pellets SNG-BTL			
		RU round wood pellets SNG-BTL			
	Agricultural residues	Straw (FT production) synthetic diesel			
		Dry manure biogas output > 2 MWth, BACT			
	Waste	Used fats and oils transestrification to biodiese	0		
		Gaseous fuels from animal waste			
	Total		**2659.702569**	**119743143001**	**45.0**

*emissions calculated with GEMIS and Miterra-Europe (for land based emissions)

Table 2 *Biomass to bioenergy pathways for imports in sustainable storyline expressed in PJ and related emissions (land based, transport and conversion emissions included)**

		Import type	total amount (PJ)	emission kg CO2eq	Average kg CO2/GJ
Heat	Pellets from SRC wood and residues from forests	BR eucalyptus-SRC-pellets Boiler district heat	0		
		BR eucalyptus-SRC-marginal-pellets Boiler dist	0		
		CA wood residues pellets Boiler district heat	409	14496455178	35.4
		CA round wood pellets Boiler district heat	0		
		US wood residues pellets Boiler district heat	409	8951473470	21.9
		US round wood pellets Boiler district heat	0		
		RU wood residues pellets Boiler district heat	409	12692683973	31.0
		RU round wood pellets Boiler district heat	0		
Biofuels	Agricultural biofuels	EtOH sugarcane 1G Brazil			
		EtOH sugarcane 1G Brazil sustain	0.0	0	**0.00**
		palmoil-biodiesel Indonesia		0	
		palmoil-biodiesel Indonesia sustain	0.0	0	**0.00**
		soybean-biodiesel Argentina		0	
		BR eucalyptus-SRC-pellets SNG-BTL			
		BR eucalyptus-SRC-marginal-pellets SNG-BTL			
	Agricultural residues	Straw (FT production) synthetic diesel	0	0	**0.00**
		Dry manure biogas output > 2 MWth, BACT	0.0	0	**0.00**
	Waste	Used fats and oils transestrification to biodiesel	0.0	0	**0.00**
		Gaseous fuels from animal waste	0.0	0	**0.00**
	Total		**1227.8**	**36140612621**	**29.4**

*emissions calculated with GEMIS and Miterra-Europe (for land based emissions)

Table 3 *Biomass to bioenergy pathways for forest biomass produced in the EU in three storylines expressed in PJ and related emissions (land based, transport and conversion emissions included)**

		Import type	total amount (PJ)	emission kg CO2eq	Average kg CO2/GJ
Heat	Pellets from SRC wood and residues from forests	BR eucalyptus-SRC-pellets Boiler district heat	0		
		BR eucalyptus-SRC-marginal-pellets Boiler dist	471.1		
		CA wood residues pellets Boiler district heat	471.1	16688351240	**35.42**
		CA round wood pellets Boiler district heat	0		
		US wood residues pellets Boiler district heat	235.6	5152478022	**21.87**
		US round wood pellets Boiler district heat	0		
		RU wood residues pellets Boiler district heat	235.6	7305922921	**31.01**
		RU round wood pellets Boiler district heat	0		
Biofuels	Agricultural biofuels	EtOH sugarcane 1G Brazil			
		EtOH sugarcane 1G Brazil sustain	54.5	-382757788.6	**-7.02**
		palmoil-biodiesel Indonesia		0	
		palmoil-biodiesel Indonesia sustain	54.5	-3447573628	**-63.26**
		soybean-biodiesel Argentina		0	
		BR eucalyptus-SRC-pellets SNG-BTL			
		BR eucalyptus-SRC-marginal-pellets SNG-BTL			
	Agricultural residues	Straw (FT production) synthetic diesel	0.0	0	
		Dry manure biogas output > 2 MWth, BACT	0.0	0	
	Waste	Used fats and oils transestrification to biodiesel	55.0	411400000	**7.48**
		Gaseous fuels from animal waste		0	
	Total		**1577.4**	**25727820767**	**16.31**

*emissions calculated with GEMIS and Miterra-Europe (for land based emissions)

Table 4 *Biomass to bioenergy pathways for waste biomass produced in the EU in three Storylines expressed in PJ and related emissions (transport and conversion emissions included)**

Waste heat			**Total PJ**			**Total ton CO2 eq**			**Average emissions (Kg CO2 eq/GJ)**		
			Economic	**Climate**	**Sustainability**	**Economic**	**Climate**	**Sustainability**	**Economic**	**Climate**	**Sustainability**
used fat/oil	used fat/oil	liquid combustion(heat only)	100.5	50.3	23.1	92295	46200	21250	0.9	0.9	0.9
Post consumer wood	Pelletisation	Residential pellet boilers(medium)		201.3	92.6		1325157	609517		6.6	6.6
Post consumer wood	Pelletisation	Residential pellet boilers(large))	402.1	251.6	23.1	2442325	1528186	140580	6.1	6.1	6.1
Post consumer wood	Pelletisation	Residential pellet boilers(small)			92.6			640608			6.9
Total			**502.7**	**503.2**	**231.5**	**2534620**	**2899543**	**1411955**	**5.0**	**5.8**	**6.1**

Waste electricity			**Total PJ**			**Total ton CO2 eq**			**Average emissions (Kg CO2 eq/GJ)**		
			Economic	**Climate**	**Sustainability**	**Economic**	**Climate**	**Sustainability**	**Economic**	**Climate**	**Sustainability**
MSW (not landfill, composting)		Combustion(electricity only)	226.0	113.0		62560233	31271802	0	276.8	276.8	
MSW (not landfill, composting)		CHP	226.0	225.9	262.6	34755642	34746403	40391159	153.8	153.8	153.8
verge grass	biogas	CHP	56.5	56.5	105.1	899893	899654	1673293	15.9	15.9	15.9
animal waste	biogas	CHP	56.5	169.5	157.6	317312	951682	885031	5.6	5.6	5.6
Total			**565.0**	**564.8**	**525.3**	**98533080**	**67869541**	**42949483**	**174.4**	**120.2**	**81.8**

*emissions calculated with GEMIS and Miterra-Europe (for land based emissions)

Annex 16 Water quality impact indicator

Assessment done by: Jan Peter Lesschen (Alterra)

1. **Key messages/conclusions**

Changes in water quality show larger differences between 2004 and 2020 than between the three 2020 Storylines. Overall there is a decline in N-leaching between 2004 and 2020 at EU level and this decline is larger for Storyline 2 and 3, although differences between the Storylines are rather small. Changes in water quality are caused by changes in mineral fertilizer and manure N inputs and changes in cropping shares, which drive the fertilizer demand and the N uptake by crops. The comparison of the storyline results in terms of changes in water quality between 2004 and 2020 shows that the different sustainability criteria applied per storyline only lead to minor differences in nitrate concentration in leaching water at EU level. Differences between the Storylines at national and regional level can be larger. At EU-27 level total N leaching is generally lowest for Storyline 2, since this storyline has the largest area of grassy perennial energy crops at the expense of rotational arable cropping. These perennial energy crops have a lower fertilizer need and a better N uptake, which results in lower nutrient surpluses and less nitrate leaching. More regions in particularly France, Germany and some Central and Eastern European countries show a decline in nitrate concentration in Storylines 2 and 3 as compared to Storyline 1.

2. General description of indicator

Definition:
The indicator for water quality is defined as the nitrate (NO_3) concentration in leaching water expressed in mg NO_3 per liter. Nitrate is the main pollutant of water from agriculture, and causing eutrophication in surface water and health risks for drinking water.

Description:
Water quality is affected by eutrophication, organic pollution and hazardous substances. The use of agricultural chemicals like pesticides and fertilizers contaminates surface and groundwater. In agriculture losses of nutrients to surface and groundwater is the main cause of water pollution (Galloway *et al.*, 2003). For that reason we focus on contamination of water due to fertilizer and manure application. A change in the use of these nutrients due to shifts in cropping and livestock patterns caused by the introduction of a demand for bioenergy crops is expected to have impact on water quality. The indicator for water quality is defined as the nitrate concentration in leaching water. The indicator is calculated for 2004 (the available base year of CAPRI) and for three Storylines for 2020 as described in Chapter 3.

Since water quality is not a fixed definition, but a general term, it can be expressed in different ways depending on the context. The Water Framework Directive links to the Nitrates Directive with regard to water pollution from agriculture. The Nitrates Directive (91/676/EEC) has the objective of reducing water pollution caused or induced by nitrates from agricultural sources. Therefore we selected the NO_3 concentration of leaching water as the main indicator for water quality. Also because this indicator is directly related to human health, as the WHO uses a maximum level of 50 mg NO_3 per liter as acceptable for drinking water. However, water quality can also be described by other environmental indicators. Therefore, we present in addition the summarized results of the following indicators related to water quality:

1) Nitrogen balance (in kg N/ha/year)
2) Phosphorus balance (in kg P/ha/year)
3) N losses due to leaching (in kg N/ha/year)

3. Assessment

Approach

The impact of the bioenergy target from the Renewable Energy Directive (RES) and NREAPs on water quality was assessed with MITERRA-Europe for three Storylines which are based on data of the *2020 Outlook for EU agriculture*. This outlook takes account of the most recent CAP Health Check reform, the 2020 EU wide RES and NREAP targets and the most recent OECD-FAO projections on agricultural prices, population and welfare developments (EC, 2010c)[53] assessed by CAPRI in a baseline scenario. The CAPRI baseline scenario run provides an assessment of the effects of reaching the 2020 biofuel targets on agricultural markets (production levels), cropping shares and livestock population with the CAPRI, AGLINK and ESIM models. As described in Chapter 3 (Section 3.4) of the main report, the CAPRI results in the baseline run were further elaborated in a post-model exercise into land use changes for production of biomass for biofuels, bioelectricity and bioheat in three storyline situations. These land use changes in Storyline 1 (Economy first), Storyline 2 (Climate first) and Storyline 3 (Overall sustainability first) are the main input for the impact assessment with the Miterra model as presented here. In all Storylines farm management is assumed to remain stable between now and 2020 and in all three Storylines the same number of livestock is used. Additionally, no measures from the Nitrates Directive were included, which can significantly decrease the amount of leached nitrate for the 2020 Storylines. Thus the Storylines mainly differ in the crop distribution, and indirectly in fertilizer application.

Models, expert knowledge used

MITERRA-Europe is an environmental assessment model that calculates nitrogen (N_2O, NH_3, NO_x and NO_3) and greenhouse gas (CO_2, CH_4 and N_2O) emissions, as well as soil organic carbon stock changes, on a deterministic and annual basis, using emission and leaching factors. The MITERRA-Europe model was developed to assess the effects and interactions of policies and measures in agriculture on N losses on a regional level (NUTS-2) in the EU-27 (Velthof *et al.*, 2009; Lesschen *et al.*, 2011). MITERRA-Europe is partly based on CAPRI (Britz and Witzke, 2008), and GAINS (Klimont and Brink, 2004), and was supplemented with an N leaching module and a soil carbon module. The input data of MITERRA-Europe consists of activity data (e.g. from Eurostat and FAO), spatial environmental data, and emission factors. The model includes measures to mitigate NH_3 and GHG emissions and NO_3 leaching. The emission factors for GHG are derived from the IPCC 2006 guidelines, whereas the N excretion factors and NH_3 emissions factors are derived from GAINS.

MITERRA-Europe has its own approach to calculate N losses by leaching and surface runoff. N losses from surface runoff are calculated by multiplying the N input of mineral fertilizer, manure and grazing by a surface runoff fraction. The surface runoff fractions were calculated at NUTS-2 level based on slope, land use, precipitation surplus, soil texture and soil depth. Nitrogen leaching is calculated by multiplying the N surplus by a leaching fraction. N surplus is the sum of all N inputs to soils, consisting of applied manure, grazing, mineral fertilizer, deposition and nitrogen

53 EC, 2010c, Prospects for agricultural markets and income 2010-2020.
http://ec.europa.eu/agriculture/publi/caprep/prospects2010/index_en.htm

fixation, minus the N removal by crops. The leaching fractions were established at NUTS-2 level based on texture, land use, precipitation surplus, soil organic carbon content, temperature and rooting depth. (Velthof *et al.*, 2009). The NO_3 concentration of leaching water is calculated by dividing the total N leaching by the annual rainfall surplus.

Input (data)
Many data contained in the CAPRI database are also used by MITERRA-Europe, especially in relation to crops and livestock numbers. CAPRI covers 38 crop activities and 18 livestock activities, which are derived from Eurostat statistics. In addition to these statistical data, several spatial data sources are needed and used. MITERRA-Europe uses other sources as well (e.g. GAINS for animal numbers and FAO for crop yield statistics and fertilizer consumption). The reference year for this study was 2004, which is the currently available base year of CAPRI. All statistical input data were based on three year averages. The projected values for crop areas, animal numbers, crop yields and mineral fertilizer consumption for the 2020 Storylines were based on the relative changes in CAPRI data for the period 2004-2020. All other parameters were assumed to be constant over time.

4. Results

Figure 1 shows the nitrate concentration of leaching water for 2004 and the three 2020 Storylines. The results show that between 2004 and the 2020 Storylines changes in water quality occur, with overall lower NO_3 concentrations for most countries and higher for some other countries, e.g. Italy, Netherlands, Poland and Lithuania.

To understand the differences between the Storylines it is important to have insight in the driving factors for the NO_3 concentration in leaching water. Since possible changes in rainfall are not included, the NO_3 concentration of leaching water is related to the N surplus, which is affected by the manure and fertilizer N input and crop N uptake. In Table 1 the main explaining variables are summarized for the four scenarios. For the 2020 Storylines the N input to the soil is lower compared to 2004, both due to a decrease in mineral fertilizer use and manure inputs. Between the 2020 Storylines the manure input and the grassland area remains equal, since the number of livestock does not change between the Storylines. The mineral fertilizer input does change, since in all three 2020 Storylines a fixed amount of fertilizer per hectare is applied for each crop type. Thus, differences in cropping shares lead to different mineral fertilizer N inputs, since no fertilizer is applied on fallow and abandoned land and perennial energy crops have a lower fertilizer demand compared to rotational arable crops. Therefore, a decline in fertilizer input between 2004 and 2020 is seen in those regions where the storyline results in the smallest rotational arable area share. How this works out differs strongly per country and region. But overall this more often results in higher NO_3 concentrations in Storyline 1 and the lowest in Storyline 2.

Figure 1. *NO_3 concentration of leaching water per country for 2004 and the three 2020 Storylines*

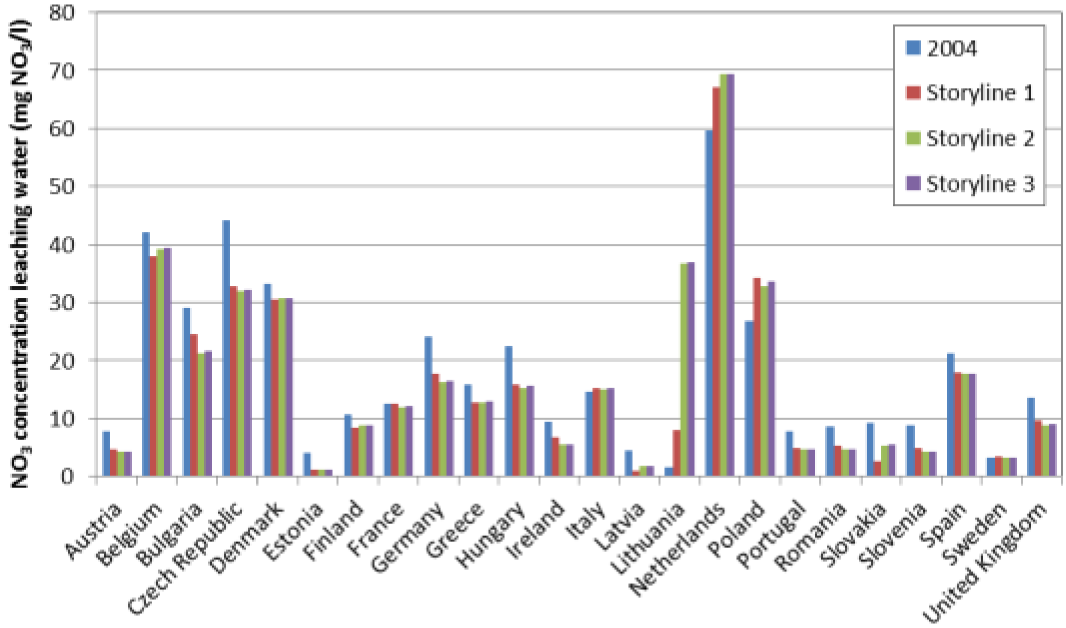


Table 1. *Main explaining variables for the three scenarios*

	2004	Storyline 1	Storyline 2	Storyline 3
Area cropped (10^6 ha)	111.0	118.5	116.0	113.0
Of which:				
Perennial energy crops	*0*	*12.0*	*11.3*	*6.8*
Biofuel crops (10^6 ha)	*0*	*4.8*	*0*	*0*
Other crops (10^6 ha)	*111.0*	*101.7*	*104.7*	*106.2*
Area grassland (10^6 ha)	65.2	61.6	61.6	61.6
Area set-aside / fallow	10.6	7.8	9.7	12.2
Area abandoned (10^6	9.9	8.7	9.2	9.8
Livestock units (10^6)	162.4	158.0	158.0	158.0
Mineral fertilizer N input	11.21	11.06	11.11	11.15
Manure N input (Mton	8.04	7.62	7.62	7.62

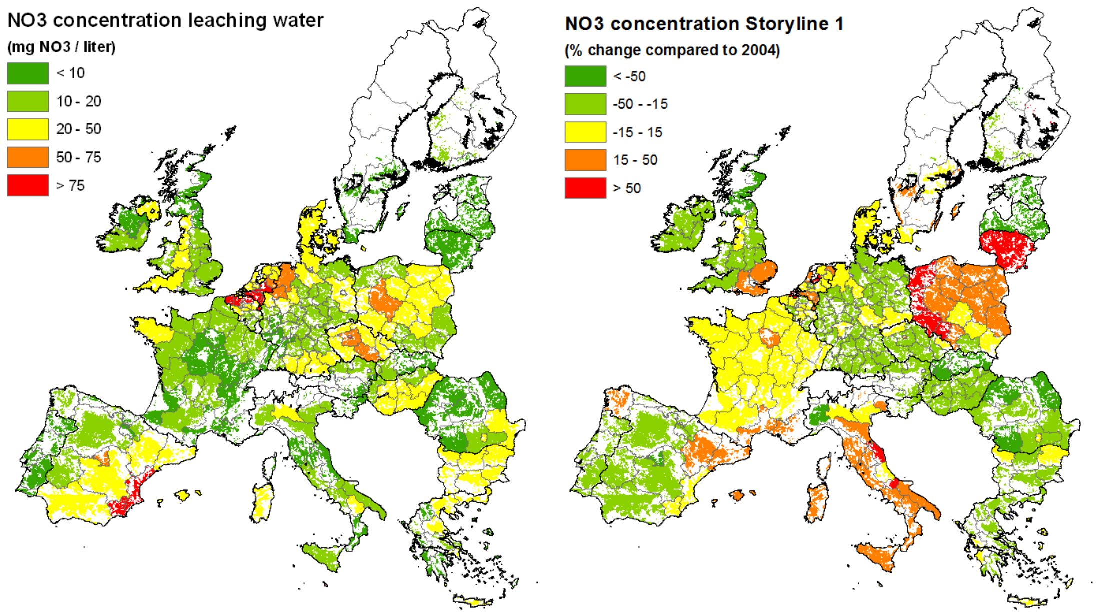
The changes between 2004 and 2020 are due to changes in mineral N fertilizer and manure inputs and differences in cropping shares, which lead to differences in N uptake. This implies that these changes can partly be related to changes in cropping shares resulting from reaching the RES and NREAP targets.

