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Space for energy crops – assessing the potential contribution to Europe's energy future

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Executive Summary

The use of land for further energy production in the EU has been the subject of considerable debate. Without much discussion of the evidence in this difficult area there seems to be a perception in some quarters that there is a great deal of currently underused land on European farms that could be mobilised quickly to produce biomass through the planting of energy crops. However the foundations for this assumption appear weak and are in need of further investigation.

This study focuses on the scope for additional production of energy crops in Europe (outside forests), the possible nature and scale of any 'spare' land and some of the sustainability issues associated with increasing output. Addressing these questions is particularly challenging because of the lack of up to date and specific data on most aspects of this subject. Much of the land use and cover data available for EU countries does not identify 'spare land' and is not designed to do so. It has been necessary to draw heavily on our own judgements and elements of the literature to identify the more promising categories of land that might be 'spare' and to assess their suitability for commercial energy production, at least in principle.

Certain categories of land have been ruled out of the analysis. These include land currently being used for crops or fodder production to avoid any conflicts with food production. Land that is under environment agreement on farms, eg buffer strips is also excluded. Our assessment focuses primarily on land that is currently within the official agricultural area (including some fallow land) and land that in the recent past has ceased to be cultivated (abandoned land) or has been unsuitable for cultivation (contaminated land). Excluding some of these areas mainly for agronomic and environmental reasons, we estimate that an order of magnitude of between 1 and 1.5 million hectares of land could be investigated further for energy crop cultivation. This figure may be on the high side in that it includes significant areas that are not identified easily in current agriculture or land use statistics.

Some of the areas would have significant environmental impacts. Cultivation of any semi-natural habitat (especially those listed under Annex I of the habitats Directive) by a dedicated bioenergy crop would result in significant biodiversity and probably carbon losses. Local or regional assessments would be needed in order to produce more robust area potential figures and in order to assess the specific environmental impacts from any new cultivation.

If all of this area were to be mobilised, it could generate 7.7 to 16.7 million dry tonnes of biomass per annum with an embedded energy content of between 139 and 300 Peta Joules of energy. When converted to useful energy, such as electricity or biofuels, total energy production would be lower due to unavoidable losses in conversion and extraction processes. To put these figures in context, if this additional biomass was used to produce biofuels, this would replace around 0.5 and one per cent of current EU road transport energy consumption. The most efficient energy use for this biomass would be achieved if it were reserved for dedicated heat applications, replacing just over five and 11 per cent of final sectoral heat energy consumption in the EU. In the context of total EU final energy consumption (across all sectors) in 2012 the contribution would amount to little more than 0.5 per cent irrespective of the conversion route adopted (ie biofuels, heat or electricity).

These figures indicate that the overall energy potential from dedicated energy crops on 'spare' land in Europe is low. While important contributions can be made to sectoral energy consumption, potential overall output looks modest even if the area cropped is larger than the level discussed in this paper.

Across the EU, land remains out of cultivation for a wide variety of reasons. These include economic and market forces; topographic, bioclimatic and edaphic considerations; contamination or pollution factors; and a variety of institutional factors. In most cases the question about why land is or is not likely to be in energy crop production is one of economics, ie can a suitable return on investment be made if energy crops are cultivated on such land and will individual land owners and managers make the decision to cultivate? Larger areas of land could be utilised for energy crops if production cost was not a consideration, and indeed there will always be cases of production in parts of Europe which are not economic in conventional terms, but other factors prevail, as occurs with livestock. But **if real world considerations apply it will not be cost-effective to establish commercial energy crops on areas where conditions are too unfavourable, water supplies are limited, or the distance to the processing plant is too far etc.** Cost concerns represent an important dimension of the constraints on utilising 'spare' land. Economic interventions or incentives on a significant scale can help to overcome some of these constraints. However, not all structural barriers will be surmountable within reasonable levels of intervention, for example where there are many small patches of unused land distributed over a wide area.

Before further steps are taken to incentivise or promote energy biomass cultivation on perceived 'spare' land:

- More should be done by national and EU institutions to provide up to date and accurate data, in particular that on land uses that fall outside of the main economic sectors, in order to base assessments and provide recommendations for robust policy making in this sphere. The majority of the data sources available at the pan-EU level lack the specificity, focus and rigour on which to determine accurately the numbers on which to base policy.
- This lack of information should not, however, be a reason to delay the development of policy in this area. Rather, policy makers should approach with caution claims around the availability of land for energy (and other) uses in Europe and bear in mind the need to set out appropriate environmental safeguards for the use of this land.
- Without further guidance and information, broad-brush incentives for additional energy crop cultivation at the EU level should be approached with care as they have a limited role in delivering a sustainable renewable energy future for Europe. There is a clear need for better guidance and information to guide the development of energy crops, avoid detrimental land use change and take into account local and site-specific conditions.
- The actual potential for and usefulness of energy crop cultivation in medium to long-term energy strategies needs to be assessed at the regional level. Such assessments should take into consideration the regional availability of different biomass resources as well as other forms of renewable energy in order to facilitate a more holistic assessment of potential renewable energy mixes.
- Energy crops are only part of a much wider spectrum of sources of biomass that need to be considered together in a wider frame embracing uses of bioresources beyond the energy sector as well as within it.