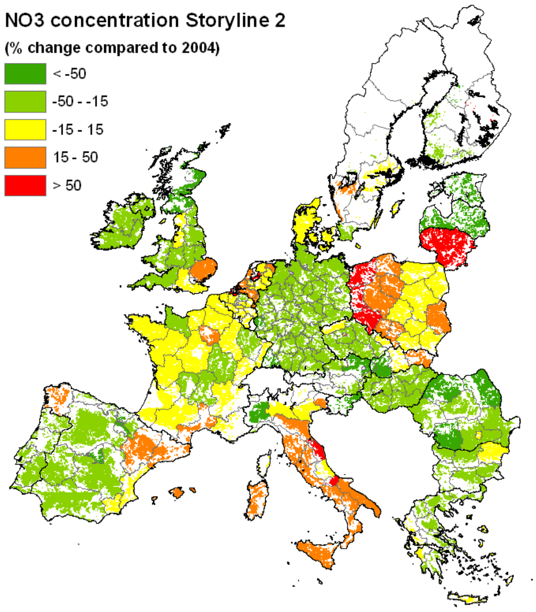
According to the CAPRI 2020 scenario an increase in mineral fertilizer use is projected for several countries, including Italy, Lithuania and Poland. The higher fertilizer use increases the N surplus and leaching risk. For the Netherlands the NO_3 leaching is higher due to a further increase of the livestock sector, which increases the amount of N from manure application and grazing, but overall this is not caused by bioenergy cropping. According to the Nitrates Directive countries have to implement measures in Nitrates Vulnerable Zones to reduce nitrate leaching. In the simulations, these measures were not included since it is uncertain to which extent they will be implemented by 2020. This might have led to an overestimation of the nitrate leaching

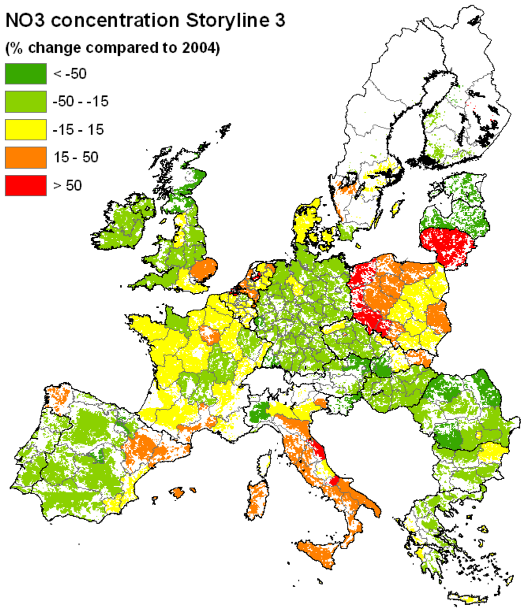
The differences between the three 2020 Storylines are small. The highest NO_3 concentration of the leaching water occurs for 15 EU-countries under Storyline 1, for six countries under Storyline 3 and for two countries under Storyline 2 (Figure 1). These differences can be explained by the different cropping shares for the Storylines, especially the share and type of perennial energy crops. Although the N input for the perennial energy crops is lower compared to rotational arable crops, and in Storyline 1 the area with rotational arable crops is the largest, which results in a higher N surplus and therefore higher leaching rate. Furthermore, in Storyline 1 most of the perennial energy crops are poplar and willow, whereas in Storyline 2 and 3 there is a larger contribution of miscanthus and switchgrass to the perennial mix. The latter have a more dense rooting system and a more efficient nutrient uptake.

In Figure 2 the spatial distribution of the NO_3 concentration of leaching water is shown at NUTS-2 level. The figure shows that the threshold of 50 mg NO_3 per liter is exceeded in several regions. Also within countries differences occur, with for some regions an increase in water quality and for others a decrease, e.g. Spain and Italy.

Figure 2. *NO_3 concentration of leaching water for NUTS-2 regions for 2004 (upper left) and the relative changes in NO_3 concentration for the three 2020 Storylines*







In Table 2 the other indicators for water quality are shown at EU-27 level for the different scenarios. Compared to 2004 all indicators show an improved water quality for the 2020 Storylines, with lower nutrient surpluses and less N leaching and surface runoff. The differences between the three 2020 Storylines are small, but do not show the same changes for each indicator. Storyline 2 has on average the lowest total N leaching, whereas Storyline 1 has the lowest leaching to groundwater and surface runoff, while P surplus is lowest in Storyline 3. The explanation of these differences is not straightforward, since many factors (distribution of crop shares, crop yields, nutrient inputs) are influencing these indicators, but in general a lower surface runoff is related to lower N inputs per ha, and a lower leaching rate is the result of a lower N surplus. The N surplus can be low because of low N inputs (e.g. for perennial energy crops)_or a high N uptake. The lower P surplus for Storyline 3 can be explained by the relatively large share of Miscanthus, which has a low P demand, compared to the other energy crops.

Table 2. *Main indicators for water quality for the EU-27 expressed in kg per ha UAA*

	N surplus *kg N/ha*	**P surplus** *kg P/ha*	**N leaching surface water** *kg N/ha*	**N leaching groundwater** *kg N/ha*	**N surface runoff** *kg N/ha*	**Total N leaching** *kg N/ha*
2004	56.54	7.88	4.72	5.26	3.79	13.77
Storyline 1	49.68	6.18	4.09	4.80	3.71	12.60
Storyline 2	48.57	5.95	3.98	4.85	3.75	12.57
Storyline 3	49.00	5.93	4.01	4.89	3.76	12.66

Table 3. *Total N leaching (kg N/ha UAA) per country for 2004 and the three 2020 Storylines*

Country	2004	Storyline 1	Storyline2	Storyline 3
Austria	8.6	5.5	5.2	5.2
Belgium	52.8	48.5	49.9	50.0
Bulgaria	15.7	14.4	13.4	13.5
Cyprus	28.1	29.7	29.8	29.7
Czech Republic	27.4	21.2	20.9	21.0
Denmark	25.6	23.9	24.0	24.0
Estonia	5.0	2.1	2.0	2.0
Finland	5.5	4.2	4.2	4.2
France	14.7	15.0	14.5	14.5
Germany	21.7	17.0	16.0	16.3
Greece	8.0	6.5	6.5	6.5
Hungary	14.0	10.9	10.7	10.8
Ireland	16.5	12.8	11.4	11.4
Italy	13.8	14.7	14.5	14.6
Latvia	4.7	2.2	2.6	2.6
Lithuania	4.1	10.7	35.2	35.3
Malta	71.0	74.9	75.0	74.9
Netherlands	66.4	74.3	76.4	76.4
Poland	12.4	15.9	15.2	15.5
Portugal	8.2	5.3	5.2	5.2
Romania	5.7	4.4	4.2	4.2
Slovakia	6.4	3.4	4.4	4.4
Slovenia	13.5	8.4	7.8	7.8
Spain	9.2	7.8	7.7	7.7
Sweden	2.4	2.7	2.5	2.5
United Kingdom	16.5	12.1	11.5	11.5
EU-27	**13.8**	**12.6**	**12.6**	**12.7**

In Table 3 the values for total N leaching are also shown at Member State level. The largest differences between the Storylines are observed for some Eastern European countries (e.g. Lithuania, Bulgaria and Slovakia), since there the difference in land use is often largest between the 2020 Storylines, because both the area of perennial energy crops and abandoned/fallow land is changing considerable between the Storylines for these countries. The small differences between the Storylines show that the effect of dedicated energy cropping on water quality is not very strong, but locally the impact can be larger.

Annex 17 Water quantity impact indicator

Assessment done by: Berien Elbersen and Igor Staritsky (Alterra)

1. Key messages/conclusions

Irrigation water consumption by bioenergy crops can become quite significant when GHG mitigation driven incentives take effect and stimulate the up-take of perennial biomass cropping on land that is released from food and feed production between 2003 and 2020 as is expected to result from market developments. This situation applies to Storyline 2 which shows a large area of miscanthus and switchgrass on land that is released from food and fodder production between 2003 and 2020 which was not under irrigation in 2003. This implies that most of the irrigation water needs for perennials come additional to the irrigation water demands for food and feed crops which remains relatively stable between 2003 and 2020. An additional reason is also that most of the land releases in the EU coincide with more (summer)arid regions particularly in France, Bulgaria, Hungary, Romania and even Germany.

In Storyline 1 it is more economic to convert the released lands poplar and willow plantations, with practically no irrigation water requirements, while in Storylines 2 and 3 they are more often converted to miscanthus and switchgrass. This may be more expensive in terms of biomass feedstock costs, but will be more efficient from a GHG mitigation perspective. The large difference however is that in Storyline 3 this may only be feasible if the mitigation target of 60% is reached without irrigation.

Overall, it becomes clear that if incentives of high mitigation requirements are accompanied by limitations on irrigation water use, this will limit the production of perennial biomass production towards the wetter/less arid regions, but will still provide ample opportunities to produce large amounts of ligno-cellulosic biomass with high GHG mitigation potential, as is shown in Storyline 3. A purely market driven approach to reaching the 2020 bioenergy targets, Storyline 1, will not lead to additional pressure on water resources in the EU, but will put pressure on other environmental issues, especially biodiversity as is shown in other environmental impact assessments included in this study (e.g. fact sheet on farmland bird impacts).

Finally, it should be mentioned that stimulation of perennial biomass plantations on released agricultural lands, may be efficient from a GHG saving perspective, but if the Water Framework Directive implementation is taken very strictly, this may not even be feasible in several European regions, particularly in France, Bulgaria, Hungary and Romania and even Germany.

2. General description of indicator

Definition:

This indicator includes two sub-indicators:

1) Levels of irrigation water consumption for production of bioenergy crops used as biofuel feedstock and ligno-cellulosic feedstock

2) Relative irrigation water use by energy crops between 2008-2020 in 3 storyline situations

It should be emphasized that the indicators only refer to irrigation water consumption for crops that are used for bioenergy feedstock. The crops included in this assessment are:

- Starch crops for ethanol conversion: wheat, maize, barley, oats and rye
- Sugar crops for ethanol conversion: sugarbeet
- Oil crops for biodiesel conversion: rapeseed, sunflower
- Energy maize for biogas conversion.
- Perennial crops used for 2nd generation biofuels and as solid biomass for conversion

into electricity and heat.

Description:

In recent years, there is a growing concern about water scarcity because the number of Member States (MS) that experience seasonal or long term droughts has increased over the years. Water scarcity refers to long-term water imbalances, combining low water availability with a level of water demand exceeding the supply capacity of the natural system" (EC, 2006). In 2007 the Commission adopted a Communication on Water Scarcity and Droughts54, which identified an initial set of policy options to be taken at European, national and regional levels to address water scarcity within the Union. This set of proposed policies aims to move the EU towards a water-efficient and water-saving economy. One important factor in this context is future land use, which is crucial for mitigating water stress in the long run. Since bioenergy production could potentially have important future land use implications the effects on water consumption are further analysed here.

The indicators included to analyse this effect are the absolute and relative level of water use for irrigation in bioenergy cropping between 2008 and 2020 in in three storyline situations. The irrigation water use will therefore be presented for:

1) 2008 (present bioenergy cropping)
2) 2020 Storyline 1 (Economy first)
3) 2020 Storyline 2 (Climate first)
4) 2020 Storyline 3 (Sustainability first)

The results provide a better understanding of how irrigation water demand for bioenergy cropping will change between now and 2020 and which set of sustainability criteria are most effective in reducing irrigation water use in bioenergy cropping.

3. Assessment

Approach

The impact of the biofuel target from the Renewable Energy Directive (RED) on irrigation water consumption was assessed taking the output of the CAPRI model as a starting point. The impact of the Renewable Energy Directive (RES) on irrigation water use was assessed for three Storylines which are based on data of the *2020 Outlook for EU agriculture*. This outlook takes account of the most recent Health Check reform, the 2020 EU wide RES and NREAP targets and the most recent OECD-FAO projections on agricultural prices, population and welfare developments (EC, 2010)55 assessed by CAPRI in a baseline scenario. The CAPRI baseline scenario run provides an assessment of the effects of reaching the 2020 Biofuel targets on agricultural markets (production levels), cropping shares and livestock population with the CAPRI, AGLINK and ESIM models. As described in Chapter 3 (Section 3.4) of the main report, the CAPRI results in the baseline run were further elaborated in a post-model exercise into land use changes for production of biomass for biofuels, bioelectricity and bioheat in three Storylines. These land use changes in Storyline 1 (Economy first), Storyline 2 (Climate first) and Storyline 3 (Overall sustainability first) are the main input for the impact assessment presented here.

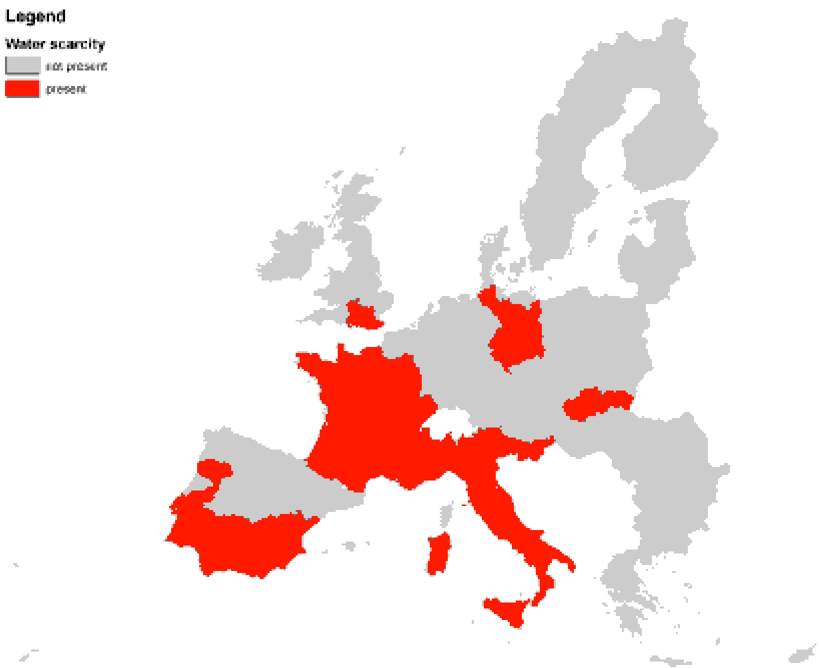
To assess the relative impact of bioenergy cropping on future irrigation water consumption, a water policy scenarios is applied, which provides for the 2020 an

54 See http://ec.europa.eu/environment/water/quantity/scarcity_en.htm

55 EC (2010), Prospects for agricultural markets and income 2010-2020. http://ec.europa.eu/agriculture/publi/caprep/prospects2010/index_en.htm

estimate of the total irrigation water availability per region assuming a strict Water Framework Directive implementation. In this situation restrictions on irrigation water use are applied, especially in water stressed regions of Europe. This implies that in water stressed regions only minor growth rates are allowed in irrigation water consumption between 2003 (reference year) and 2020. The growth rates per region used in this strict WFD scenario are specified in the Appendix 1 belonging to this fact sheet and are based on the official list of water stressed river basins (see Figure 1 underneath and Appendix 1, Table 1).

Figure 1: *European river basins affected by water scarcity today, based on European Commission, 2006a*



The irrigation developments in the strict WFD scenario are based on information derived from the Rural Development programs for 2007 to 2013 (Dworak *et al.*, 2009); research studies (Dirksen and Hubbert, 2006; Flörke and Alcamo, 2004; Bärlund *et al.*, 2008, Wriedt et al, 2008) and other additional national sources such as the draft River Basin Management plans (dRBMP) directly referenced in the Tables 1-3 in Annex 1.

Models, expert knowledge used
The CAPRI (Common Agricultural Policy Regional Impact) model is an agricultural sector economic model covering the EU-27, Norway and Western Balkans based on non-linear regional programming models consistently linked with a global agricultural trade model (Britz & Witzke, 2008). Its principal aim is to analyse impacts of changes in EU (or international) agricultural policies and markets on European agriculture and global agricultural markets, mostly at the medium term (8-10 years ahead). The CAPRI model has been extended to cover bio-ethanol and bio-diesel production in the EU, and DDGS as by-product from bio-ethanol production. At the same time, palm oil was added to the market model. The EU biofuel mandates were introduced as a fixed demand and a fixed domestic production share for bio-ethanol and bio-diesel. The model now endogenously determines changes in supply and other demand (feed, food, processing) for biofuel feedstock (cereals and vegetable oils) in European regions. For further details on the CAPRI model and the calculations see Section 3.4 of the main report. The CAPRI results in the baseline run were

further elaborated in a post-model exercise into land use changes for production of biomass for biofuels, bioelectricity and bioheat in three Storylines. These land use changes in Storyline 1 (Economy first), Storyline 2 (Climate first) and Storyline 3 (Overall sustainability first) are the main input for the impact assessment presented here.

The irrigation water requirement has been calculated as the total amount of water (in cm water layer per unit area) needed by a certain crop in addition to the rainfall for the realization of maximum potential yield. This maximum potential yield is defined as the maximum yield under prevailing weather conditions without any other growth constraints. In the absence of irrigation the maximum yield under rainfed conditions is determined by the amount of rainfall and its distribution over the growing season. This maximum water-limited yield is equal to the potential yield in the case of sufficient rainfall, and is lower than the potential yield in the case of drought. For the rotational arable crops used for bioenergy production both the potential and water-limited yield and the amount of water directly used by the crops for transpiration under potential conditions have been extracted from the data base of the Crop Growth Monitoring System (CGMS) of the MARS project of the Joint Research Centre (for further information see Annex 2). For the irrigation water needs of perennial biomass crops new model runs were done with the GWSI model as is described in Annex 3.

Once the per hectare irrigation water requirements per crop and nuts region were calculated, these were multiplied by the total irrigated area every crop was estimated to use in every storyline situation. This multiplication resulted in a total irrigation water requirements per NUTS-2 region per crop and for the total cropping area on which the assessment focuses.

For the estimation of the irrigation share per rotational crop we build on the data from the JRC spatial database on water requirements for irrigation (Wriedt *et al.*, 2008)[56]. This baseline situation is used to extrapolate the 2004 to 2020 irrigation share per crop. It is assumed that the irrigation share per rotational crop per region in 2020 will be the same as in 2004 (provided by Wriedt *et al.*, 2008). For perennial crops the irrigation share depends on the storyline specifications which determines the amount of perennials grown, the mix of perennials, the type of land used. In Storyline 3 perennials cannot be grown with irrigation. So in this storyline irrigation water use for bioenergy crops will be absent, while in the other two storyline situations no measures are taken to limit irrigation water use in bioenergy cropping.

Input (data)

1) The main input data on crop areas were directly derived from CAPRI, which covers 38 crop activities that are derived from Eurostat statistics. All statistical input data for this model are based on three year averages. The agricultural sector model CAPRI is based on a common database developed at the University of Bonn and is the successor of the formerly used SPEL database. This database is currently available at IPTS and IES, as part of the CAPRI consortium, and provide a comprehensive picture of the agricultural sector for the EU27 Member States plus the Balkans. The CAPRI database is fairly detailed and includes algorithms for data consistency and completeness. The database is up-dated every two years. For further information see: http://www.capri-model.org/docs/capri_documentation.pdf#search="COCO"

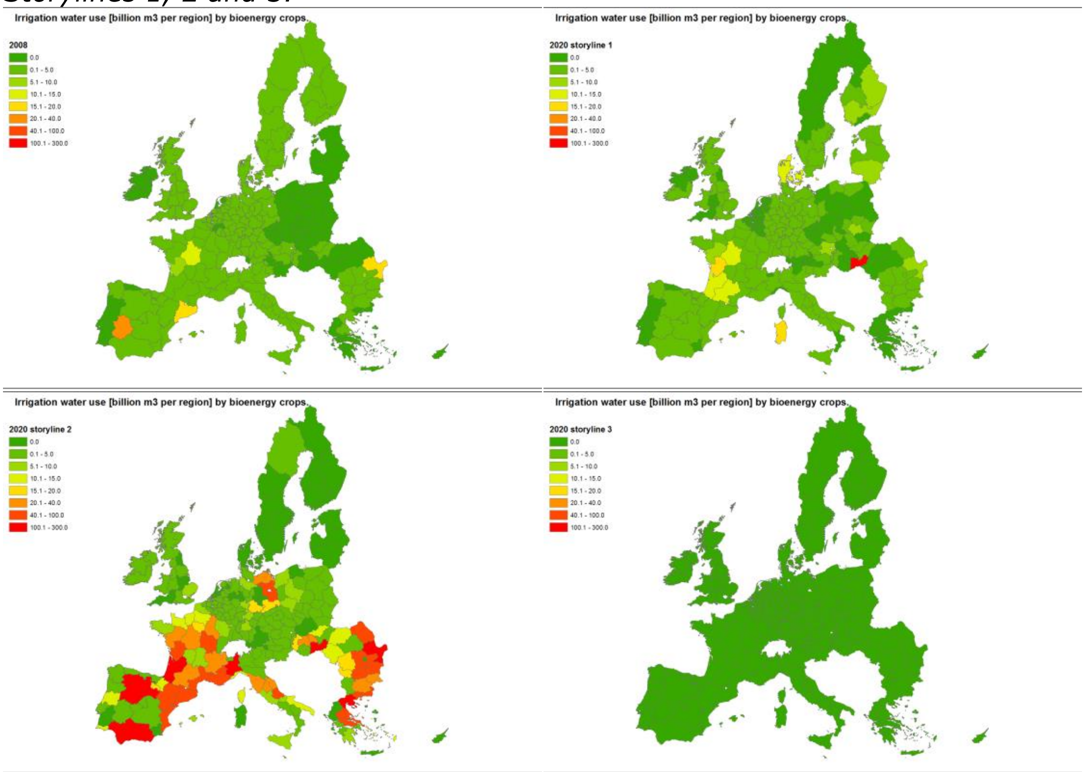
56 Wriedt, G., van der Velde, M., Aloe, A., Bouraoui, F. , 2008: Water Requirements for Irrigation in the European Union. EUR Scientific and Technical Research Series. European Commission, Joint Research Centre, Ispra.

2) CGMS data on potential and water-limited yield and the amount of water directly used by the crops for transpiration under potential conditions have been extracted from the database of the Crop Growth Monitoring System (CGMS) of the MARS project of the Joint Research Centre (see Annex 7 in this report).
3) GWSI calculations of water needs for perennial biomass crops in 3 management systems per region: 1) Modern fully irrigated, 2) Modern rainfed and 3) extensive system (see Annex 7 in this report, final section)
4) Figures on present crop specific irrigation shares per Nuts 2 were obtained from the JRC database on water requirements for irrigation (Wriedt *et al.*, 2008)2.

4. Results:

The total irrigation water requirements for bioenergy crops are calculated for 2008 and the 3 storyline situations in 2020 (see Figure 1 below). Storyline 3 does not show any irrigation water use as this is part of the storyline assumptions. Irrigation water use in 2008 and also in Storyline 1 (Economy first) shows modest irrigation water use and Storyline 2 shows by far the largest water use.
The reason for this is that in the Storyline 2 situation there is by far the largest production of switchgrass and miscanthus in high yielding systems, which require additional irrigation if produced in the more arid parts of Europe, such as the whole Mediterranean and several regions in central and eastern Europe. In the Storyline 1 situation there is also a large area with perennials, but these are mostly willow and poplar which are normally not produced with irrigation and usually produce more biomass per Euro. The largest irrigation water demand comes from the rotational arable biofuel crops in this storyline which are mostly produced in Southwestern France, mostly maize and sunflower. The very red region in Hungary, Dél-Alföld, uses much irrigation because of the large release of good agricultural land towards 2020 where miscanthus and switchgrass are grown in large quantities. The larger occurrence of switchgrass and miscanthus in Storyline 2, and also Storyline 3, is related to the higher efficiency in terms of kg biomass per hectare and also per GJ and thus in GHG mitigation per GJ. In Storyline 3 irrigation is not allowed which results in larger share of medium yielding perennials, provided they still reach the mitigation target of 60%. Therefore in this storyline there is no irrigation but this also implies a smaller perennial biomass potential and less efficient production per hectare in the more arid parts of the EU.

Figure 1 *Irrigation water use bioenergy crops (billion M³) in 2008 and 2020 Storylines 1, 2 and 3.*



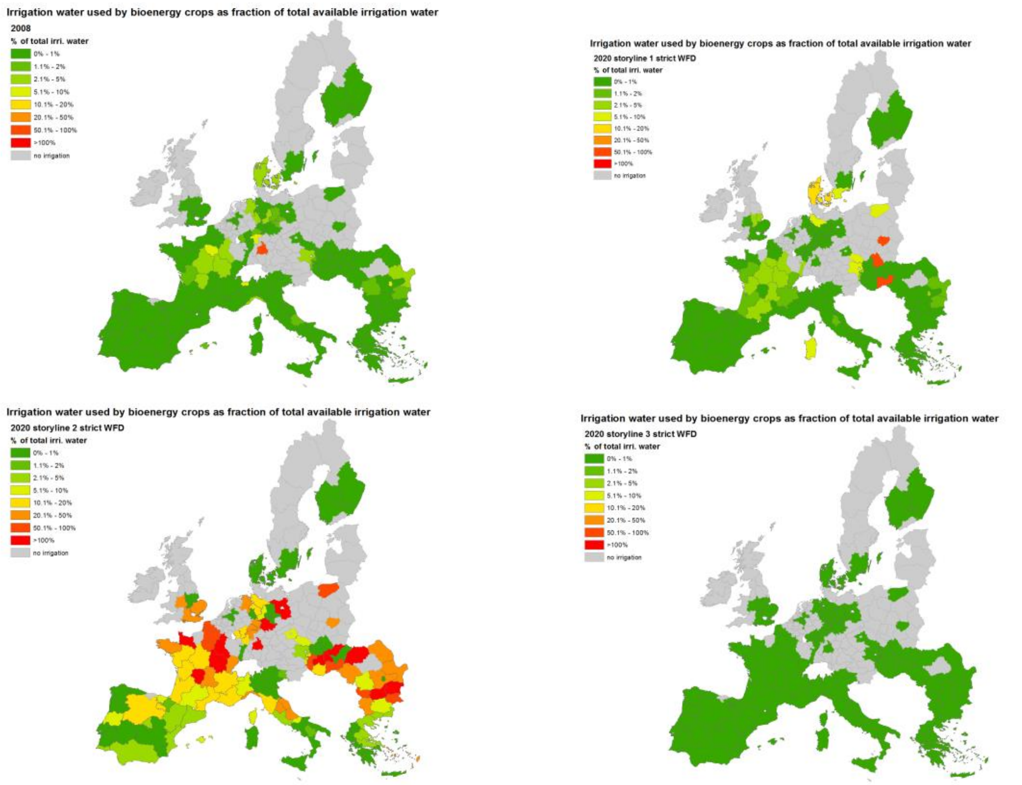
To understand the relative pressure of bioenergy on water resources, the figures from Figure 1 are related to the total irrigation water consumption in 2008 and for the 3 Storylines to the 2020 irrigation water availability in a strict WFD implementation situation (see for explanation above and Appendix 1 belonging to this fact sheet). The 4 maps in Figure 2 give an overview of the share that bioenergy production may take in the total irrigation water consumption. The grey regions on the maps indicate towards regions with no or very limited irrigation water consumption.

As expected the largest shares are seen in Storyline 2 where many regions show that e bioenergy crops would exploit 50% or even more then 100% of the irrigation water available. The reason behind these extreme shares is beside the large areas with miscanthus and switchgrass also that often these perennials are grown on land that is released from food and fodder production between 2003 and 2020 and was not under irrigation in 2003. This implies that most of the irrigation water needs for perennials come additional to the demands for food and feed crops for which the irrigation water demand remains relatively stable between 2003 and 2020. An additional reason is also that most of the land releases and abandoned land stock coincides in the EU with more (summer)arid regions of the EU such as the Mediterranean, the eastern parts of central EU.

In 2008 there are no regions where bioenergy crops take an excessive part of the irrigation water consumption, with one exception in southern Germany (Stuttgart). In Storyline 1 the bioenergy irrigation water consumption remains in practically all regions far below the 10%, with exceptions in 3 regions in Poland, Slovakia and Hungary. In these regions this mainly concerns water demands for switchgrass and miscanthus plantations, which are economic in this Storylines in these regions of the EU, on released agricultural lands.

Overall it becomes clear that irrigation water needs for biomass production may put large pressure on scarce water resources in regions of southern and central Europe if plantations with perennial biomass crops indeed start to occur at large scale on released agricultural lands. And this is likely to happen if incentives to create these plantations are only driven by GHG mitigation considerations, like is the case in Storyline 2. However, if these incentives of high mitigation requirements are accompanied by limitations on irrigation water use, this will limit the production of perennial biomass production towards the very arid regions, but will still provide ample opportunities to produce large amounts of ligno-cellulosic biomass with high GHG mitigation potential, as is shown in Storyline 3. A purely market driven approach to reaching the 2020 bioenergy targets, Storyline 1, will generally not lead to large additional pressures on water resources in the EU, but will put pressure on other environmental issues, especially biodiversity as is shown in other environmental impact assessments included in this study (e.g. fact sheet on farmland bird impacts). Finally it should be mentioned that stimulation of perennial biomass plantations on released agricultural lands, may be efficient from a GHG saving perspective, but if the Water Framework Directive implementation is taken very strictly, this may not even be feasible in several European regions, particularly in France, Bulgaria, Hungary and Romania and even Germany.

Figure 2 *Relative consumption of irrigation water by bioenergy crops of total irrigation water availability in 2008 and in 2020 under strict implementation of the WFD*.



***Appendix 1**: Background on water scarcity per region/river basin now and in the future for estimating the maximum irrigation water supply 2020 under a strict implementation of the WFD.*

Crops placed in newly irrigated areas can only be irrigated with part of the irrigation water that is saved between now and 2020. Due to the WFD obligation to use water more efficiently, all MS will take significant actions to improve irrigation technologies and practices (less water per ha used). In detail, this means:

- River Basins currently facing water stress (see Table 1) have to reduce water abstraction for irrigation by 40%[57].
- Some River Basins which are not water scarce will need to increase irrigation in order to ensure competitive agriculture (see Table 3).
- For the remaining MS/River Basins (basins not covered in Table 1 and 2) more efficient technologies lead to a water saving of 0.5% per year (Based on Flörke, et al, 2004), which means that about 8,5% of irrigation water is saved between 2004 and 2020 (see Table 3 showing final growth factors used to estimate available irrigation water supply by 2020).

Exact specifications regarding irrigation water changes allowed under both the liberal and the strict WFD implementation are specified in Table 3 in this Annex.

***Table 1** European river basins and their status as water scarce as based on European Commission decision (2006)*

EU-code	***RD B***	***MS***	***River Basin District Name (English)***	***Water scarce region? 0=No 1=yes***
GRM4015	89	AT	Danube	0
ATA5001	90	AT	Rhine	0
ATA5002	91	AT	Elbe	0
BEA5009	56	BE	Scheldt (Brussels Area)	0
BEA5008	57	BE	Scheldt	0
BEA5011	60	BE	Meuse	1
BEA5001	61	BE	Rhine	0
BEA4001	62	BE	Seine	1
BEA5012	113	BE	Meuse	0
BEA5007	121	BE	Scheldt in Flanders	1
BGM4005	52	BG	West Aegean Region Basin District	0
BGM5002	53	BG	Black Sea Basin District	0
BGM5001	54	BG	Danube Region Basin District	0
BGM4002	55	BG	East Aegean Region Basin District	0
ATM5001	78	CZ	Danube	0
CZA6004	118	CZ	Oder	0
CZA5002	120	CZ	Elbe	0
DEM5001	110	DE	Danube	0
DEA5001	111	DE	Rhine	0
DEA5010	112	DE	Meuse	0
DEA5023	161	DE	Eider	0
DEA5019	207	DE	Ems	0
DEA5005	208	DE	Weser	0
DEA6004	209	DE	Odra	1
DEA6023	210	DE	Schlei/Trave	0

57 This value was provided by Commission services based on the 2007 Communication on water scarcity and droughts. See Dworak et al., 2009a

DEA6017	211	DE	Warnow/Peene	0
DEA5002	212	DE	Elbe	1
DKA5014	136	DK	Jutland and Funen	0
DKA6022	137	DK	Zealand	0
DKA6026	138	DK	Bornholm	0
DKA5025	139	DK	Vidaa-Krusaa	0
EEA6015	140	EE	West Estonia	0
EEA6018	141	EE	East Estonia	0
EEA6021	142	EE	Gauja	0
ESA1029	40	ES	Andalusia Atlantic Basins	1
ESA1019	41	ES	Basque County internal basins	0
ESM2009	42	ES	Andalusia Mediterranean Basins	1
ESA1003	43	ES	Duero	0
ESA1012	44	ES	Galician Coast	0
ESA1006	45	ES	Guadalquivir	1
ESA1005	46	ES	Guadiana	1
ESM2004	47	ES	Jucar	1
ESA1007	48	ES	Minho	0
ESA1021	49	ES	Northern Spain	0
ESM2008	50	ES	Segura	1
ESA1004	51	ES	Tagus	0
ESM2010	203	ES	Internal Basins of Catalonia	0
ESM2002	204	ES	Ebro	0
ESM2012	205	ES	Balearic Islands	0
FIA6008	143	FI	Vuoksi	0
FIA6009	144	FI	Kymijoki-Gulf of Finland	0
FIA6005	145	FI	Kokemäenjoki-Archipelago Sea-Bothnian Sea	0
FIA6007	146	FI	Oulujoki-Iijoki	0
FIA6010	147	FI	Kemijoki	0
FIA6020	148	FI	Tornionjoki (Finnish part)	0
FIN9001	149	FI	Teno-, Näätämöjoki and Paatsjoki (Finnish part)	0
FIA6024	150	FI	Aland islands	0
FRA5006	63	FR	Scheldt, Somme and coastal waters of the Channel and the North Sea	0
FRA5010	64	FR	Meuse	0
FRA5013	65	FR	Sambre	0
FRA5001	66	FR	Rhine	0
FRM2001	67	FR	Rhone and Coastal Mediterranean	1
FRM2011	68	FR	Corsica	0
FRA1002	194	FR	Adour, Garonne, Dordogne, Charente and coastal waters of aquitania	1
FRA1001	195	FR	Loire, Brittany and Vendee coastal waters	1
FRA4001	196	FR	Seine and Normandy coastal waters	1
GRM4017	93	GR	Western Peloponnese	0
GRM4016	94	GR	Northern Peloponnese	0
GRM4014	95	GR	Eastern Peloponnese	0
GRM4010	96	GR	Western Sterea Ellada	0
GRM4012	97	GR	Epirus	0
GRM4019	98	GR	Attica	0
GRM4008	99	GR	Eastern Sterea Ellada	0
GRM4007	100	GR	Thessalia	0
GRM4006	101	GR	Western Macedonia	0

GRM4011	102	GR	Central Macedonia	0
GRM4005	103	GR	Eastern Macedonia	0
GRM4002	104	GR	Thrace	0
FRM2011	105	GR	Crete	0
GRM4013	106	GR	Aegean Islands	0
HUM5001	92	HU	Danube	1
IEA4009	33	IE	Eastern	0
IEA1011	34	IE	Neagh Bann	0
IEA1008	35	IE	North Western	0
IEA4006	36	IE	South Eastern	0
IEA1009	37	IE	Shannon	0
IEA4005	38	IE	South Western	0
IEA1010	39	IE	Western	0
ITM4003	79	IT	Eastern Alps	1
ITM4001	80	IT	Po Basin	1
ITM2005	81	IT	Northern Appenines	1
ITM2013	82	IT	Serchio	1
ITM2006	83	IT	Middle Appenines	1
ITM2003	84	IT	Southern Appenines	1
ITM2007	85	IT	Sardinia	1
ITM4004	86	IT	Sicily	1
LTA6016	151	LT	Venta	0
LTA6019	152	LT	Lielupe	0
LTA6014	153	LT	Daugava	0
LTA6012	172	LT	Nemunas	0
LUA5001	76	LU	Rhine	0
LUA5010	77	LU	Meuse	0
LVA6014	154	LV	Daugava	0
LVA6021	155	LV	Gauja	0
LVA6019	156	LV	Lielupe	0
LVA6016	171	LV	Venta	0
NLA5019	72	NL	Ems	0
NLA5010	73	NL	Meuse	0
NLA5001	74	NL	Rhine	0
NLA5006	75	NL	Scheldt	0
PLM5003	117	PL	Dniestr	0
PLA6004	119	PL	Elbe	0
PLM5001	122	PL	Danube	0
PLA6028	157	PL	Swieza	0
PLA6027	158	PL	Jarft	0
PLA6025	159	PL	Pregolya	0
PLA6012	160	PL	Nemunas	0
PLA6001	206	PL	Vistula	0
PLA6004	213	PL	Odra	0
PTA1007	12	PT	Minho and Lima	0
PTA1018	14	PT	Cavado, Ave and Leca	1
PTA1003	15	PT	Douro	1
PTA1013	16	PT	Vouga, Mondego and Lis	1
PTA1004	17	PT	Tagus and Western Basins	1
PTA1014	18	PT	Sado and Mira	1
PTA1005	19	PT	Guadiana	1
PTA1017	20	PT	Algarve Basins	1

M5001	109	RO	Danube	0
SEA6002	162	SE	Bothnian Bay	0
SEA6003	163	SE	Bothnian Sea	0
SEA6013	164	SE	North Baltic	0
SEA6011	165	SE	South Baltic	0
SEA6006	166	SE	Skagerrak and Kattegat	0
SEA2004	167	SE	Troendelag	0
SEA5004	168	SE	Glomma	0
SEA2001	169	SE	Nordland	0
SEA2002	170	SE	Troms	0
SIM5001	87	SI	Danube	1
SIM4018	88	SI	North Adriatic	1
SKA6001	70	SK	Vistula	1
SKM5001	71	SK	Danube	1
UKA5021	23	UK	Solway Tweed	0
UKA4002	24	UK	South West	0
UKA4003	25	UK	Severn	0
UKA4004	26	UK	Western Wales	0
UKA4011	27	UK	Dee	0
UKA4007	28	UK	North West	0
UKA1011	30	UK	Neagh Bann	0
UKA1008	31	UK	North Western	0
UKA4010	32	UK	North Eastern	0
UKA5003	197	UK	Scotland	0
UKA5024	198	UK	Northumbria	0
UKA5016	199	UK	Humber	0
UKA5015	200	UK	Anglian	0
UKA5022	201	UK	Thames	1
UKA4008	202	UK	South East	1

Source: European Commission (2006)

Table 2 *River basins expected to still experience a water abstraction increase until 2020*

MS /River Basin	Abstraction increase until 2020	Comment	Source
UK**/South West, Thames	+25%	Demand for irrigation water is likely to increase across much of England and Wales over the next 10 years, possibly by 25% by 2020, especially for vegetable production.	(1)
GR/all RB	+8,5%	No RBMP available	(2)
PT*	+9%	No RBMP available	(2)
RO/ all Basins	+9%		(2)
ES/*	+10%	No RBMP available	(2)
MT/all Basins	+10%	No RBMP available	(3)
EE	+35%		dRBMP (5)
HU/Danube	+25%		dRBMP (6)
SK/all Basins	+8%		(7)
CZ/all Basins	+5%		dRBMP (8)

*All RBs which are not on the list of water scarce RB.
**Just considering the regions of England and Wales