1 Introduction

Policies to support the use of bioenergy in the EU, in particular biofuels, historically have taken insufficient account of the need to reduce Greenhouse Gas (GHG) emissions and address broader environmental concerns. Whether or not it is appropriate or sustainable to use significant areas of land outside forests to produce energy has been the subject of considerable debate. Recently, the indirect land use change (ILUC) impacts of EU biofuel production and consumption (particularly from agricultural feedstocks) have become widely recognised, and land conversion for biofuel feedstock production is accepted generally to have environmental and social consequences. The European Commission's recent proposal to address ILUC in biofuel policy serves as recognition of this at the EU level.

The focus of this report is on the potential for further energy crop production from dedicated crops in Europe on land not already used for food production, forestry, or other uses of social value, including nature conservation. There is already production of crops for energy purposes in Europe, including oilseed rape for biodiesel but here the question in only how much additional production might be achieved, given the limitations in land availability that we have assumed.

In the broadest sense, energy crops cover a wide range from conventional food crops, such as oil seed rape through to short rotation coppice and new forestry plantations. Here we focus on agricultural energy crops, by which we mean crops that are grown exclusively or primarily for the purpose of producing biomass for energy purposes in an agricultural rather than a forestry context. These crops are for the most part unsuitable for consumption by human or animals. These include perennial energy grasses and short rotation coppice. Conventional food crops are excluded on the basis of their indirect land use change impact and competition for existing agricultural land. Woody biomass from forests or agricultural and forestry waste streams are covered in other studies[1].

Bioenergy policy is inherently cross-disciplinary touching upon agriculture, forestry and other land use policy areas. Understanding land use and land use statistics, as well as an effective evidence base, is essential to informed and appropriate policy making. It is, therefore, critical that questions surrounding the availability of appropriate land for this purpose in Europe and its potential to support sustainable energy crop production are addressed. These questions include: what is the sustainable potential for additional land based energy crops in Europe; how much bioenergy might this generate; why is this potential not yet being realised; and what criteria might need to be applied to ensure that this potential is mobilised in a sustainable way? Answering these questions is fundamental to informing the debate on the role of bioenergy in Europe's energy future and to help shape EU and national policies to deliver a sustainable outcome. This report seeks to address at least some of these questions, as far as is possible and to highlight gaps in the current evidence base that require further investigation.

[1] For woody biomass see IINAS *et al*, 2014; for agricultural, forestry and industrial wastes see Harrison, P (Ed) 2014.

There has been a range of studies over recent years that comment on the availability of land for energy production in Europe and elsewhere. These range from those attesting to the high potential for energy crops and the wealth of land on which they can be grown, to those that take a more conservative view. A common perception is that there is a great deal of currently underused land that could be mobilised quickly to produce biomass for energy through the planting of energy crops. However, a great deal of uncertainty remains around the quantity of this land, it's quality in terms of achieving suitable crop yields and whether or not its conversion to energy production is suitable or sustainable[2]. With renewable energy policy targets clearly set out in national law (and in many cases far from being met), and continued statements about the need for meeting an increasing food demand, one must ask the question why this potentially 'spare' land is not being used for some form of production currently.

To claim that no such land exists would be disingenuous. The overall agricultural area of the EU is declining and is expected to continue to do so (see Hart *et al*, 2013); farmland abandonment is a genuine phenomenon in a number of abandoned areas (see Alcántara Concepción *et al*, 2012; Keenleyside and Tucker, 2010); and some areas would benefit from increased or continued habitat management through certain types of farming practices. At least some of this land, which is in some sense out of productive use, could be made available for the cultivation of energy crops. Choosing whether this is appropriate or not becomes an issue that extends beyond the energy debate as increasing demand for biofuels and biomass is not the only factor putting pressure on land in the EU and globally. Continuing urban development, a growing area of woodland and the need for recreational space all play a role in the wider European land use dynamic (Hart *et al*, 2013; Allen *et al*, 2013). It is therefore important to see the role and value of these lands from a perspective broader than that of crop production. Abandoned or marginal land[3], for example, is not simply a dormant resource waiting to be used. These areas are often providing a range of benefits and services to society such as space for wildlife, carbon sequestration and recreational areas (see Hart *et al,* 2013). Where it is possible to cultivate or bring back into cultivation such areas, there are consequences that need to be addressed in order to present a balanced view of the sustainable potential for bioenergy from additional land in the EU.

1.1 Policy context

1.1.1 The status quo

Energy from biomass is promoted by current EU law, mainly in order to deliver Greenhouse Gas (GHG) emission savings, particularly, although not exclusively, through targets in the Renewable Energy Directive (RED)[4]. Two widely used energy biomass pathways are prominent: the production of transport biofuels, and the use of solid biomass to generate heat and power or to supply anaerobic digesters. The current economic conditions and the historical development of the biomass sector means that for the moment the majority of

[2] Ie whether other services being delivered from such land suffer as a result of cultivation, such as space for wildlife, regulating water flow, carbon sequestration or recreational space

[3] Definitions are provided later in the text

[4] (2009/28/EC)

renewable transport fuels comes from agricultural land in the form of liquid fuels[5], whereas the majority of energy biomass for heat and power comes from woody biomass from forests[6].

The current policy drivers would, if left unchanged, result largely in a continuation of the status quo, with the bulk of feedstocks used to deliver biofuels being sourced from agricultural land, whether comprising mainstream food crops, or non-food energy crops (including woody crops) and biomass for energy generation coming primarily from forests. Whilst there is a case for utilising wastes and residues to deliver bioenergy on a large scale (see for example Harrison (ed), 2014), dedicated land based biomass production remains the most likely source in current economic conditions (Box 1).