Sources

(1) Enviroment Agency (2001): Water resources for the future: A strategy for England and Wales, Bristol.
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(3) Sapiano, M. (2008): Water-use efficiency Report Malta (2008). http://www.planbleu.org/publications/atelier_efficience_eau/MALTA.pdf
(5) Gauja: http://www.envir.ee/orb.aw/class=file/action=preview/id=1101117/2009.08.31+Koiva+vesikonna+veemajanduskava+eelnou.pdf
West Estonia: http://www.envir.ee/orb.aw/class=file/action=preview/id=1101116/2009.08.31+Laane-Eesti+vesikonna+veemajanduskava+eelnou.pdf
East Estonia: http://www.envir.ee/orb.aw/class=file/action=preview/id=1101115/2009.08.31+Ida-Eesti+vesikonna+veemajanduskava+eelnou.pdf
(6) Danube RBMP: http://www.vizeink.hu/files/vizeink.hu_0326_Orszagos_VGT_kezirat_aug.pdf
(7) VÚVH (2009): Prognózy vývoja obecných socio-ekonomických ukazovate¾ov. Príl 6.2. http://www.vuvh.sk/rsv/docs/PMP/prilohy/priloha_6/Pr%edl_6_2.pdf

(8) Odra: http://www.pod.cz/plan-oblasti-povodi-Odry/index.html

Elbe-Upper and Middle Elbe: http://www.pla.cz/planet/projects/planovaniov/hlavni.aspx
Danube: Dyje and Morava: http://www.pmo.cz/POP-12-2009.asp
Elbe-Berounka, Elbe-Lower Vlatava, Elbe-Upper Vlatava: http://www.pvl.cz/planovani/aktuality.html?lang
Elbe-Ohre and Lower Elbe: http://www.poh.cz/VHP/vhp.htm

Table 3 *Final irrigation developments allowed under both maximum (liberal) and minimum (strict) implementation of WFD scenarios*

			Minimum water use: Strict WFD implementation	2020 Strict WFD implementation
NUTSCODE1	**NUTS_NAAM**		**% water savings 2003-2020**	**Max available Million M3 (= 1000 Million liters)**
at11	Burgenland (A)		**8.5**	**20.55**
at12	Niederösterreich		**8.5**	**69.32**
at21	Kärnten		**8.5**	**0.02**
at22	Steiermark		**8.5**	**0.67**
at31	Oberösterreich		**8.5**	**0.32**
at32	Salzburg		**8.5**	**0.01**
at33	Tirol		**8.5**	**0.00**
at34	Vorarlberg		**8.5**	**0.01**
be21	Prov. Antwerpen		**-40**	**1.39**
be22	Prov. Limburg (B)		**8.5**	**1.42**
be23	Prov. Oost-Vlaanderen		**8.5**	**0.24**
be24	Prov. Vlaams Brabant		**8.5**	**0.05**
be25	Prov. West-Vlaanderen		**-40**	**0.13**
be31	Prov. Brabant Wallon		**8.5**	**0.01**
be32	Prov. Hainaut		**-40**	**0.10**
be33	Prov. Liège		**-40**	**0.11**
be34	Prov. Luxembourg (B)		**-40**	**0.00**
be35	Prov. Namur		**-40**	**0.00**
bg31	Severozapaden		**8.5**	**25.56**
bg32	Severen tsentralen		**8.5**	**35.99**
bg33	Severoiztochen		**8.5**	**13.63**
bg34	Yugoiztochen		**8.5**	**22.23**
bg41	Yugozapaden		**8.5**	**456.31**
bg42	Yuzhen tsentralen		**8.5**	**36.40**
cz01	Praha		**5**	**0.13**
cz02	Strední Cechy		**5**	**8.41**
cz03	Jihozápad		**5**	**0.36**
cz04	Severozápad		**5**	**3.43**
cz05	Severov?chod		**5**	**0.53**
cz06	Jihov?chod		**5**	**13.17**
cz07	Strední Morava		**5**	**1.05**
cz08	Moravskoslezsko		**5**	**0.00**
de1	Baden-Württemberg		**8.5**	**9.60**
de2	Bayern		**8.5**	**3.61**
de3_5_6	Berlin, Bremen, Hamburg		**8.5**	
de4	Brandenburg		**-40**	**12.23**

de7	Hessen		**8.5**	**40.26**
de8	Mecklenburg-Vorpommern		**8.5**	**3.98**
de9	Niedersachsen		**8.5**	**115.82**
dea	Nordrhein-Westfalen		**8.5**	**17.15**
deb	Rheinland-Pfalz		**8.5**	**52.44**
dec	Saarland		**8.5**	**0.25**
ded	Sachsen		**8.5**	**3.26**
dee	Sachsen-Anhalt		**8.5**	**50.15**
def	Schleswig-Holstein		**8.5**	**1.06**
deg	Thüringen		**8.5**	**4.02**
dk	Hovedstaden		**8.5**	**95.52**
ee00	Estonia		**35**	**0**
es11	Galicia		**10**	**275.61**
es12	Principado de Asturias		**10**	**29.98**
es13	Cantabria		**10**	**1.81**
es21	Pais Vasco		**10**	**37.81**
es22	Comunidad Foral de Navarra		**10**	**611.68**
es23	La Rioja		**-40**	**130.46**
es24	Aragón		**-40**	**2127.55**
es30	Comunidad de Madrid		**10**	**157.51**
es41	Castilla y León		**10**	**2490.24**
es42	Castilla-la Mancha		**-40**	**2433.14**
es43	Extremadura		**-40**	**1688.10**
es51	Cataluña		**-40**	**1621.99**
es52	Comunidad Valenciana		**-40**	**2887.67**
es53	Illes Balears		**-40**	**75.73**
es61	Andalucia		**-40**	**6654.54**
es62	Región de Murcia		**-40**	**1373.10**
fi13	Itä-Suomi		**8.5**	**0.00**
fi18	Etelä-Suomi		**8.5**	**0.00**
fi19	Länsi-Suomi		**8.5**	**0.00**
fi1a	Pohjois-Suomi		**8.5**	**0.00**
fi20	Åland		**8.5**	**0.00**
fr10	Ile de France		**-40**	**25.78**
fr21	Champagne-Ardenne		**-40**	**10.79**
fr22	Picardie		**-40**	**21.94**
fr23	Haute-Normandie		**-40**	**2.85**
fr24	Centre		**-40**	**325.40**
fr25	Basse-Normandie		**-40**	**5.47**
fr26	Bourgogne		**-40**	**21.56**
fr30	Nord - Pas-de-Calais		**10**	**14.62**
fr41	Lorraine		**-40**	**1.52**
fr42	Alsace		**10**	**100.59**
fr43	Franche-Comté		**-40**	**4.20**
fr51	Pays de la Loire		**-40**	**266.90**

fr52	Bretagne		**-40**	**16.43**
fr53	Poitou-Charentes		**-40**	**322.34**
fr61	Aquitaine		**10**	**896.30**
fr62	Midi-Pyrénées		**-40**	**488.94**
fr63	Limousin		**-40**	**7.38**
fr71	Rhône-Alpes		**-40**	**321.19**
fr72	Auvergne		**-40**	**36.78**
fr81	Languedoc-Roussillon		**-40**	**584.76**
fr82	Provence-Alpes-Côte d'Azur		**-40**	**710.39**
fr83	Corse		**10**	**154.45**
gr11	Anatoliki Makedonia, Thraki		**8.5**	**935.61**
gr12	Kentriki Makedonia		**8.5**	**2956.96**
gr13	Dytiki Makedonia		**8.5**	**230.64**
gr14	Thessalia		**8.5**	**2126.07**
gr21	Ipeiros		**8.5**	**312.19**
gr22	Ionia Nisia		**8.5**	**14.42**
gr23	Dytiki Ellada		**8.5**	**694.04**
gr24	Sterea Ellada		**8.5**	**1504.03**
gr25	Peloponnisos		**8.5**	**1284.33**
gr30	Attiki		**8.5**	**128.43**
gr41	Voreio Aigaio		**8.5**	**40.75**
gr42	Notio Aigaio		**8.5**	**48.47**
gr43	Kriti		**8.5**	**1224.95**
hu10	Közép-Magyarország		**25**	**24.19**
hu21	Közép-Dunántúl		**25**	**36.30**
hu22	Nyugat-Dunántúl		**25**	**18.45**
hu23	Dél-Dunántúl		**25**	**10.15**
hu31	Észak-Magyarország		**25**	**12.72**
hu32	Észak-Alföld		**25**	**463.71**
hu33	Dél-Alföld		**25**	**222.66**
ie01	Border, Midlands and Western		**8.5**	**0**
ie02	Southern and Eastern		**8.5**	**0**
itc1	Piemonte		**-40**	**3050.42**
itc2	Valle d'Aosta/Vallée d'Aoste		**-40**	**7.25**
itc3	Liguria		**-40**	**30.14**
itc4	Lombardia		**-40**	**2628.39**
itd2	Provincia Autonoma Trento		**-40**	**21.23**
itd3	Veneto		**-40**	**594.99**
itd4	Friuli-Venezia Giulia		**-40**	**70.88**
itd5	Emilia-Romagna		**-40**	**1009.95**
ite1	Toscana		**-40**	**170.44**
ite2	Umbria		**-40**	**86.38**
ite3	Marche		**-40**	**74.70**
ite4	Lazio		**-40**	**302.55**
itf1	Abruzzo		**-40**	**99.08**

itf2	Molise		**-40**	**54.35**
itf3	Campania		**-40**	**391.67**
itf4	Puglia		**-40**	**1488.89**
itf5	Basilicata		**-40**	**274.26**
itf6	Calabria		**-40**	**397.57**
itg1	Sicilia		**-40**	**1183.95**
itg2	Sardegna		**-40**	**341.47**
lt00	Lithuania		**8.5**	**0.00**
lu00	Luxembourg (Grand-Duché)		**8.5**	**0.00**
lv00	Latvia		**8.5**	**0.00**
nl11	Groningen		**8.5**	**0.88**
nl12	Friesland (NL)		**8.5**	**1.07**
nl13	Drenthe		**8.5**	**1.34**
nl21	Overijssel		**8.5**	**2.87**
nl22	Gelderland		**8.5**	**9.22**
nl23	Flevoland		**8.5**	**2.56**
nl31	Utrecht		**8.5**	**1.30**
nl32	Noord-Holland		**8.5**	**1.90**
nl33	Zuid-Holland		**8.5**	**2.84**
nl34	Zeeland		**8.5**	**1.46**
nl41	Noord-Brabant		**8.5**	**28.98**
nl42	Limburg (NL)		**8.5**	**12.11**
pl11	Lódzkie		**8.5**	**1.09**
pl12	Mazowieckie		**8.5**	**1.82**
pl21	Malopolskie		**8.5**	**0.02**
pl22	Slaskie		**8.5**	**1.56**
pl31	Lubelskie		**8.5**	**2.33**
pl32	Podkarpackie		**8.5**	**0.02**
pl33	Swietokrzyskie		**8.5**	**4.49**
pl34	Podlaskie		**8.5**	**0.05**
pl41	Wielkopolskie		**8.5**	**0.00**
pl42	Zachodniopomorskie		**8.5**	**0.00**
pl43	Lubuskie		**8.5**	**1.66**
pl51	Dolnoslaskie		**8.5**	**0.02**
pl52	Opolskie		**8.5**	**0.00**
pl61	Kujawsko-Pomorskie		**8.5**	**1.11**
pl62	Warminsko-Mazurskie		**8.5**	**4.69**
pl63	Pomorskie		**8.5**	**2.31**
pt11	Norte		**-40**	**348.53**
pt15	Algarve		**-40**	**411.90**
pt16	Centro (PT)		**8.5**	**144.64**
pt17	Lisboa		**-40**	**347.29**
pt18	Alentejo		**-40**	**341.82**
ro21	Nord-Est		**9**	**130.37**
ro22	Sud-Est		**9**	**704.30**

ro31	Sud - Muntenia		**9**	**444.78**
ro41	Sud-Vest Oltenia		**9**	**198.07**
ro42	Vest		**9**	**63.04**
ro11	Nord-Vest		**9**	**8.91**
ro12	Centru		**9**	**1.26**
ro32	Bucuresti - Ilfov		**9**	**70.59**
se11	Stockholm		**8.5**	**0.65**
se12	Östra Mellansverige		**8.5**	**2.45**
se21	Småland med öarna		**8.5**	**16.64**
se22	Sydsverige		**8.5**	**0.43**
se23	Västsverige		**8.5**	**0.07**
se31	Norra Mellansverige		**8.5**	**0.08**
se32	Mellersta Norrland		**8.5**	**13.13**
se33	Övre Norrland		**8.5**	**2.62**
si00	Vzhodna Slovenija		**-40**	**2.63**
sk01	Bratislavsk? kraj		**8.5**	**48.05**
sk02	Západné Slovensko		**-40**	**131.66**
sk03	Stredné Slovensko		**-40**	**4.06**
sk04	V?chodné Slovensko		**25**	**3.49**
UKC00000	North East		**25**	**0.22**
UKD00000	North West (including Merseyside)		**25**	**0.18**
UKE00000	Yorkshire and The Humber		**25**	**2.07**
UKF00000	East Midlands		**-40**	**16.26**
UKG00000	West Midlands		**25**	**4.90**
UKH00000	Eastern		**-40**	**30.61**
UKJ00000	South East		**-40**	**12.04**
UKK00000	South West		**25**	**1.23**
UKL00000	Wales		**25**	**0.62**
UKM00000	Scotland		**25**	**0.00**
UKN00000	Northern Ireland		**25**	**0.00**

Annex 18 Greenhouse gas balance for direct land use changes

Assessment by: Jan Peter Lesschen (Alterra)

1. Key messages/conclusions

Changes in GHG emissions and soil organic carbon stock show larger differences between 2004 and 2020 than between the three 2020 Storylines. Largest changes in the GHG emissions are caused by a decline in livestock, mainly cattle, between 2004 and 2020 with a related decrease in CH_4 emissions and are thus not related to changes in cropping patterns caused by increased demand for biomass. The influence of dedicated biomass cropping is on N_2O soil emission and results show that there are relatively small changes between the three Storylines, although differences between Storylines at regional scale can be larger. At an EU scale Storyline 2 has a slightly lower N_2O emission. However, when looking at regional level the picture is less straight forward. The explanation for (slightly) lower N_2O soil emissions is related to the total cropped area and the perennial area share in it, which is generally larger in Storylines 1 and 2 then in Storyline 3.
For most countries a decrease or increase in SOC stocks of less than 5% is projected (Figure 3) and this does not differ much between the Storylines. For several regions an increase in SOC stocks of more than 5% is projected, these are mainly the regions were a large increase in perennial energy crops is projected (Figure 1). The differences between the three Storylines in terms of soil carbon stocks are rather small. Storyline 2 has the smallest area of rotational crops, which results in higher soil carbon stocks for most regions (Germany, France, Romania and Spain).

The overall conclusion of this assessment can be that effects of increased biomass cropping on the land based GHG emissions in agriculture are rather limited, but that they generally work out positively when it leads to increases in perennial cropping area, especially if these take place at the expense of rotational crops.

2. General description of indicator

Definition:
The indicator for the greenhouse gas balance is defined as the sum of the nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2) emissions from agriculture and is expressed in kg CO_2-equivalents per hectare. The CO_2 emission is derived from the change in soil organic carbon stocks.

Description:
N_2O emissions related to managed land use originating from fertilizer and manure application, urine and dung during grazing, and drainage of organic soils, will change when land use changes. In addition, CO_2 emissions due to land use change are caused by changes in soil carbon stocks. When land is converted from one land use to another carbon can accumulate (carbon sequestration) or diminish (carbon emissions). Carbon stocks under land that is not subject to land use change or a change in land management are assumed to remain constant. Changes in CH_4 emissions are not related to land use changes, but to changes in the livestock population.

The GHG balance indicator is calculated for 2004 (the most recent base year of CAPRI) and for three Storylines for 2020 as described in Chapter 3 (Section 3.4) . For the conversion to CO_2-equivalents the following global warming potentials (GWP) were used: for N_2O 298, for CH_4 25 and for CO_2 1, this is according to the IPCC 2007 report.

3. Assessment

Approach

The impact of the Renewable Energy Directive (RES) on the GHG balance was assessed with MITERRA-Europe for three Storylines which are based on data of the *2020 Outlook for EU agriculture*. This outlook takes account of the most recent Health Check reform, the 2020 EU wide RES and NREAP targets and the most recent OECD-FAO projections on agricultural prices, population and welfare developments (EC, 2010)58 assessed by CAPRI in a baseline scenario. The CAPRI baseline scenario run provides an assessment of the effects of reaching the 2020 Biofuel targets on agricultural markets (production levels), cropping shares and livestock population with the CAPRI, AGLINK and ESIM models. As described in Chapter 3 (Section 3.4) of the main report, the CAPRI results in the baseline run were further elaborated in a post-model exercise into land use changes for production of biomass for biofuels, bioelectricity and bioheat in three storyline scenarios. These land use changes in Storyline 1 (Economy first), Storyline 2 (Climate first) and Storyline 3 (Overall sustainability first) are the main input for the impact assessment with the MITERRA-Europe model as presented here. In all Storylines farm management is assumed to remain stable between now and 2020 and for all three Storylines the same number of livestock is used. Thus the Storylines mainly differ in the crop distribution, and indirectly in fertilizer application.

Models, expert knowledge used

MITERRA-Europe is an environmental assessment model that calculates nitrogen (N_2O, NH_3, NO_x and NO_3) and greenhouse gas (CO_2, CH_4 and N_2O) emissions, as well as soil organic carbon stock changes, on a deterministic and annual basis, using emission and leaching factors. The MITERRA-Europe model was developed to assess the effects and interactions of policies and measures in agriculture on N losses on a regional level (NUTS-2) in the EU-27 (Velthof *et al.*, 2009; Lesschen *et al.*, 2011). MITERRA-Europe is partly based on CAPRI (Britz and Witzke, 2008), and GAINS (Klimont and Brink, 2004), and was supplemented with an N leaching module and a soil carbon module. The input data of MITERRA-Europe consists of activity data (e.g. from Eurostat and FAO), spatial environmental data, and emission factors. The model includes measures to mitigate NH_3 and GHG emissions and NO_3 leaching. The emission factors for N_2O and CH_4 are derived from the IPCC 2006 guidelines.

The carbon module of MITERRA-Europe (Lesschen *et al.*, 2009) assesses changes in soil organic carbon (SOC) based on the default IPCC Tier1 approach (IPCC, 2006). Only changes in soil organic carbon were considered, since changes in biomass carbon are zero for arable crops. The amount of SOC in mineral soils is calculated by multiplying a default reference value with relative stock change factors:

$$SOC = SOC_{REF} * F_{LU} * F_{MG} * F_{I} \qquad (1)$$

with

SOC_{REF} = reference carbon content of the soil (ton C per ha)
F_{LU} = coefficient for land use
F_{MG} = coefficient for management
F_{I} = coefficient for input crop production

SOC_{REF} is the reference carbon stock to a depth of 30 cm, which is a function of soil type and climate region and ranges from 36 to 113 ton C ha^{-1}. The IPCC assumes a

58 EC (2010), Prospects for agricultural markets and income 2010-2020. http://ec.europa.eu/agriculture/publi/caprep/prospects2010/index_en.htm

period of 20 years to reach a new equilibrium for soil carbon stocks. For each of the CAPRI crop activities a F_{LU}, F_{MG} and F_I factor was assigned (Lesschen *et al.*, 2009). Changes in soil carbon stocks caused by changes in cropping shares were calculated and divided by 20 years, which is according to the IPCC guidelines the assumed period to reach a new equilibrium in soil carbon stocks, to obtain annual CO_2 emissions. Additionally, CO_2 emissions from agriculture on organic soils, liming and urea application were calculated, using the emission factors from the IPCC 2006 guidelines. Agriculture on organic soils is a major source of CO_2, since peat oxidation is enhanced by drainage and tillage.

Input (data)
Many data contained in the CAPRI database are also used by MITERRA-Europe, especially in relation to crops and livestock numbers. CAPRI covers 38 crop activities and 18 livestock activities, which are derived from Eurostat statistics. In addition to these statistical data, several spatial data sources are needed and used. MITERRA-Europe uses other sources as well (e.g. GAINS for animal numbers and FAO for crop yield statistics). The reference year for this study was 2004, which is the currently available base year of CAPRI. All statistical input data were based on three year averages. The projected values for crop areas, animal numbers, crop yields and mineral fertilizer consumption for the 2020 Storylines were based on the relative changes in CAPRI data for the period 2004-2020. All other parameters were assumed to be constant over time.

4. Results:

Table 1 gives a summary of the total GHG emission in the EU-27 for 2004 and the three 2020 Storylines. Nitrous oxide and methane are the main greenhouse gasses from agriculture with an emission of 173 respectively 245 Mton CO_2-equivalents in 2004. For the 2020 Storylines lower GHG emissions are projected, which is due to the decrease in CH_4 emissions as a result of lower number of cattle, which cannot be related to bioenergy cropping, but rather to overall market developments and reforms in CAP. In order to understand the impacts of the three Storylines which have the same bioenergy targets, but vary according to implementation of sustainability criteria, a comparison of the results for 2020 is needed. Overall it turns out that the differences in GHG emissions between the three 2020 Storylines at EU-27 level are very limited, but that this is not necessarily the case at regional level. The differences that occur are caused by differences in N_2O emissions and SOC stocks as these are mainly caused by differences in cropping patterns caused by different implementations of the RES targets. At EU level Storyline 2 has the lowest N_2O emissions, since this storyline has the smallest area of biofuel and arable crops, which have a higher fertilizer need. The average carbon stock of agricultural soils is projected to increase in 2020, with the highest SOC stocks projected for Storyline 2 as a result of a large area of perennial energy crops and more set-aside and abandoned land compared to Storyline 1. However, the soil carbon sequestration rate is only 3.7% of the total GHG emissions for Storyline 1, 4.4% for Storyline 2 and 2.7% for Storylines 3.

Table 1. *Summary of the main sources of GHG emissions in the EU-27 for 2004 and the three 2020 Storylines (in Mton CO_2-equivalents)*

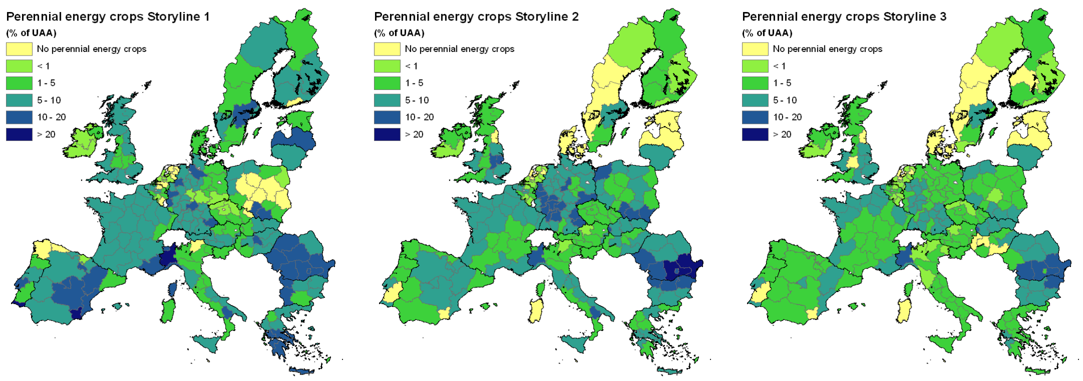
	2004	Storyline 1	Storyline 2	Storyline 3
N_2O total	172.6	176.0	175.5	175.6
N_2O soil emissions	141.0	143.7	143.2	143.3
N_2O indirect emissions	23.9	21.8	21.8	21.9
N_2O manure management	7.7	10.4	10.4	10.4
CH_4 total	245.1	208.3	208.3	208.3
CO_2 emission (organic soils and	52.6	54.32	54.28	54.30
Total GHG emission	470.2	438.6	438.0	438.2
Average soil carbon stock (ton	50.51	50.96	51.05	50.84
CO_2 emission from SOC change		-16.2	-19.2	-11.8

To understand the differences between the Storylines it is important to have insight in the driving factors for the GHG emissions. CH_4 is mainly related to the livestock sector, with emissions from enteric fermentation and manure management. N_2O is related both to the livestock and arable sector with emissions from manure management and from soil emissions due to fertilizer and manure inputs. Finally, the changes in soil organic carbon stocks are related to land use changes, especially changes to or from land under perennial crops and set-aside/abandoned land. In Figure 1 the distribution in perennial energy crops is shown for the three Storylines. In Storyline 1 in most regions of the EU perennial energy crops are cultivated, whereas in Storyline 2 and 3 there is relatively more in Eastern Europe. Furthermore in Storyline 1 there is a larger area of land dedicated to either rotational biofuel crops or perennial crops, while in Storyline 2 and 3 the area of arable crops dedicated to biofuel cropping is absent as it does not reach the stricter mitigation targets set in these Storylines. Therefore the area of set-aside, fallow and abandoned land is larger in Storyline 2 and 3. In Table 2 the main explaining variables are summarized for the four simulations. In the 2020 scenarios the number of livestock units is lower, especially the number of beef cattle is projected to decrease (-25%), whereas pig and poultry numbers will increase (11% and 16% respectively). However, the total manure input is lower for the 2020 scenarios, and also a small decrease in mineral fertilizer use is projected.

Table 2. *Main explaining variables for the three scenarios at EU level*

	2004	Storyline 1	Storyline 2	Storyline 3
Area cropped (10^6 ha)	111.	118.5	116.0	113.0
Of which:				
Perennial energy crops (106 ha)	*0*	*12.0*	*11.3*	*6.8*
Biofuel crops (106 ha)	*0*	*4.8*	*0*	*0*
Other crops (106 ha)	*111.*	*101.7*	*104.7*	*106.2*
Area grassland (10^6 ha)	65.2	61.6	61.6	61.6
Area set-aside / fallow (10^6 ha)	10.6	7.8	9.7	12.2
Area abandoned (10^6 ha)	9.9	8.7	9.2	9.8
Livestock units (10^6)	162.	158.0	158.0	158.0
Mineral fertilizer N input (Mton N)	11.2	11.06	11.11	11.15
Manure N input (Mton N)	8.04	7.62	7.62	7.62

***Figure 1**. Distribution of perennial energy crops for the three 2020 Storylines*



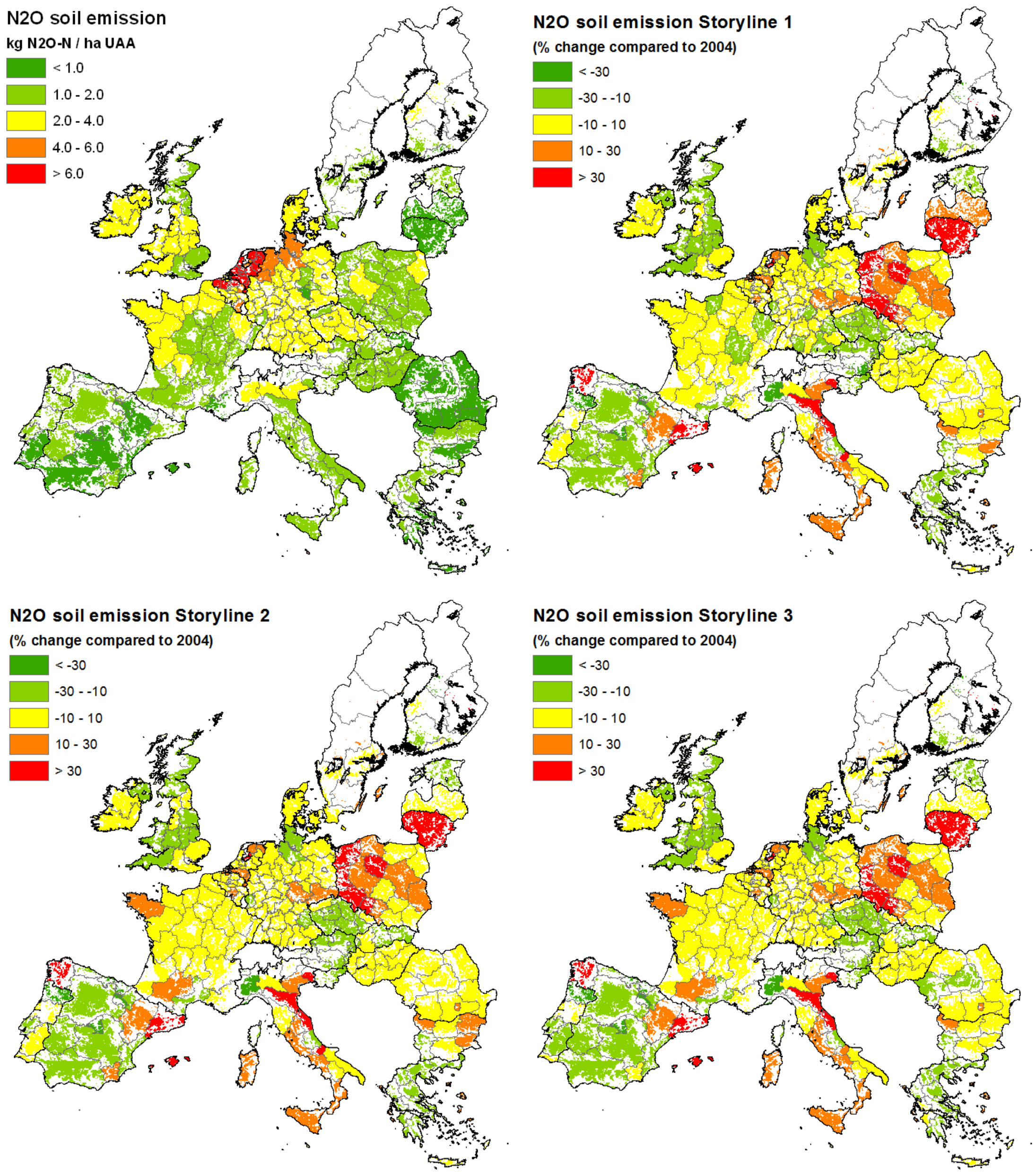
At national and regional level larger differences in N_2O soil emissions and SOC stocks occur between the three Storylines. In Table 3 the total N_2O soil emissions per country are presented for 2004 and the three 2020 Storylines in Figure 2 the same is presented per region. Differences between 2004 and 2020 are mainly related to projected changes in mineral fertilizer consumption. At an EU average level the N_2O soil emission is highest for Storyline 1 and lowest for Storyline 2, although the differences are small. At country level we see in the United Kingdom and Lithuania for example the N_2O soil emission to be higher for Storylines 2 and 3 which is due to the higher share of cropping (of arable crops with a higher fertilizer demand and less perennial energy crops (see also Fig. 2).

***Table 3**. N_2O soil emission per country for 2004 and as projected for the three 2020 Storylines (in Mton CO_2-equivalents per year)*

	2004	Storyline 1	Storyline 2	Storyline 3
Austria	2.36	1.85	1.83	1.83
Belgium	3.51	3.50	3.50	3.50
Bulgaria	2.47	2.56	2.52	2.50
Cyprus	0.18	0.20	0.20	0.20
Czech Republic	3.70	3.28	3.27	3.27
Denmark	3.40	3.44	3.41	3.41
Estonia	0.61	0.52	0.51	0.51
Finland	2.63	2.57	2.50	2.51
France	29.91	30.92	30.84	30.69
Germany	25.32	25.46	24.88	25.38
Greece	3.16	2.69	2.75	2.72
Hungary	4.32	4.30	4.34	4.24
Ireland	7.23	6.87	6.86	6.86
Italy	12.12	12.70	12.68	12.65
Latvia	0.58	0.61	0.54	0.54
Lithuania	1.20	1.71	2.70	2.70
Malta	0.03	0.03	0.03	0.03
Netherlands	7.52	8.19	8.20	8.20
Poland	13.03	15.61	15.04	15.15
Portugal	1.76	1.49	1.48	1.48
Romania	5.34	5.25	5.13	5.17
Slovakia	1.15	0.99	1.01	1.01
Slovenia	0.51	0.43	0.43	0.43
Spain	13.89	13.03	12.98	12.86
Sweden	2.64	2.97	2.90	2.90
United Kingdom	16.35	14.39	14.49	14.43
EU-27	164.89	165.57	165.04	165.17

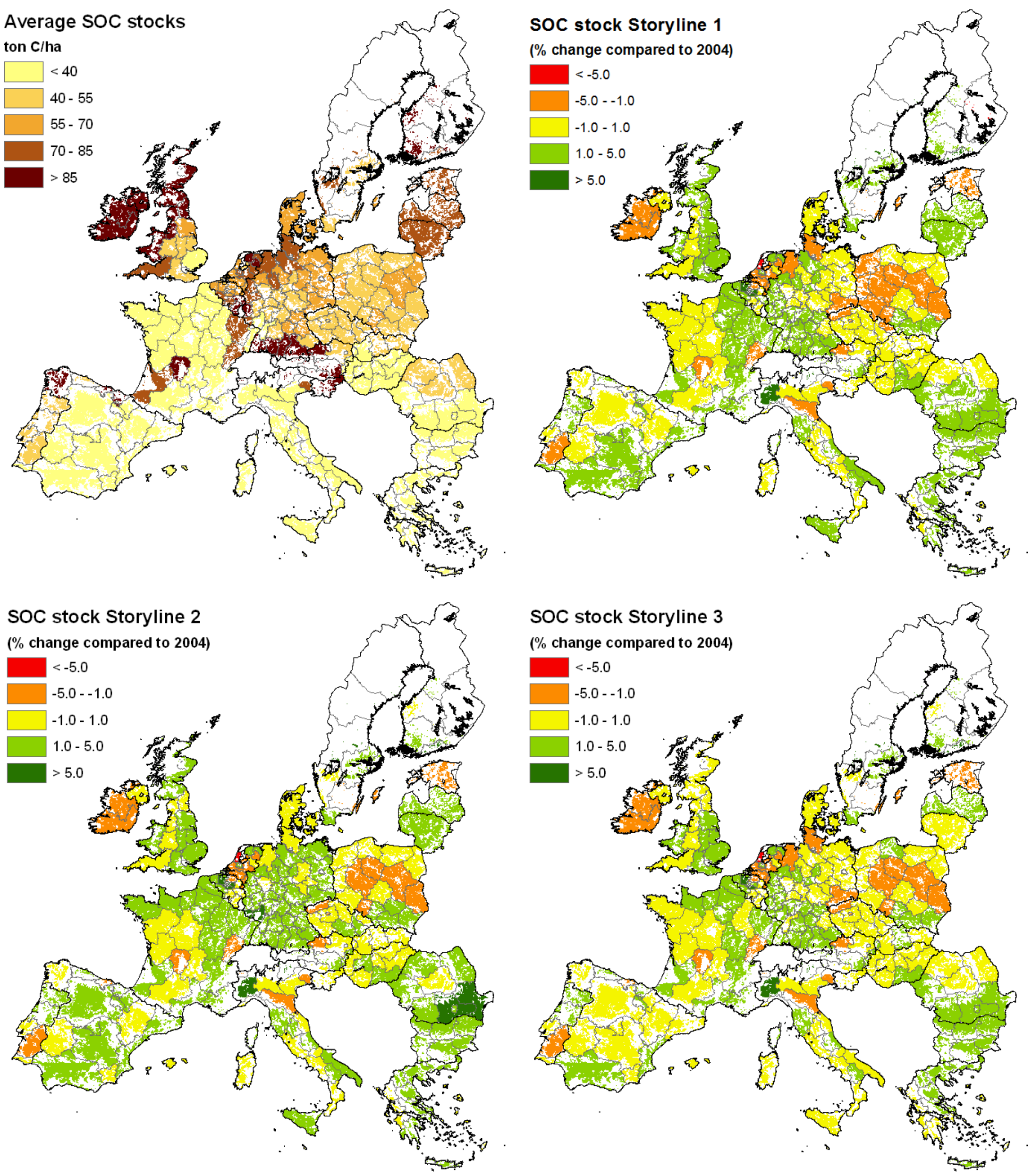
In Figure 2 the first map shows the average N_2O emission on agricultural soils per NUTS-2 region. High N_2O emissions occur in Northwest Europe, especially Belgium and The Netherlands, while in the south and east they are low. The relative difference in N_2O soil emission between 2004 and 2020 for the three 2020 Storylines shown by the last 3 maps (Figure 2) is rather similar, although small differences can be observed, e.g. in Storyline 1 there are more regions in France showing a decline in N_2O soil emission, whereas there are several regions in Poland and Latvia, showing higher emissions in Storyline 1 in comparison to the other Storylines. However, overall the projected changes in mineral fertilizer consumption and use of animal manure between 2004 and 2020 are much larger than the differences between the three Storylines.

Figure 2. *N_2O soil emission (direct + indirect) from agriculture for 2004 and the relative changes for the three 2020 Storylines*



As to changes in soil organic carbon stock we see that between 2004 and 2020 relatively large decreases are observed in Ireland, due to conversion of permanent grassland, but this change is seen in all three storyline and does not relate to conversion of grassland into bioenergy crops, but rather to increases in arable land under influence of agricultural market development and reform of CAP. The impact of bioenergy production on soil organic carbon stocks is generally relatively small and effects of different implementation of the RES policy in the three Storylines are limited. For most countries a decrease or increase in SOC stocks of less than 5% is projected (Figure 3) and this does not differ much between the Storylines. For several regions an increase in SOC stocks of more than 5% is projected, these are mainly the regions were a large increase in perennial energy crops is projected (Figure 1). The differences between the three Storylines in terms of soil carbon stocks are rather small. Storyline 2 has the smallest area of rotational crops, which results in higher soil carbon stocks for most regions (Germany, France, Romania and Spain).

Figure 2. *Average soil carbon stocks of agricultural land for 2004 and the relative changes for the three 2020 Storylines*



The overall conclusion of this assessment can be that effects of increased biomass cropping on the land based GHG emissions in agriculture are rather limited, but that they generally work out positively when it leads to increases in perennial cropping area, especially if these take place at the expense of rotational crops.

Annex 19 Soil degradation risk

Assessment done by:
Gisat (Lukas Brodsky, Katerina Spazierova)
Alterra (Berien Elbersen, Igor Staritsky and Jan-Peter Lesschen)

1. Key messages/conclusions

Overall changes in soil erosion between 2004 and 2020 will not be large, e.g. ranging at levels of low erosion rate (between 0.01 to 1.0 t/ha/year), But regional patterns show both declines and increases. The way the RED targets are implemented in relation to sustainability criteria have some influence on the regional patterns of change in soil erosion between 2004 and 2020. The regions of potential increase in soil erosion are mainly located in Italy, Spain, France, Central Europe (Czech Republic and Poland) and northern Germany. In these regions the highest increases in soil erosion, although still small, are seen in Storyline 1 in which a much larger area of biofuel cropping is allowed while in the other 2 Storylines the area with perennials is larger. The latter type of crops, with a dense and whole year coverage give a better protection against erosion then row crops. The higher resilience against soil erosion also occurs when measures are taken to maintain the fallow land categories, hence the situation in storyline3.

2. General description of indicator

Definition:
Risk for soil degradation in terms of increased soil erosion

The risk indicator, potential erosion, is presented as change in soil loss on agricultural land being potentially affected by increase of biomass cropping between 2004 and 2020.

Description:
This indicator includes the identification of regions where there is a higher chance for soil degradation in terms of soil erosion because of changes in land use caused by increased biomass cropping. The indicator for soil erosion status is based on an EU wide soil erosion and sensitivity for erosion per land cover type (using Corine land Cover database). The results are presented as EU-27 maps at regional (NUTS-2 level) and 1 km grid level for agricultural areas.

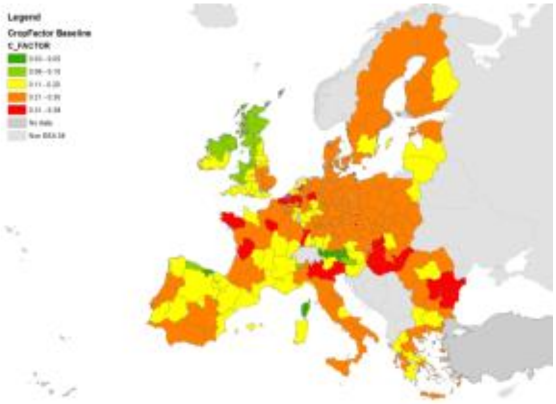
The potential risk for loss of soil organic matter below tolerable levels and risk of soil compaction because of an increased biomass cropping cannot be reasonably mapped because of the absence of data and models to evaluate such impact quantitatively.