Box 1: Biofuels and land use

Between 2008 and 2010 the volume of biofuels consumed in the EU increased by 39 per cent, reaching 13 Mtoe and accounting for 4.27 per cent of total transport energy. The total area of land required to grow the feedstock needed in 2010 was 5.7 Mha. Of this, 3.2 Mha (57 per cent) was within the EU and 2.4 Mha (43 per cent) outside (Ecofys *et al*, 2013). Modelling studies that predict the expansion of cropland that would occur as a result of an unchanged EU biofuel policy show clearly that more land will be needed for crop production as a result of biofuel policy than would have been needed in the absence of the policy (Allen *et al*, 2013). For example a conservative estimate[7] of an additional 1.73 - 1.87 Mha of global cropland could be needed in 2020 in order to fulfil EU biofuel targets (Laborde, 2011)*. Out of this total global land use change, between 105,000 ha and 118,000 ha are predicted to be located within in the EU. In addition to this biofuel supply chain significant areas of land are being devoted to maize production to feed anaerobic digestion, production biogas, particularly in Germany.

Source: Own compilation **Notes:** *It should be noted that the figures quoted by Laborde (2011) relate to the additional global cropland area that would be required to meet EU biofuel targets. This should not be confused with the area of indirect land use change that is estimated to result from biofuel feedstock cultivation, which has been estimated to be much larger (see Bowyer *et al*, 2011)

Policy makers have begun to address the impact of land use change, both direct and indirect, associated with the use of conventional (food and feed) crops for conversion into biofuels. As the debate has progressed there has been an increasing perception that dedicated energy crops, which some argue can be grown on marginal and degraded land, offer one option to limit the impacts of displacing food and feed production from current farmland. Non-land using feedstocks such as agricultural, forestry or industrial wastes and residues are recognised also as having a potential role to play in Europe's energy future. Yet even certain non-land-using feedstocks, such as agricultural or forestry residues, may require land resources in some form or another for the production process, with seasonality and temporal variations in their production necessitating the introduction of 'support crops', which would include energy crops, to improve the economic viability of the energy conversion process. The sustainability of using energy crops in this way, the potential scale of their 'support' role and how this might be regulated remain unclear.

[5] Just under 99 per cent of biofuels currently used in EU road transport come primarily from food and feed crops (Allen *et* al, 2013)

[6] It should be noted that with advanced conversion technologies there is potential for any biomass type to be used to generate liquid fuels as much as they might be used for producing heat and power.

[7] This estimate includes generous and positive yield increases as well as continuing and favourable trade balances.

There are certainly consequences that need to be considered in relation to additional crop production. Crop production requires resources such as soil, nutrients and water, but more importantly land and energy. If not done so sustainably, or sited appropriately, growing crops for biomass to meet renewable energy demands could have direct or indirect land use change impacts resulting in potential additional GHG emissions, as well as wider impacts on ecosystem services, like carbon sequestration, and biodiversity (see for example Searchinger *et al*, 2008)

1.1.2 To 2020

Under current renewable energy policy there are some guiding sustainability criteria that govern the production of some, but importantly not all, forms of bioenergy. The implementation of Article 17 of the Renewable Energy Directive (RED) in 2009 saw the establishment of sustainability criteria for biofuels and bioliquids as well as minimum thresholds for lifecycle greenhouse gas savings. However, no criteria were put forward for solid and gaseous biomass[8] used to generate electricity or for heating and cooling.

In 2012, the European Commission took the sustainability criteria for biofuels one step further and issued a proposal[9] to the European Parliament and the Council to amend the RED and the Fuel Quality Directive (FQD) in order to take account of indirect land use change[10]. For biofuels used for transport both the Commission's proposal and the Parliament's agreed position[11] treat energy crops differently: the Parliament's text would include a six per cent cap on biofuels from land-using crops, both conventional and non-food energy crops; whereas the Commission's text would only cap the use of conventional food and feed crops, thereby allowing an expansion of energy crop use[12].

In 2012, evidence emerged suggesting a need for more thorough consideration of the sustainability of solid and gaseous biomass (eg Angostini *et* al, 2013; Bowyer *et* al, 2012), particularly as Member States intend to meet two thirds of their 2020 renewable energy targets from such sources[13]. In spring of 2013, draft sustainability criteria for solid and gaseous biomass were presented to Member State representatives and leaked to the press[14]. An amended text was expected to be adopted by the Commission towards the end of 2013. However, no formal proposals have yet been released and there remain no EU sustainability criteria for solid and gaseous biomass.

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[8] This term refers to the biomass used to generate heat and electricity, as opposed to transport biofuels. Solid refers to the use of biomass such as wood pellets whereas gaseous refers to the production of biogas from biomass.

[9] Proposal COM(2012) 595 final of 17.10.2012 for a Directive of the European Parliament and of the Council amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources.

[10] The Parliament agreed a position on the text (European Parliament, 2013) but the Council is yet to form an opinion on the file.

[11] The European Council is yet to adopt a position.

[12] The Commission approach would not only allow expansion in energy crop use but also enable advanced fuels produced from them to count additionally towards the 10 per cent volume target in 2020.

[13] For example the UK now produces 38 per cent of its renewable electricity from biomass (DECC, 2013).