3. Assessment

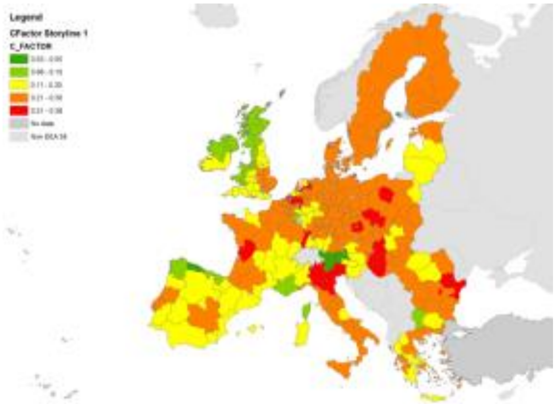
Approach, model

The impact of the Renewable Energy Directive (RED) targets for bioenergy in 2020 on soil erosion changes between 2004 and 2020 was assessed taking the output of the JRC-PESERA data layer (Soil Erosion Risk Assessment in Europe) as a starting point. The implementation of these so-called RES (Renewable Energy) targets was elaborated in three Storylines specifying different sustainability criteria to be directing the land use changes towards 2020.

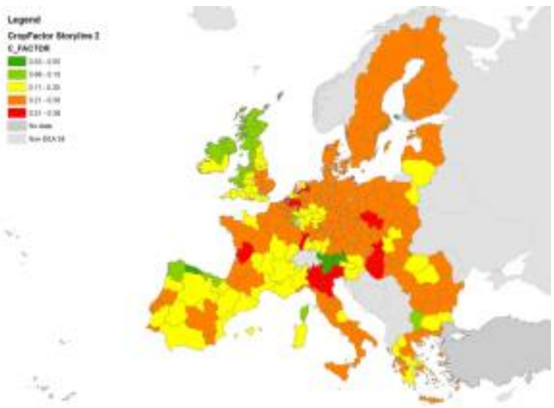
Figure 1 *Crop C-factor values in 2004, and 2020 in the three storyline situations*



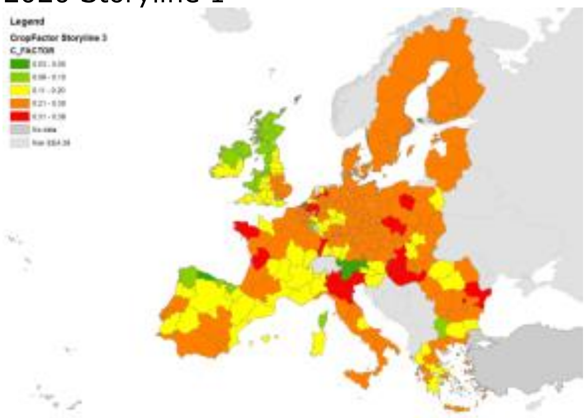
2004



2020 Storyline 1



2020 Storyline 2



2020 Storyline 3

The JRC Soil Erosion Risk Assessment in Europe, PESERA data layer, is a set of maps for the year 2000 which can be used as an aid for identifying regions that are prone to erosion (Van der Knijff, *et al.* 2000). The erosion estimates in the data layer come from a model-based approach utilizing the well known Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978). The model is designed to estimate long-term annual erosion rates on agricultural fields. It requires a number of geo-information input data that are critical to the model's results. Input variables can be derived in principal from standard meteorological data, soil maps, multi-temporal satellite imagery, digital elevation model and potentially from in-situ data. As USLE is a linear combination of 6 main factors, the quality of the results depends equally on the quality of the input data. Although the equation has shortcomings and limitations, it is widely used because of its relative simplicity and robustness (Van der Knijff, *et al.* 2000). One major shortcoming in the applied methodology by JRC is that in the final map of the potential erosion risk the assessment was run by USLE model assuming "that there is a total absence of soil cover (i.e. $C = 1$)".

This oversimplification, hard to imagine a fully bare Europe, gives however the possibility to use the data layer as input to the impact assessment for different Storylines. The selected Storylines of land use change can be converted into specific C (Cover factor) value maps (Figure 1 and Table 1).

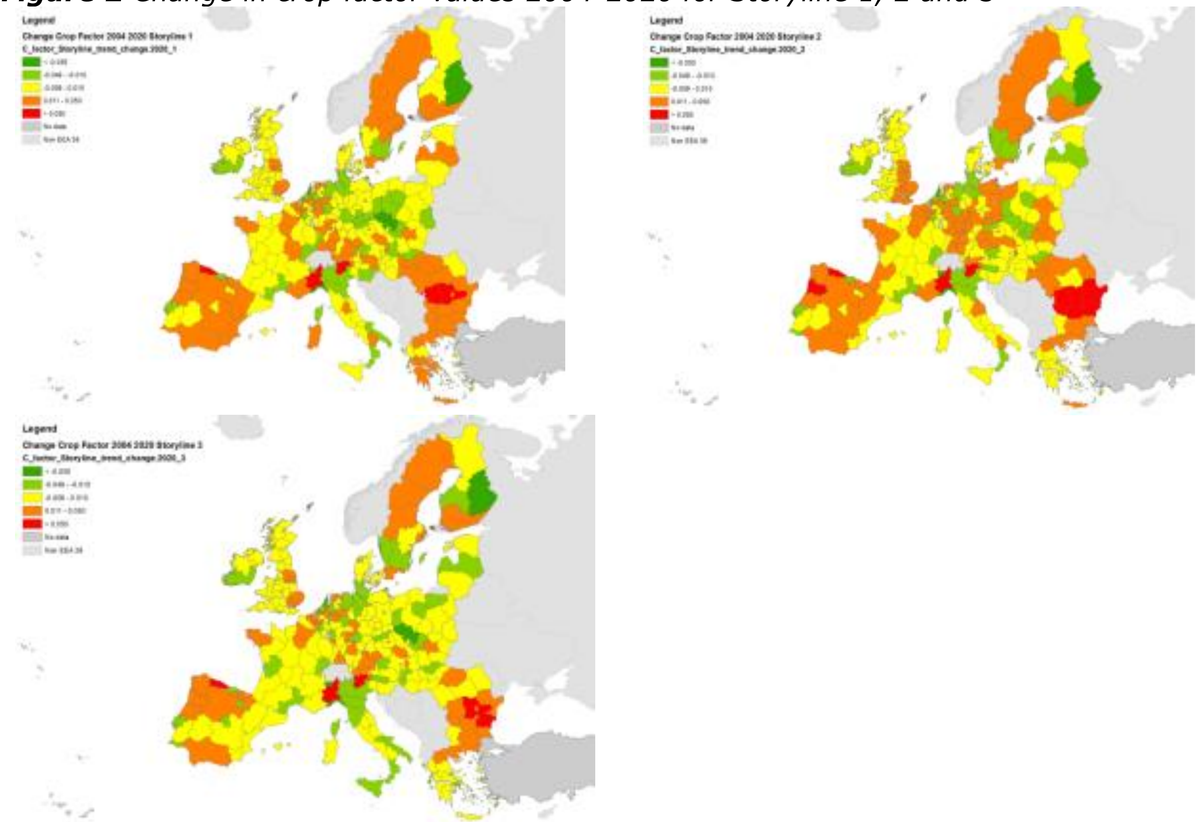
***Table 1**. Tabulated Crop C-factor values*

CROPS	C-factor
# (Cereals)	
SWHE 'Soft wheat'	0.35
DWHE 'Durum wheat'	0.35
RYEM 'Rye and meslin'	0.35
BARL 'Barley'	0.35
OATS 'Oats and summer cereal mixes without triticale'	0.35
MAIZ 'Grain maize'	0.6
OCER 'Other cereals including triticale'	0.35
PARI 'Paddy rice'	0.15
# (Oilseeds)	
RAPE 'Rape'	0.5
SUNF 'Sunflower'	0.5
SOYA 'Soya'	0.55
OLIV 'Olives for oil'	0.33
OOIL 'Other oils'	0.33
PULS 'Pulses'	0.35
POTA 'Potatoes'	0.5
SUGB 'Sugar beet'	0.5
TEXT 'Flax and hemp'	0.3
TOBA 'Tobacco'	0.3
OIND 'Other industrial crops'	0.3
TOMA 'Tomatoes'	0.5
OVEG 'Other vegetables'	0.5
APPL 'Apples pears and peaches'	0.1
OFRU 'Other fruits'	0.1
CITR 'Citrus fruits'	0.1
TAGR 'Table grapes'	0.1
TABO 'Table olives'	0.33
TWIN 'Wine'	0.3
OWIN 'Other wine'	0.3
# Production measured in constant prices	
NURS 'Nurseries'	0.2
FLOW 'Flowers'	0.2
OCRO 'Other crops'	0.2
# Fodder production	
MAIF 'Fodder maize'	0.6
ROOF 'Fodder root crops'	0.5
OFAR 'Fodder other on arable land'	0.3
GRAS 'Gras and grazings'	0.2
GRAE	0.1
GRAI	0.02
SETA 'Set aside idling'	0.1
NONF 'Non food production on set aside'	0.1
FALL 'Fallow land'	0.1
RCG	0.2
Miscanthus	0.2
Switchgrass	0.2
Willow	0.2
Poplar	0.2

Specific C-value layers for the 3 Storylines and the 2004 base year have been assessed as follows. First, NUTS-2 information on cropping patterns were combined with C factors for the specific crops (Table. 1). The C factors were collected from published literature, mainly from FAO sources. These C factors were combined with the cropping areas per crop in 2004 and per storyline in 2020 which enabled the calculation of a weighted average C factor per region (see Figure 1).

Changes in this C-factor between 2004 and 2020 for the three Storylines could then be calculated (see Figure 2). These C-factor values give an indication of the sensitivity to erosion.

Figure 2 *Change in crop factor values 2004-2020 for Storyline 1, 2 and 3*



In order to calculate the real changes in erosion between 2004 and 2020 first an overlay was made with the arable land grids of Corine Land Cover. The combined parameters per grid were then used as input in the USLE formula to calculate final erosion levels for 2020 for the three specific Storylines and for 2004. The changes between 2004 and 2020 for every storyline could then be derived (see Figure 3), resulting in final average new soil erosion values for 2020 in the 3 storyline situations (Figure 4).

Input (data)

1. Land use changes (2004 – 2020) :

The main input data for the three soil impact risk indicators are cropping patterns in 2004 and 2020 resulting from the assessment of the 3 Storylines (Economy first, Climate first, the wider EU environment first) These Storylines are described in detail in Chapter 3 of this report.

2. PESERA map (van der Knijff *et al.*, 2000):

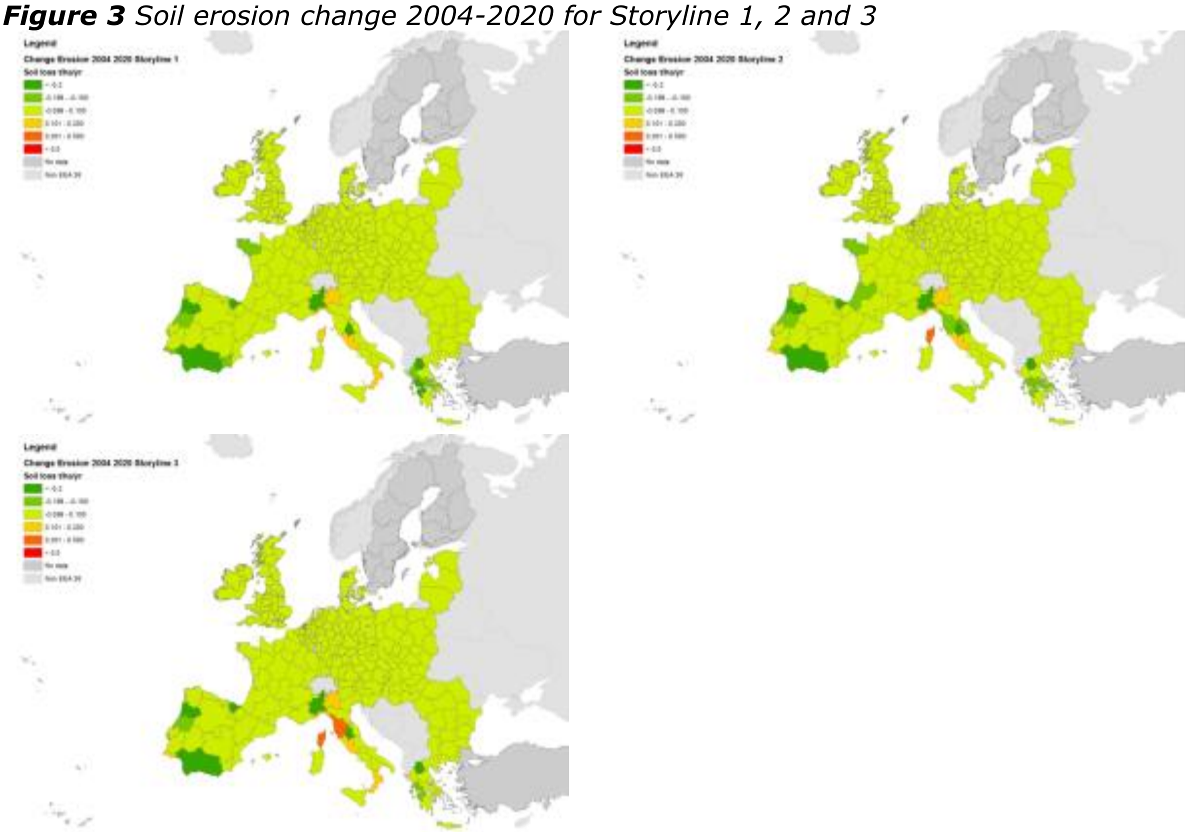
The JRC Soil Erosion Risk Assessment in Europe, PESERA data layer, is used as a basis for the assessment. The layer is the result of application of the Universal Soil Loss Equation to predict rill- and inter-rill erosion. Therefore, the model is not expected to perform well in areas where gully erosion is the dominant erosion type or mass-movements like landslides and rock-falls.

3. CORINE Land Cover 2000 (EEA, Buttner *et al.*, 2002):
The CLC2000 map was used as a basis for the arable land mask delineating the area for which the analysis is performed.

4. Results

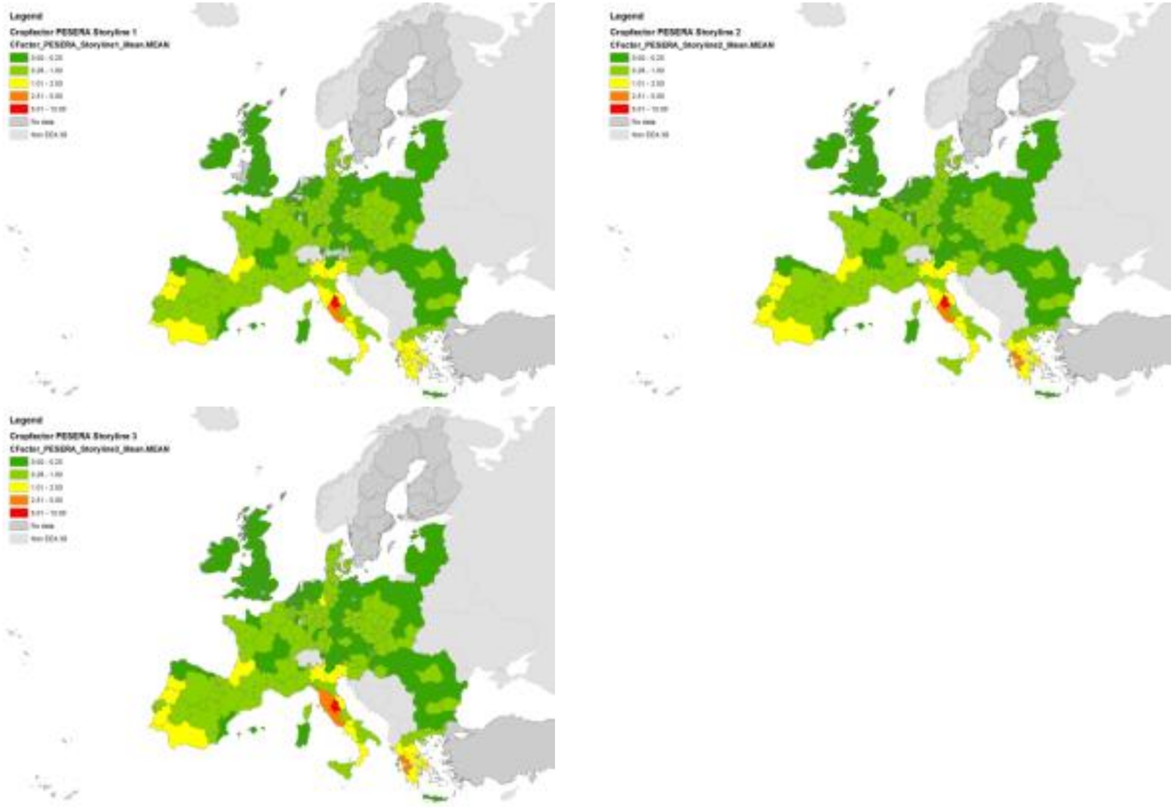
The results show that the way RES targets are implemented in the three Storylines does lead to regional differences in changes in soil erosion across Europe. Overall changes are however small (see Figure 3), ranging between -0.2 to 0.5 of soil loss t/ha/year, with practically all regions showing a (small) decline in soil erosion. Since this is seen in all Storylines these changes are much more related to the overall land use changes 2004-2020 not induced by increased demand for bioenergy. However the only regions showing an increase in soil erosion are found in Italy (Lombardia, Liguria, Toscana, Lazio, Calabria), France (Corsica) and Portugal (Algarve) and show a different change pattern per storyline (Figure 3).

Figure 3 *Soil erosion change 2004-2020 for Storyline 1, 2 and 3*



Although the differences are minimal, Storyline 3 shows an increase in more regions then in Storylines 1 and 2. The explanation is related to the fact that the dedicated perennial cropping area is generally smaller in Storyline 3, particularly in the southern regions of Europe. Where a large land release in agriculture between 2004 and 2020 goes together with an increase in dedicated cropping, the erosion goes down, as perennial crops provide a good soil coverage all year round. But in Storyline 3 there are limits set on use of irrigation in dedicated cropping, making it more complicated to grow perennials on lower quality lands that reach a mitigation level of 60%. The area coverage with perennials is therefore lower in Storyline 3 then in Storylines 1 and 2 and if this coincides with regions with large land releases and high sensitivity to erosion it leads to an increase in erosion.

Figure 4 *Regional mean soil erosion values for 2020 in Storyline 1, 2 and 3*



How these changes result in average future soil erosion levels in 2020 is shown in Figure 4. Overall it is clear that the regions having higher levels of soil erosion are all found in Italy, Spain, Greece and Aquitaine in France. This pattern is not really different between the storyline situations. This implies that additional soil protective measures remain necessary when introducing bioenergy cropping in these regions at large scale, but also without bioenergy cropping soil erosion measures are needed, particularly in regions where increases in arable cropping take place. Overall it is clear that conversions of row crops towards permanent crops, such as with perennial biomass crops, are the best measures to decrease erosion risks.

Annex 20 Farmland birds

Assessment done by: Klaus Peter Zulka (Environment Agency Austria, Vienna, Austria)

1. **Key messages/conclusions**

The effect of the three bioenergy development Storylines on farmland bird diversity was investigated by calculation of a regional bird assemblage score. This score is based on threat category, landscape association and habitat association and is then weighted with the projected land use proportions in 2020 in the three storyline situations. This leads to a NUTS2 region characteristic farmland bird indicator that can be compared between the three Storylines and the initial situation in 2004. The results show that between 2004 and 2020 substantial changes will occur in farmland bird diversity in many EU regions. The way these changes are distributed differs clearly between the three Storylines. Large biodiversity losses can be expected in regions in Bulgaria, Romania, Portugal, Spain Hungary and Greece and, in particular for Storyline 1, large losses are also projected for regions in Poland and Italy. Under Storyline 2, farmland biodiversity gains are predicted for regions in Sweden, Austria and the Czech Republic. In Finland, France, Greece and Italy, farmland biodiversity will benefit in some regions and be reduced pronouncedly in other regions. For many regions, the results differ largely between the Storylines, with Storyline 3 (overall sustainability) usually yielding a much better farmland bird score than the other two Storylines (economy first, climate first).

Aggregated across Europe, in Storyline 1 (economy first) the total EU-27 farmland bird score compared to 2004 will be reduced by 839 points. Storyline 2 (climate first) will show a decline of 447 points and Storyline 3 (overall sustainability) will in total lead to a small increase of 70. What counts however is the regional distribution of the change in score and it is clear that in Storyline 3 also the large majority of the regions show an improvement, in Storyline 1 there are clearly more regions showing a decline then an increase in farmland bird score and Storyline 2 takes a middle position.

Metapopulation theory suggests that habitat spread too thinly across a country might be of low value for the conservation of species, since extinction events in one habitat patch may no longer be compensated by re-colonisation once patches get too far apart. We thus analysed the behaviour of our modelling system by introducing a threshold of habitat proportion, below which the landscape composition is no longer suitable for a species assemblage. Introducing such a threshold does not change the ranking of Storylines (3 better than 2004 better than 2 better than 1), but enlarges the differences between the storyline scores, if the threshold is selected between 0 and 7% of the utilised agricultural area.

Overall it may be concluded that an unfettered development of bioenergy will lead to farmland bird losses in a majority of EU regions, but also on average across Europe. A focus on bioenergy production with perennials (Storyline 2, climate first) will do considerablybetter, but still leads to overall farmland bird losses. However, Storyline 3 shows that biodiversity losses are not an inevitable consequence of bioenergy production. Under such an overall sustainability concept, farmland bird biodiversity might even slightly improve on average across Europe, although some of the regions may still experience local losses compared to 2004.

2. General description of indicator

Definition:
Farmland bird biodiversity status indicator

The indicator measures the status of a farmland bird assemblage in a NUTS 2 region; based on the one side on the species and their threat levels, their landscape and habitat type dependence and based on the other side on the land use composition present in the farmland.

Description:

Bird species in the agricultural landscape may be bound to particular landscape elements. For example, survival and persistence of the Grey Partridge (Perdix perdix) was linked to the existence of unsprayed grassy margins or set-asides with high invertebrate diversity. Invertebrates are an important food source for the hatchlings, population dynamics of Grey Partridge in an agricultural landscape strongly depend on the survival of hatchlings (reviewed in Wilson *et al.* 2009, p. 173). For many farmland species, fallow areas and set-asides function as shelter areas during agricultural disturbances, as breeding sites and as food sources. Temporarily abandoned land shows similar properties, but the weed diversity and the structural diversity may be much lower than in long-term set-aside fallows. Perennials are a new feature in agricultural landscapes. Farmland bird assemblages of such perennials typically do not resemble woodland assemblages, but are composed of species preferring farmland or open scrubland. (Dauber *et al.* 2010, p. 6). Species using hedges as song posts can be expected to benefit from some types of perennials, if these are planted in an interspersed pattern. Disturbance levels of fallows, temporary abandoned lands and perennials are typically much lower than on rotational arable land.
This dependence on the landscape elements can be scored and weighted by the amount of landscape change that is expected to occur. For example, a bird that primarily uses fallows in agricultural landscape would benefit if this category increases and suffer if it is (partly) converted into other land use forms, such as perennials or arable fields.

Using species-specific information on the habitat requirements, association with agricultural landscapes, and SPEC (Species of European Conservation Concern) status, we obtained an indicator for bird species dependence on a particular farmland element type which can be applied at multiple spatial scales. In the present analysis, we applied it at the NUTS 2 scale. For these conservation-relevant species, a habitat association score (see underneath for further explanation) is computed and summed for the species occurring in a particular NUTS 2 region.

SPEC is a species priority ranking system that was introduced in the first report on the conservation status of European birds (Tucker & Heath 1994) and further developed in the second report (BirdLife 2004). The SPEC categories 1 to 3 basically integrate data on the global threat status of European birds, the importance of European populations for the global conservation of these species and the conservation status of the European population (BirdLife 2004, p. 11). SPEC category 1 is assigned to "European species of global conservation concern, i. e. classified as Critically, Endangered, Vulnerable, Near Threatened or Data Deficient under the IUCN Red List Criteria at a global level" (BirdLife 2004, p.11). SPEC category 2 is assigned to "species whose global populations are concentrated in Europe, and which have an Unfavourable conservation status in Europe". SPEC category 3 comprises "species whose global populations are not concentrated in Europe, but which have an Unfavourable conservation stratus in Europe" (BirdLife 2004, p.11).
Global conservation status is measured in the threat categories CR (Critically

Endangered), EN (Endangered, VU (Vulnerable), NT (Near Threatened) , DD (Data Deficient) and Least Concern (LC). Species have been assigned to these Red List categories according to the Red List criteria version 3.1 (IUCN 2001, for the implementation guidelines see IUCN Standards and Petitions Subcommittee 2010).

3. Assessment

Approach
For the delineation of the farmland bird species pool, we used the union set of four sources: (1) the High Nature Value Farmland (HNV) bird set (Paracchini *et al.* 2008, p. 73, appendix VI), (2) a comprehensive list of species classified as farmland species in Donald *et al.* (2006), (3) an internal compilation of species classified as having an unfavourable conservation status and being associated with farmland, (4) an internal compilation of farmland birds, including their habitat associations (i.e. use of a habitat), used as an input in the High Nature Value Farmland project (Andersen *et al.*, 2003).

From this species pool, species of European concern (SPEC 1 to 3) were selected (as categorized in BirdLife 2004). The **threat level** 't' was scored from:
1 = SPEC 3 species,
2 = SPEC 2 species,
3 = SPEC 1 species categorised as NT or DD in the global IUCN Red Lists,
4 = SPEC 1 species categorized as VU, EN, or CR on the IUCN Red Lists, cf. BirdLife (2004).

For these species, the **agricultural landscape association** 'l' was evaluated and scored (0, 1, 2 or 3):
Score 0 = Species of which the farmland association was considered loose or irregular; these species were excluded from further analyses.
Score 1= Species that use the agricultural landscape regularly, but only during parts of their life and for some specific action, such as foraging. They utilize a variety of other habitats as well and thus their dependence on farmland is limited.
Score 2= Species that depend on the agricultural landscape to a higher degree, but are not entirely restricted to agricultural habitats.
Score 3= Species that spend most of their life in agricultural landscapes and use agricultural landscape elements typically for breeding, foraging and hibernating.
Agricultural landscapes are considered as mosaics of landscape elements including fields, fallows, set-asides; they may contain grassland patches, but are dominated by arable fields.

In a second step, the **habitat association** 'h' of the species on a particular habitat type 'j' in the landscape mosaic was scored. Four habitat types were distinguished: fallows (including set-asides), (intensively used) arable fields, perennials and recently abandoned fields. Again, scores from 0 to 3 were assigned;
Score 0 = if the species avoids the habitat type,
Score 1 = for species using the habitat type occasionally
Score 2 = if the habitat type is important for the life of the species,
Score 3 = if the habitat type is indispensable for the species' presence in the landscape.

Thus, for each species 'i', habitat type 'j' and NUTS 2 region 'k', a threat-weighed **habitat dependence score** was calculated as follows:

$$S_{ijk} = t * l * h_j$$

with t representing the threat score, l representing the landscape association score and h_j representing the habitat association with habitat type j.

Four habitat types were distinguished and scored: (1) fallow land, (2) arable land, (3) perennials, (4) temporarily abandoned land (cf. Tab. 1).

For each habitat type j and NUTS 2 region k, a **regional assemblage score** is then calculated as follows:

$T_{jk} = \sum S_{ijk}$

for all species i occurring in the region.

Weighting T_{jk} with the area proportion P_{jkl} of the habitat type j within the agricultural landscape of the NUTS 2 region k (utilized agricultural area UAAR including perennials and abandoned land) yields a **status score** U_{jkl} for the particular farmland bird assemblage of this habitat type j within the NUTS 2 region k in a particular landscape composition (2004 and Storylines 1 to 3).

$T_{jk} * P_{jkl} = U_{jkl}$

Summing this status score across all habitat types j gives a status measure for the farmland bird biodiversity in the NUTS 2 region k in the scenario l:

$V_{kl} = \sum U_{jkl}$

This measure can be used to compare regions of high farmland biodiversity and, if summed across regions, yields a measure of farmland bird status under a particular landscape composition (2004 and Storyline 1 to 3):

$W_{l} = \sum U_{kl}$

This measure can be used to calculate three **flow statistics** for the difference between the 2004 situation and the three Storylines:

$F_1 = W_{S1} - W_{2004}$

$F_2 = W_{S2} - W_{2004}$

$F_3 = W_{S3} - W_{2004}$

Threshold of habitat proportion

Metapopulation theory suggests that habitat availability and metapopulation extinction risk are not linearly related (Hanski 1999). Beyond a certain threshold of habitat proportion in a landscape, survival probability may decrease dramatically (e. g. Fahrig 2001). The reasons for such a discontinuity are (1) a highly elevated extinction risk of small populations in isolated habitat patches and (2) a decreased probability of recolonisation if habitat patches are spaced apart too distantly. In such fragmented or relictual landscapes (McIntyre &Hobbs 1999), even species with high dispersal capacity such as farmland birds will encounter difficulties to find and repopulate suitable habitat. A linear weighting of species scores by available habitat area, as done so far in the analyses might thus overestimate the habitat quality for rare habitat types once they occupy small proportions of the landscapes. We thus simulated the effects of a threshold of habitat proportion out of the utilised agricultural area below which the habitat area is considered to be of no use for farmland biodiversity. We then compared the Storylines with the 2004 situation under the influence of a varying threshold of habitat proportion.

Models, expert knowledge used

The scores on farmland habitat association were estimated primarily using published species information sources (in particular Snow 1998a, 1998b, Šťastný *et al.* 2006, Dvorak *et al.* 1993, Bezzel 1985, 1993) and additionally using expert knowledge.

Input (data)
Data on (national) presence, global threat (IUCN Red List category), and SPEC status were obtained from BirdLife (2004). The occurrence in NUTS 2 regions was derived from the distribution maps in Huntley *et al.* (2007).

The proportion of habitat types within the agricultural landscape was calculated from the CAPRI model and own elaboration (see main report).

4. Results

The farmland bird assemblage scores were highest for the habitat type "fallow", and "abandoned land". High assemblage scores were obtained for these habitat types in NUTS 2 regions of Bulgaria, Greece, Spain, parts of France, Hungary, Italy, parts of Poland, Portugal, Romania, Slovenia, and Slovakia, i. e. mainly in the Mediterranean countries and the New Member States (Table 1).

***Table 1**: Assemblage scores T_{jk} for habitat types j and NUTS 2 regions k. Hotspots (scores > 180) are highlighted in yellow colour.*

Country	NUTS 2 Code	NUTS 2 region name	Score fallow	Score arable	Score perennial	Score abandoned
Austria	AT110000	Burgenland	205	47	26	141
Austria	AT120000	Niederösterreich	222	58	25	147
Austria	AT210000	Kärnten	112	25	14	77
Austria	AT220000	Steiermark	140	28	16	98
Austria	AT310000	Oberösterreich	121	24	19	85
Austria	AT320000	Salzburg	91	21	10	59
Austria	AT330000	Tirol	101	27	10	67
Austria	AT340000	Vorarlberg	105	26	12	72
Bulgaria	BG010000	Severozapaden	242	45	29	170
Bulgaria	BG020000	Severen Tsentralen	278	55	29	190
Bulgaria	BG030000	Severoiztochen	302	63	29	206
Bulgaria	BG040000	Yugozapaden	282	57	28	193
Bulgaria	BG050000	Yuzhen Tsentralen	287	58	29	196
Bulgaria	BG060000	Yugoiztochen	287	58	29	196
Belgium	BL210000	Prov. Antwerpen	107	27	17	75
Belgium	BL220000	Prov. Limburg (b)	119	25	17	79
Belgium	BL230000	Prov. Oost-Vlaanderen	112	25	17	76
Belgium	BL240000	Prov. Vlaams Brabant	94	24	16	65
Belgium	BL250000	Prov. West-Vlaanderen	101	27	16	72

Belgium	BL310000	Prov. Brabant Wallon	97	24	17	68
Belgium	BL320000	Prov. Hainaut	114	24	18	77
Belgium	BL330000	Prov. Liège	108	25	18	74
Belgium	BL340000	Prov. Luxembourg (b)	113	24	19	77
Belgium	BL350000	Prov. Namur	101	24	18	71
Cyprus	CY000000	Cyprus	149	23	17	100
Czech Republic	CZ010000	Praha	133	33	19	89
Czech Republic	CZ020000	Strední Cechy	163	34	19	109
Czech Republic	CZ030000	Jihozapad	171	34	19	115
Czech Republic	CZ040000	Severozapad	156	34	19	104
Czech Republic	CZ050000	Severovychod	149	33	20	100
Czech Republic	CZ060000	Jihovychod	265	62	29	176
Czech Republic	CZ070000	Stredni Morava	175	42	28	118
Czech Republic	CZ080000	Moravskoslezsko	143	34	18	95
Germany	DE110000	Stuttgart	136	25	18	91
Germany	DE120000	Karlsruhe	135	28	19	92
Germany	DE130000	Freiburg	131	27	18	89
Germany	DE140000	Tübingen	123	27	19	84
Germany	DE210000	Oberbayern	135	27	19	92
Germany	DE220000	Niederbayern	150	34	20	100
Germany	DE230000	Oberpfalz	135	28	18	91
Germany	DE240000	Oberfranken	130	27	19	89
Germany	DE250000	Mittelfranken	153	28	18	103
Germany	DE260000	Unterfranken	166	34	19	110
Germany	DE270000	Schwaben	138	28	15	91
Germany	DE400000	Brandenburg	173	42	17	115
Germany	DE710000	Darmstadt	166	34	19	110
Germany	DE720000	Gießen	156	34	17	103
Germany	DE730000	Kassel	132	33	18	88
Germany	DE800000	Mecklenburg-Vorpommern	177	42	17	119
Germany	DE910000	Braunschweig	143	33	19	97
Germany	DE920000	Hannover	143	34	18	96
Germany	DE930000	Lüneburg	145	34	18	98
Germany	DE940000	Weser-Ems	130	28	17	89
Germany	DEA10000	Düsseldorf	132	31	18	86
Germany	DEA20000	Köln	135	32	18	88
Germany	DEA30000	Münster	133	31	18	87
Germany	DEA40000	Detmold	132	31	18	86
Germany	DEA50000	Arnsberg	121	25	19	81
Germany	DEB10000	Koblenz	118	26	18	79
Germany	DEB20000	Trier	124	25	19	84
Germany	DEB30000	Rheinhessen-Pfalz	147	27	17	100
Germany	DEC00000	Saarland	144	26	19	97
Germany	DED00000	Chemnitz	172	34	18	116
Germany	DEE00000	Sachsen-Anhalt	160	34	18	106
Germany	DEF00000	Schleswig-Holstein	139	33	18	93
Germany	DEG00000	Thüringen	131	28	18	89
Denmark	DK000000	Danmark	133	28	18	92

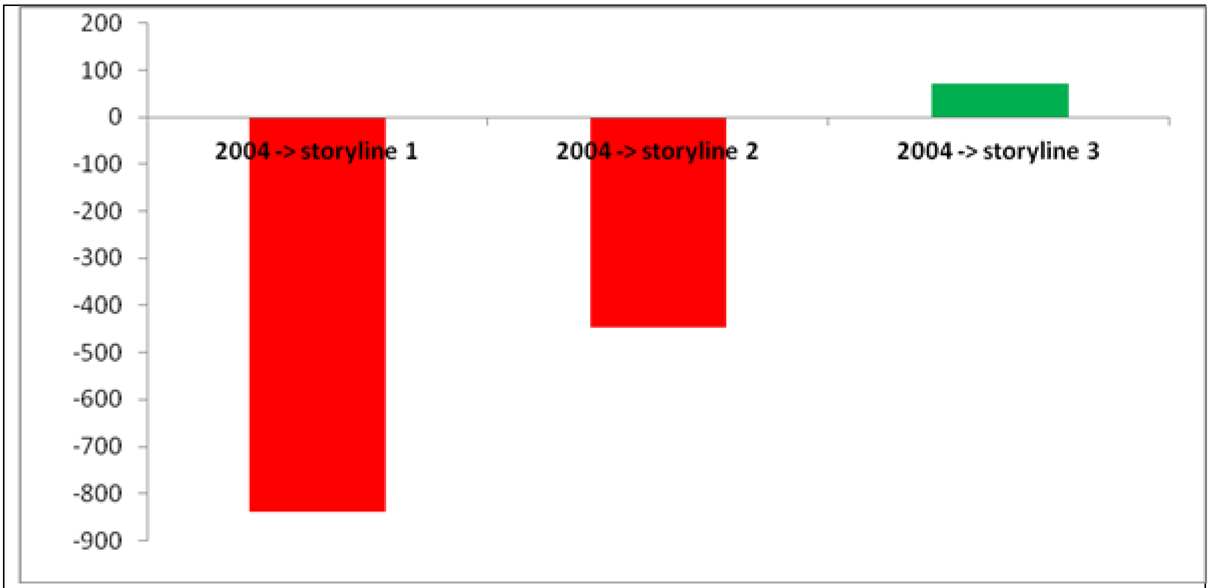
Estonia	EE000000	Eesti	139	31	14	92
Greece	EL110000	Anatoliki Makedonia, Thraki	263	51	20	180
Greece	EL120000	Kentriki Makedonia	239	43	20	164
Greece	EL130000	Dytiki Makedonia	230	40	20	158
Greece	EL140000	Thessalia	218	39	17	150
Greece	EL210000	Ipeiros	212	39	17	147
Greece	EL220000	Ionia Nisia	192	39	15	133
Greece	EL230000	Dytiki Ellada	178	34	15	122
Greece	EL240000	Sterea Ellada	198	39	15	136
Greece	EL250000	Peloponnisos	183	37	15	124
Greece	EL300000	Attiki	164	37	14	111
Greece	EL410000	Voreio Aigaio	200	35	14	139
Greece	EL420000	Notio Aigaio	183	35	15	128
Greece	EL430000	Kriti	145	33	8	99
Spain	ES110000	Galicia	241	55	19	162
Spain	ES120000	Principado de Asturias	198	42	19	134
Spain	ES130000	Cantabria	202	49	17	136
Spain	ES210000	País Vasco	208	45	17	146
Spain	ES220000	Navarra	274	55	17	189
Spain	ES230000	La Rioja	262	63	17	182
Spain	ES240000	Aragón	311	64	20	214
Spain	ES300000	Comunidad de Madrid	261	59	14	182
Spain	ES410000	Castilla y León	303	67	20	210
Spain	ES420000	Castilla-la Mancha	285	68	14	197
Spain	ES430000	Extremadura	260	59	14	181
Spain	ES510000	Cataluña	294	58	20	201
Spain	ES520000	Comunidad Valenciana	276	66	14	185
Spain	ES530000	Illes Balears	167	34	8	111
Spain	ES610000	Andalucía	287	68	14	198
Spain	ES620000	Región de Murcia	211	45	14	147
Finland	FI130000	Itõ-suomi	85	17	16	57
Finland	FI180000	Etelõ-suomi	85	17	16	57
Finland	FI190000	Võli-suomi	85	17	16	57
Finland	FI1A0000	Pohjois-suomi	84	17	16	56
Finland	FI200000	Uusimaa (suuralue)	69	15	12	46
France	FR100000	Île de France	179	48	19	125
France	FR210000	Champagne-Ardenne	189	38	19	131
France	FR220000	Picardie	180	40	19	124
France	FR230000	Haute-Normandie	153	33	19	106
France	FR240000	Centre	230	55	19	156
France	FR250000	Basse-Normandie	149	33	19	106
France	FR260000	Bourgogne	197	42	19	135
France	FR300000	Nord - Pas-de-Calais	141	31	19	98
France	FR410000	Lorraine	155	28	19	105
France	FR420000	Alsace	198	44	20	134
France	FR430000	Franche-comté	168	30	20	116
France	FR510000	Pays de la Loire	202	48	17	138
France	FR520000	Bretagne	145	33	17	100
France	FR530000	Poitou-Charentes	228	55	17	153
France	FR610000	Aquitaine	236	55	20	159
France	FR620000	Midi-Pyrénées	232	53	20	155
France	FR630000	Limousin	187	41	20	126
France	FR710000	Rhône-Alpes	232	54	20	158
France	FR720000	Auvergne	232	55	20	157
France	FR810000	Languedoc-Roussillon	293	58	20	203