[14] European Commission (2013) Proposal for a Directive of the European Parliament and of the Council on sustainability criteria for solid and gaseous biomass used in electricity and/or heating and cooling and biomethane injected into the natural gas network [http://www.endseurope.com/docs/130819a.pdf].

1.1.3 Beyond 2020

Beyond 2020 the policy landscape surrounding biofuels and bioenergy could change dramatically. On 22 January 2014, the European Commission set out its vision for EU climate and energy policy up to 2030 (European Commission, 2014) proposing significant changes from the current *status quo* (IEEP, 2014). Two elements of this proposal are important here. First, the Commission envisages no 'public support' for biofuels produced from food-based feedstocks, and no longer foresees any transport specific targets for renewables post 2020[15]. This may, depending on how it would be implemented, offer an opportunity for non-food dedicated energy crops to expand in area. Second, the proposal would remove the national level of implementation of renewable energy targets. The full implications of such a move are still being debated: one outcome would be a reduction in motivation for Member States to produce liquid biofuels, but a greater incentive to generate renewable energy from biomass. This could come from dedicated energy crop production.

The Commission's impact assessment (IA)[16] accompanying the 2030 climate and energy package suggests a significant energy potential that could come from bioenergy sources. Some caution is needed when interpreting these numbers, as the IA uses modelling approaches to estimate the future land area concerned, and thus biomass potentials. Notably, the IA assumes large areas of perennial cropping (including plantation wood), from seven to twelve million hectares in 2030 depending on the scenario. This additional area is modelled to come from a reduction of cropland for other crops in 2030 compared to 2005 of two to five million hectares depending on the scenario and importantly a reduction in what is classified as 'other natural vegetation' of 13 to 15 million hectares[17]. While 'other natural vegetation' is not further defined in the IA, this suggests huge negative environmental impacts if such vast areas of land under semi-natural habitats were indeed converted. The estimates of sustainably available land considered in the current report are derived from the existing land use pattern and should not be compared directly to future estimates. However, our estimate of potentially sustainably available land clearly falls short of the scale required according to the IA, and one must question the environmental impact that would result if such significant areas were converted to energy biomass production.

The extent, economic and environmental viability of 'available' land have yet to be investigated comprehensively. Despite this, policy decisions are being influenced by the perception that substantial amounts of this land might indeed exist and be available within a relatively short period of time. With the main aim of renewable energy policy being to reduce GHG emissions, the questions to be answered are where, if anywhere, is there space to use land for dedicated biomass production, will this result in increased GHG emissions, and what are the sustainability considerations that need to be taken into account?

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[15] A point further reinforced by recent State Aid guidelines for renewable energy - http://ec.europa.eu/competition/sectors/energy/eeag_en.pdf .

[16] http://ec.europa.eu/clima/policies/2030/docs/swd_2014_xxx_en.pdf

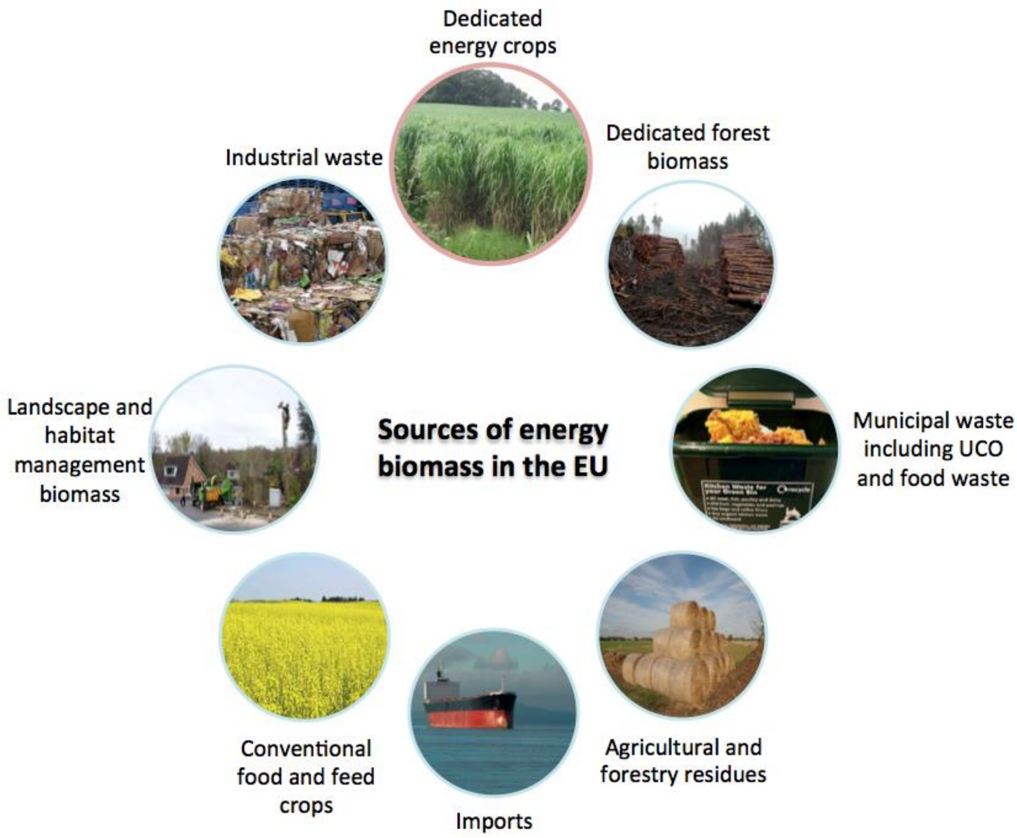
[17] Forest land sees an increase of eight million hectares in 2030 compared to 2005 and a two million hectare increase is modelled for 'Wetlands, settlements, other land'.