France	FR820000	Provence-Alpes-Côe D'azur	259	47	20	178
France	FR830000	Corse	155	33	12	105
Hungary	HU100000	Kozep-Magyarorszag	255	56	26	172
Hungary	HU210000	Közép-Dunántúl	267	62	26	178
Hungary	HU220000	Nyugat-dunantul	201	40	18	138
Hungary	HU230000	Del-dunantul	213	46	26	144
Hungary	HU310000	Eszak-magyarorszag	246	56	27	163
Hungary	HU320000	Észak-Alföld	271	59	26	183
Hungary	HU330000	Dél-Alföld	230	49	25	152
Ireland	IR010000	Border, Midland And Western	83	26	7	60
Ireland	IR020000	Southern And Eastern	83	26	7	60
Italy	IT110000	Piemonte	207	46	18	141
Italy	IT120000	Valle d'Aosta	103	27	13	69
Italy	IT130000	Liguria	187	42	16	127
Italy	IT200000	Lombardia	225	46	18	151
Italy	IT310000	Trentino-alto Adige	106	25	17	71
Italy	IT320000	Veneto	193	42	18	129
Italy	IT330000	Friuli-Venezia Giulia	194	40	17	128
Italy	IT400000	Emilia-Romagna	208	46	19	140
Italy	IT510000	Toscana	246	47	20	171
Italy	IT520000	Umbria	193	35	17	128
Italy	IT530000	Marche	177	37	15	116
Italy	IT600000	Lazio	226	41	20	147
Italy	IT710000	Abruzzo	202	39	18	135
Italy	IT720000	Molise	216	31	18	147
Italy	IT800000	Campania	193	31	19	134
Italy	IT910000	Puglia	249	44	17	170
Italy	IT920000	Basilicata	230	37	19	155
Italy	IT930000	Calabria	225	39	16	153
Italy	ITA00000	Sicilia	203	29	14	141
Italy	ITB00000	Sardegna	218	33	13	150
Lithuania	LT000000	Lietuva	187	34	19	125
Latvia	LV000000	Latvija	160	31	19	107
Malta	MT000000	Malta	49	11	0	31
Netherlands	NL110000	Groningen	108	26	17	71
Netherlands	NL120000	Friesland	112	25	17	76
Netherlands	NL130000	Drenthe	137	32	18	90
Netherlands	NL210000	Overijssel	136	32	19	89
Netherlands	NL220000	Gelderland	135	32	18	88
Netherlands	NL230000	Flevoland	115	26	18	78
Netherlands	NL310000	Utrecht	100	26	13	68
Netherlands	NL320000	Noord-holland	94	19	17	64
Netherlands	NL330000	Zuid-holland	106	25	15	72
Netherlands	NL340000	Zeeland	114	25	17	78
Netherlands	NL410000	Noord-brabant	128	32	19	85
Netherlands	NL420000	Limburg (nl)	134	32	17	87
Poland	PL110000	Lodzkie	187	34	19	125
Poland	PL120000	Mazowieckie	210	34	19	138
Poland	PL210000	Malopolskie	169	34	18	111
Poland	PL220000	Slaskie	169	34	20	113
Poland	PL310000	Lubelskie	209	34	19	141
Poland	PL320000	Podkarpackie	169	34	20	115
Poland	PL330000	Swietokrzyskie	210	34	19	140
Poland	PL340000	Podlaskie	192	33	20	127

Poland	PL410000	Wielkopolskie	172	34	19	116
Poland	PL420000	Zachodniopomorskie	151	34	19	101
Poland	PL430000	Lubuskie	169	34	19	113
Poland	PL510000	Dolnoslaskie	146	34	19	98
Poland	PL520000	Opolskie	192	42	27	128
Poland	PL610000	Kujawsko-pomorskie	167	34	18	111
Poland	PL620000	Warminsko-mazurskie	187	34	19	125
Poland	PL630000	Pomorskie	168	34	19	112
Portugal	PT110000	Norte	250	53	17	174
Portugal	PT150000	Algarve	253	56	14	177
Portugal	PT160000	Centro (p)	266	61	14	185
Portugal	PT170000	Lisboa e Vale do Tejo	222	46	14	157
Portugal	PT180000	Alentejo	252	55	14	178
Romania	RO010000	Nord-est	201	32	20	143
Romania	RO020000	Sud-est	340	71	31	228
Romania	RO030000	Sud	183	36	18	123
Romania	RO040000	Sud-vest	242	48	29	167
Romania	RO050000	Vest	231	51	30	157
Romania	RO060000	Nord-vest	191	38	21	130
Romania	RO070000	Centru	214	46	21	151
Romania	RO080000	Bucuresti	161	31	17	110
Sweden	SE010000	Stockholm	80	19	13	52
Sweden	SE020000	Östra Mellansverige	86	21	13	56
Sweden	SE040000	Sydsverige	98	23	13	62
Sweden	SE060000	Norra Mellansverige	86	19	15	56
Sweden	SE070000	Mellersta Norrland	73	19	10	46
Sweden	SE080000	Övre Norrland	66	15	11	43
Sweden	SE090000	Småland Med Öarna	84	13	13	55
Sweden	SE0A0000	Västsverige	120	28	15	77
Slovenia	SI000000	Slovenija	203	38	18	143
Slovakia	SK010000	Bratislavsky	282	62	29	187
Slovakia	SK020000	Zapadne Slovensko	282	62	29	187
Slovakia	SK030000	Stredné Slovensko	272	62	29	183
Slovakia	SK040000	Vychodne Slovensko	236	48	29	161
UK	UKC00000		87	26	10	62
UK	UKD00000		95	26	10	66
UK	UKE00000		106	26	15	74
UK	UKF00000		85	26	10	61
UK	UKG00000		86	26	10	61
UK	UKH00000		108	26	15	76
UK	UKJ00000		90	26	12	65
UK	UKK00000		97	26	12	68
UK	UKL00000		95	26	10	66
UK	UKM00000		101	26	10	69
UK	UKN00000		81	26	7	56

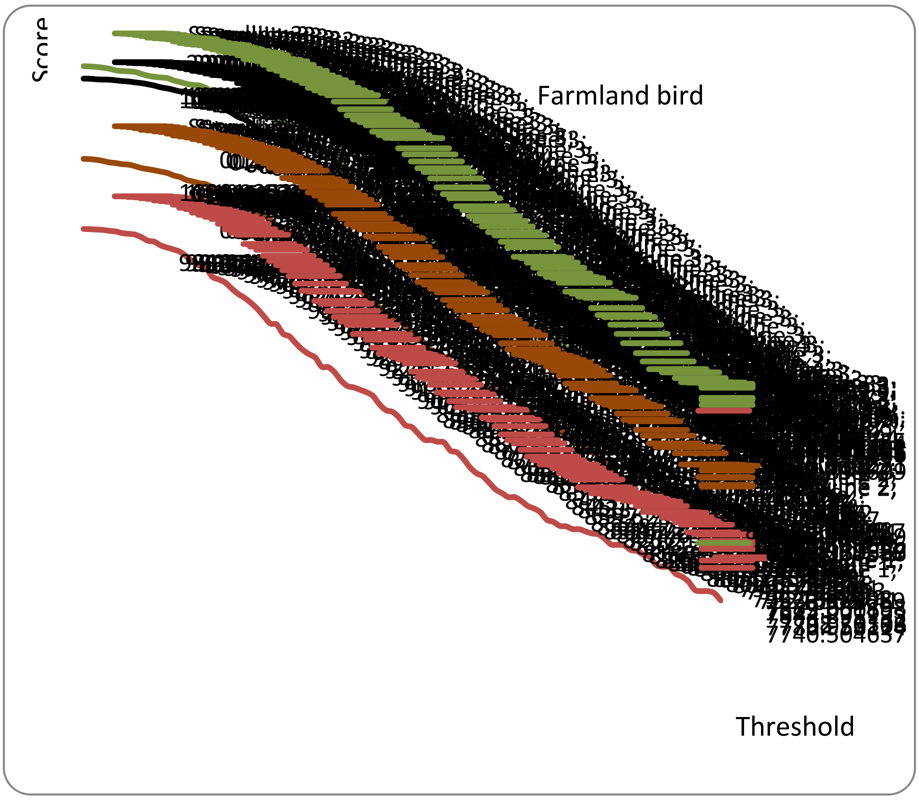
Step 2:
Weighting these figures with proportions of the habitat type in the agricultural landscapes yields status scores for NUTS 2 regions for 2004 and the three Storylines. Storyline 1 would lead to biodiversity losses compared to 2004. With Storyline 2, the loss is reduced a little. By contrast, implementation of Storyline 3 would lead to a slight farmland biodiversity improvement compared to the status of 2004.

Figure 1 *Flow statistic in farmland bird scores between 2004 and the three scenarios. No habitat threshold is applied at this stage.*



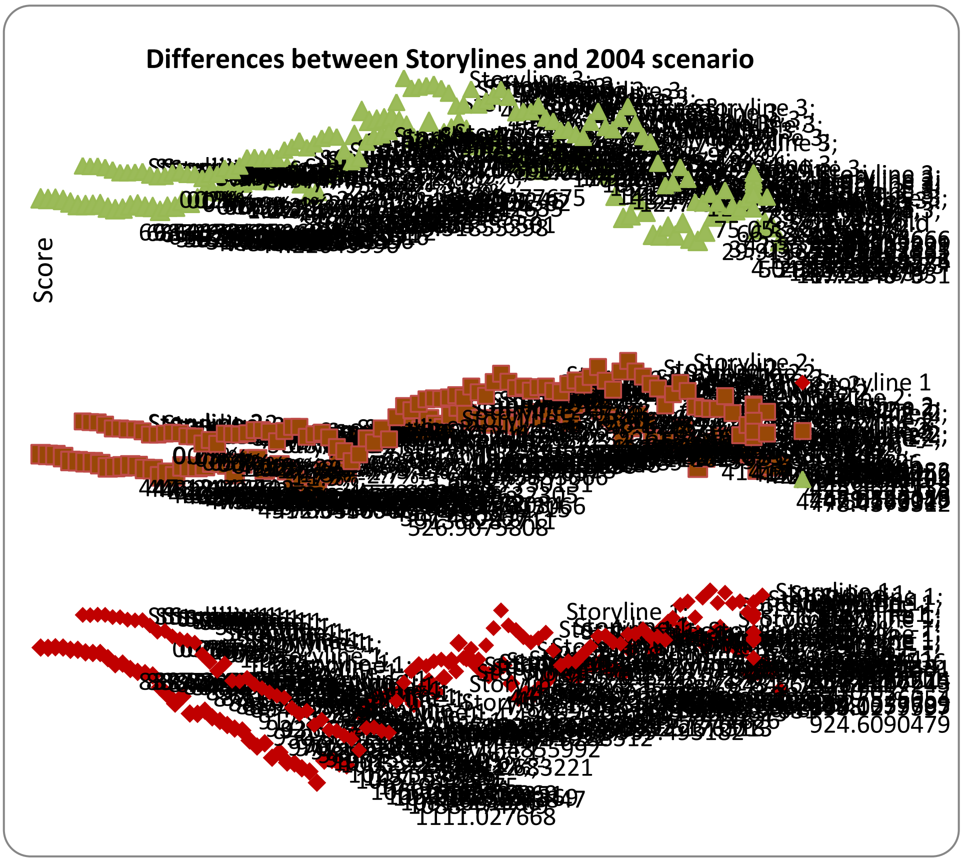
Step 3: Consideration of a habitat threshold.
If habitat area below a certain percentage of the agriculture is not considered useful for the farmland birds, then the farmland bird scores decrease with increasing threshold (Fig. 2). The ranking between Storylines (Storyline 3 better than status of 2004 better than Storyline 2 better than Storyline 1) remains unchanged across the range of threshold values, however, above a threshold of 7%, Storyline 3 is no longer an improvement over the baseline situation of 2004 (Figure 2).

Figure 2 *Progression of farmland bird scores with increasing threshold level.*



This can be further illustrated by plotting the differences of scores ("flow statistics") against threshold values. The largest differences of Storylines are observed at a threshold of about 4%. Between 4% and 8%, the potential of Storyline 3 in conserving farmland biodiversity is displayed more pronouncedly. If a threshold of > 8% is assumed, this advantage disappears again (Figure 3).

Figure 3 *Flow statistics (change of farmland biodiversity score compared to 2004 score) of the three Storylines plotted against threshold value.*



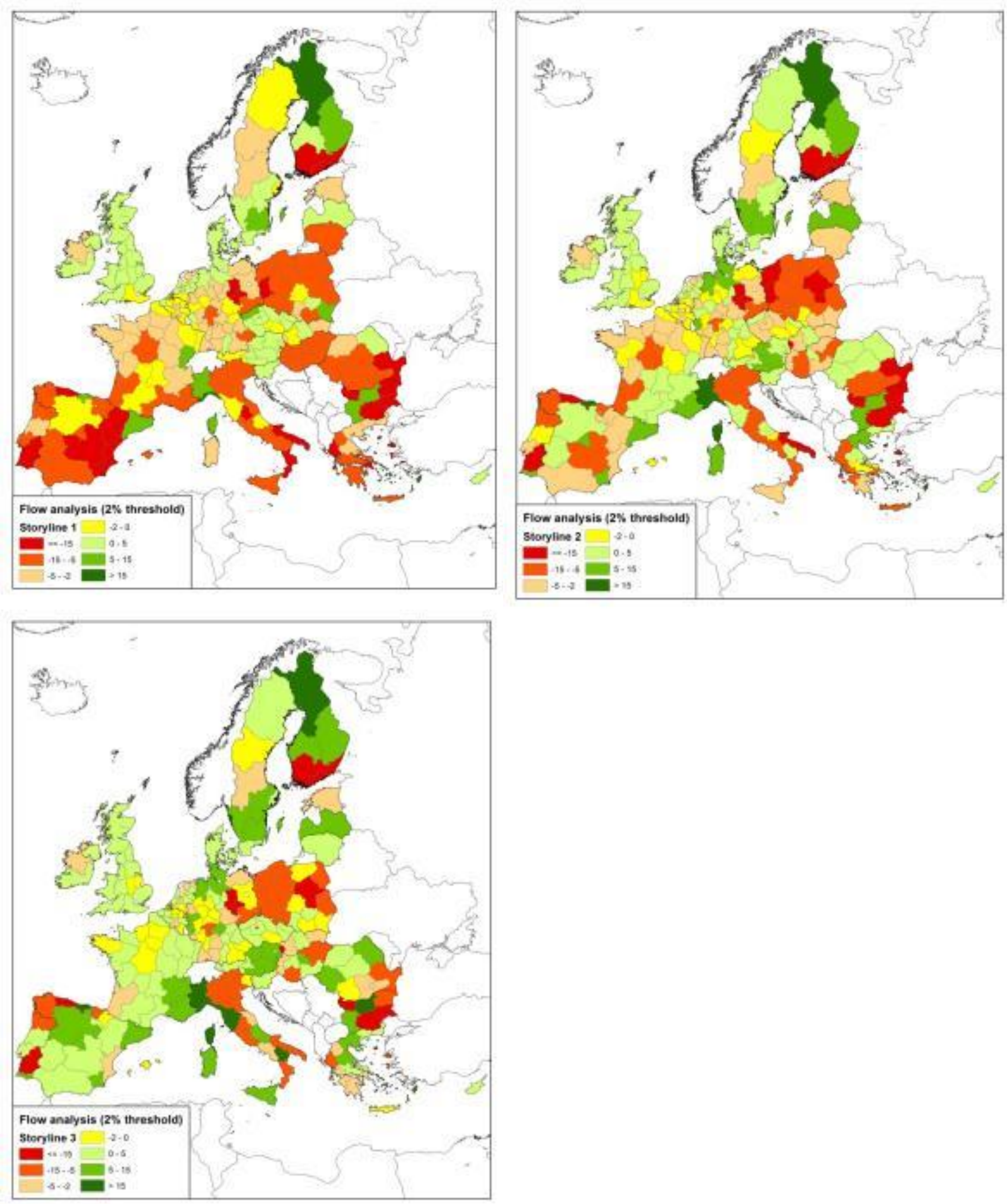
To inspect biodiversity change patterns across Europe in more detail, we assumed a 2% habitat proportion threshold in the following (see Figure 4) . With Storyline 1, substantial farmland bird losses may be expected in the Mediterranean countries pain, Portugal, Italy and Greece, but also in the Balkan countries Bulgaria, Romania and Hungary. Further countries of which the biodiversity is negatively affected are Lithuania, Estonia and Poland, losses are moderate in France, Sweden and Germany. In the other countries, farmland bird biodiversity shows on average a more or less neutral response to the land use changes modelled under Storyline 1.

Table 2*. Main explaining variables for the three scenarios at EU level*

	2004	Storyline 1	Storyline 2	Storyline 3
Area cropped (10^6 ha)	111.0	118.5	116.0	113.0
Of which:				
Perennial energy crops (106 ha)	*0*	*12.0*	*11.3*	*6.8*
Biofuel crops (106 ha)	*0*	*4.8*	*0*	*0*
Other crops (106 ha)	*111.0*	*101.7*	*104.7*	*106.2*
Area grassland (10^6 ha)	65.2	61.6	61.6	61.6
Area set-aside / fallow (10^6 ha)	10.6	7.8	9.7	12.2
Area abandoned (10^6 ha)	9.9	8.7	9.2	9.8

The largest losses identified under Storyline 1 are not surprising when looking at the main land use change situations in the 3 Storylines (see Table 2). In Storyline 1 the areas of abandoned, set-aside and fallow land are smallest, while the rotational crop area is largest. It should also be mentioned that in Storyline 1 no measures are taken to limit the demand for imported rotational biofuel crops, so additional biodiversity losses can be expected in third countries where agricultural production is stimulated due to the bioenergy demand in Europe. However, in the present analysis, these biodiversity changes are not accounted for.

Figure 4 *Declines (red) and improvements (green) in farmland bird biodiversity between 2004 and 2020 in Storyline 1, 2 and 3.*



Under Storyline 2 (climate first), farmland bird losses are more patchily distributed across Europe than under Storyline 1. Losses can be expected in parts of Spain, Italy, Bulgaria, Romania and Poland. However, in some NUTS 2 regions of these countries, Storyline 2 will lead to an improvement of the farmland bird status (Figure 4). Whereas large parts of Finland are positively influenced, the southern part might expect farmland bird losses under Storylines 2 and 1.

Under Storyline 3, farmland bird losses are restricted to a few NUTS 2 regions of Spain, Portugal. Italy, Bulgaria, Romania and Poland, but the majority of the NUTS 2 regions will be positively influenced (Figure 4). This again is not surprising given the much larger area of unused land in the categories fallow, set-aside and abandoned in this storyline (see Table 2).