1.2 Biomass for energy

There is a range of different biomass sources used for energy in the EU currently. These include industrial wastes, such as tall oil pitch and wood chippings, food and feed crops, and dedicated forestry biomass (Figure 1). The focus of this report is on dedicated energy crops

Dedicated energy crops are defined here as *crops that are unsuitable for human or animal consumption and are grown exclusively or primarily for the purpose of producing biomass for energy purposes in an agricultural rather than a forestry context.* Nearly all of the crops considered within this definition are perennial in nature, ie they can be cut and harvested for biomass over successive years without re-cultivation or sowing. The whole crop can be harvested and used for energy production. Two broad types of energy crops are considered, perennial agricultural crops and short rotation coppice (Table 1).

Figure 1: Sources of energy biomass in the EU



Source: Own compilation **Notes:** UCO = Used Cooking Oil

Table 1: Categories of energy crops considered in this study

Category	Definition	Examples
Perennial agricultural crops (Herbaceous grasses)	Perennial crops are crops that can be harvested on average once a year over several years without the need for ploughing up and new planting. Perennial energy crops of interest are mainly herbaceous grasses.	Miscanthus, switchgrass, reed canary grass, giant reed, perennial rye grass (*Lolium perenne*)
Short rotation coppice (SRC)	SRC refers to plants and trees that are harvested by cutting the growing stem to its base, allowing the growth of new stems.	Willow (*Salix sp.)*, Poplar (*Populus sp.*)

Source: Own compilation based on http://www.biomassenergycentre.org.uk.

1.2.1 Short rotation forestry

This report is concerned primarily with land that is or has recently been under agricultural management. Energy crops with more regular harvests such as *Miscanthus*, which is harvested annually, are the kind of species more likely to be grown on such land, and much easier to change in response to differing market signals and prices. Crops with longer rotation periods, such as short rotation forestry (SRF) are likely to be less widely used on such land, as they require investment periods of between eight and 20 years before harvesting, with less flexibility to react to changing markets.

Unlike short rotation coppice (SRC), SRF refers to the whole felling of trees, often at a size of 10-20 cm diameter at breast height. Tree species used in SRF are usually fast growing and include Eucalyptus, *Nothofagus* (southern Beech), Poplar, Sycamore and Ash. Appropriate siting of some short rotation forest species, where they are native and in keeping with local species distributions, can have some environmental benefits, including acting as shelterbelts, helping to prevent erosion of soils, and in providing habitat for some species. However, it is unlikely that SRF would be planted on all of the land areas considered in the study (see section 2), focusing perhaps on contaminated land where they can aid in remediation activities, or some areas of recently abandoned agricultural land. It is unlikely that SRF would be planted on any scale on fallow areas, or in any significant scale within the current cropland area.

The production of woody biomass from forests, including SRF is outside our working definition of energy crops and is covered in a companion report (IINAS *et al*, 2014) rather than in this study. Nonetheless, the yield and energy potentials from SRF are comparable with that of the energy crops that we do consider (Box 2). Therefore the overall energy potential estimates represented in this study would not change in any significant way if all or part of the land area was subject to SRF planting rather than other energy crops. Deliberate afforestation of agricultural land for commercial forestry operations is not covered in this report.

Box 2: Estimates of SRF biomass yields

A brief review of SRF yield estimates available in the literature suggest a high degree of overlap between our assumed range for energy crop yields in this study of 4.7 to 11.5 dry tonnes per hectare and year for abandoned and contaminated land (see Section 4). Average SRF yields are sometimes even below the assumed range of 11.5 to 17.25 dry tonnes per hectare and year from energy crops on fallow land.

Eppler and Petersen (2007) have compiled literature of yields for various SRF species that range between 5.0 and 9.0 dry tonnes per hectare and year. Another report cites SRF yields for Poland of 20t/ha/year in optimal conditions down to around 15t/ha/yr on average land (Mosiej *et al*, 2012). An FAO report cites yields for Finland of Sweden of below 10t/ha/yr (Christersson and Verma, undated). Searle and Malins (2014) covered eucalyptus yields in their recent review, which we draw on here.

Source: Own compilation

2 Land with potential to produce additional energy biomass in Europe

This section considers the types of land with potential for additional energy crop cultivation in the EU and provides an estimate of the areas of such land types that could potentially be brought into cultivation.

The land use and cover distribution in the EU is diverse. Over 95 per cent (409Mha) of the EU land area is rural land, with forests (38 per cent, 165Mha), cropland (25 per cent, 107Mha) and grassland (20 per cent, 84Mha) the main components. However, land is subject to ever changing dynamic processes driven by a range of economic, policy and social drivers. As such, land use and cover are in a constant state of flux. Understanding the land use dynamic requires accounting for many interrelated and contingent factors. These range from the minutiae of sectoral land classification through to the motivation of individual land managers and an understanding of the topographic and bioclimatic variations across the EU. Only a part of this picture can be gained by looking at the statistical information recorded at the EU level which is designed for purposes different to the one we are pursuing here.

2.1 Rationale for a categorisation of land areas

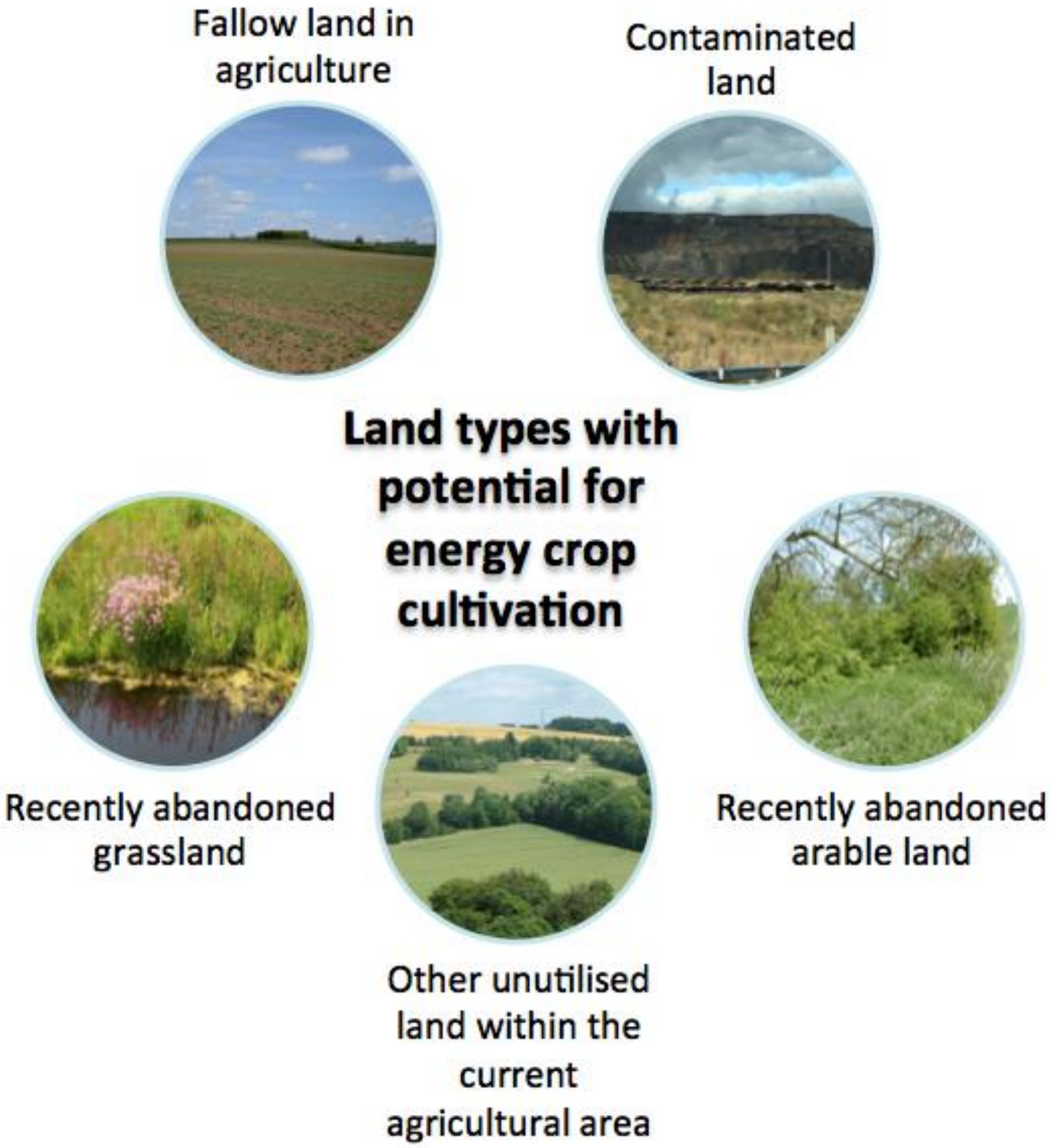
The rationale set out in this study for categorising land with potential for additional cultivation of energy crops in the EU uses the following logic. At the conceptual level, three criteria can be used to define where energy crop cultivation on land additional to the current area of cultivation might potentially be sustainable and could contribute to GHG reduction objectives. Over and above local, site specific considerations, their production as a whole:

- Should not displace food production within the current agricultural area;
- Insofar as it involves an expansion of the current arable area, as it will, it must do so with the minimum of negative impacts on the environment (including ILUC), preferably by addressing first that land which was under recent arable use; and
- Any crop production must satisfy as a minimum the conditions set out under Article 17 (3) – (6) of the RED. These are: the protection of land with high biodiversity value, high carbon stock land; land that was formerly peatland; and must respect rules governing the receipt of support through the Common Agricultural Policy. In the current RED, these criteria only apply to biofuels, but are used here in the broader context of all energy biomass covered in this report.

It is worth noting that operationalising these criteria in practice is not straightforward, and with the exception of the RED sustainability criteria, they are not established in EU or national law. They are used here purely as a guide to help rule out types of land and areas that would, if cultivated, lead to environmental impacts.

The application of these criteria to current land use information would narrow considerably the potential for deploying additional land for energy crop production. However, to apply the criteria properly would entail a level of information about land use and land management, which is not available within the EU. For this reason, a set of categories of agricultural or recently agricultural land has been defined on which to base the assessment in this study (see Figure 2 and Table 2).

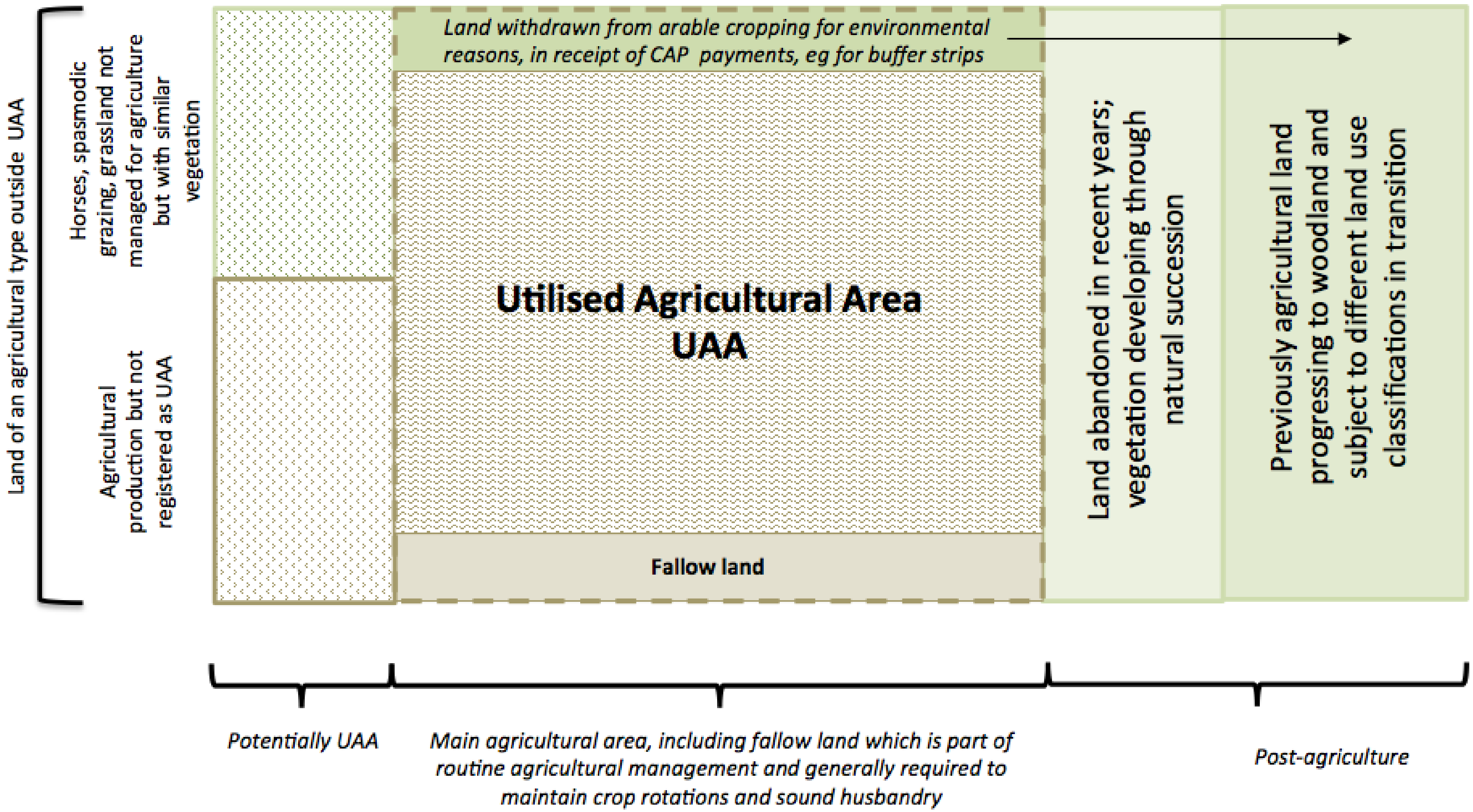
Figure 2: Land with potential to produce energy biomass



Source: Own compilation

Areas where energy crops can be produced sustainably in this sense will be within two broad groups; a) land that is used currently to produce agricultural commodities (including some fallow land), and b) a proportion of land that in the recent past has ceased to be cultivated (abandoned land) or has been unavailable or unsuitable for cultivation for specific reasons (contaminated land) (Figure 3).

Figure 3: Visualising agricultural land use transitions



Source: Own Compilation

Within these areas:

- Discussion of 'spare' land with production potential for energy crops tends to focus on those areas of agricultural land that are left **fallow** for all or at least part of one year. There are many reasons for this, reflecting the variety of agronomic, socio-economic, ecological and policy conditions in Europe that influence land management. For example, dry-land arable cropping in large parts of central Spain requires relatively large scale fallow in order to maintain soil fertility at a reasonable cost and ensure water is used sustainably. This is different from arable land that was **set aside** in recent years as a result of policy drivers. For several years prior to 2008, EU policy under the CAP required between eight and ten per cent of arable areas on certain larger arable farms to be 'set-aside'. It was, however, permissible to grow 'industrial crops', in practice mainly oilseed rape, in certain circumstances on this land. Such crops had to be dedicated for non-food use. Since 2008 and the abolition of set-aside policy, these **former set-aside** areas have been absorbed into a variety of agricultural or other uses which are difficult to quantify but include fallow, productive arable and other areas. 'Fallow land' as a broad term is reasonably well recorded in agricultural statistics.
- A significant proportion of land classed as fallow and broadly within an arable rotation is untapped because this is part of conventional good agricultural practice. Alongside this, there are areas that are kept fallow because of agri-environment policy in various forms. For example these include buffer strips, alongside watercourses, hedges and sensitive habitats. Voluntary agri-environment incentive schemes involving payments to farmers apply on some of this land. In other cases buffer strips, or alternative forms of fallow, are required of farmers as a condition of receiving direct support. Under the new Common Agricultural Policy (CAP), additional areas of arable land can be expected to fall within this category with the introduction of Ecological Focus Areas (EFAs) which will need to be established on a significant number of farms. These areas are to be maintained under agricultural practices beneficial for climate and the environment, such as the presence of fallow land, certain landscape features[18], and some limited crops. The introduction of EFAs can be expected to increase the overall area of 'policy driven' fallow with clear environmental objectives. These areas are not fully accounted for in statistical sources but they should not be considered, for agronomic or environmental reasons, as having significant potential for energy crop cultivation. One exception is that SRC will be a permitted use of EFAs under certain rules. The take up of this option is hard to predict.
- There are some areas of previously arable land that are no longer used as part of a crop rotation and have been withdrawn either in part or entirely from cultivation. Leaving aside an unknown proportion that has become pasture not utilised by livestock these areas include **abandoned** agricultural land, that is particularly challenging to identify and not recorded in any current European level statistics.

The lack of data allowing the identification of relatively precise categories of land that are of interest here in relation to energy crops is a severe impediment to pinpointing either its location or its total extent with any accuracy. Consequently, estimates are unavoidable.

[18] such as hedgerows, trees and ditches.

Furthermore, some of the data that is available is difficult to explain coherently, provides only a partial picture of the EU land resource[19] and appears to include anomalies within widely used pan-European datasets. The following analysis sets out our interpretation of the available information, and in lieu of better data, takes a pragmatic[20] view of the potential land areas suitable for future cultivation.

2.2 Identifying relevant categories and areas of land

2.2.1 Former set-aside and Fallow

Former **set-aside:** set-aside was a policy mechanism implemented under the Common Agricultural Policy (CAP) as a production control measure at a time of high levels of cereal production. Implemented initially in 1988 (Regulation (EEC) 1272/88) it became compulsory for larger producers in 1992. The term, if taken literally, means to set to one side a proportion of arable land and leave it uncultivated for a period of time. The logic being that this cessation of cultivation would reduce agricultural output and thereby help to reduce food surpluses at the time[21]. *Set-aside* was abolished officially in 2008 following the CAP 'Health Check' reforms and no longer applies to production in the EU. Former set-aside land now is under a range of different forms of management, either having been brought into cultivation, maintained as part of a fallow rotation, retained as long-term fallow connected to grassland or other uses, withdrawn from agriculture, or abandoned. Arable land can no longer be called 'set-aside' from a policy perspective, and set-aside has stopped being recorded in the European agricultural statistics.

In 2008 the abolition of set-aside policy meant that around eight million hectares of former set-aside land re-entered the agricultural mainstream, mainly the cropped area. Part of it, including large areas in the eastern Länder of Germany, was being utilised for industrial crop production and is likely to have remained in such production, eg of oilseed rape. The remainder effectively became available for cultivation. The precise response of farmers across Europe to the change in policy is unclear. Some chose to recultivate their land almost immediately. However, it is clear that in other cases some land that was set aside under the policy (largely the 'permanent' rather than the rotational variant of set-aside) will have remained out of cultivation, despite crop price increases at the time (Statisches Bundesamt, 2013; pers comm, R Oppermann; Szczerbiak (2012); FAO, 2003; Defra ACEO, 2009). Some examples of set-aside 'transitions' to different uses can be found in Annex 1. Since the abolition of set aside policy, the total recorded area of arable and fallow land has continued to decline[22], suggesting that some of this decrease occurred on the land that former set-aside once occupied. It would be helpful to know the proportion of the remaining areas of former set-aside, which now comprises the declared current fallow area. However, this would require relatively detailed regional level historic trend data and is unfortunately beyond the scope of this assessment.

[19] As in the case of survey based assessments

[20] Meaning that where estimates have been necessary we have looked at various studies on this topic, drawn on our own experience and allowed for land areas that are simply not present or visible in current land use statistics.

[21] As noted above, some Member States permitted the cultivation of energy crops on set-aside land.

[22] As has the area of utilised agricultural land (UAA)

Fallow is a term that can cause confusion; fallow describes agricultural land that has been left uncultivated as part of a crop rotation. Some versions of fallow involved cultivation of a non-commercial crop designed purely for building soil fertility. *This should not be confused with 'abandoned' agricultural land.* The following process can include leaving land uncultivated for one year as part of a short rotation or leaving land uncultivated for multiple years. Fallowing of land helps to rebuild soil fertility, prevent the accumulation of pests and diseases in crops and can provide certain environmental benefits, particularly where the land remains covered by some form of vegetation. Fallow land is not cropped but nor is it abandoned as it is still within the productive agricultural cycle. The formal EU Farm Structure Survey definition of fallow land is set out in Box 3. Other terms used sometimes to describe fallow land include 'idle' land.

Box 3: Definition of fallow land as set out in Council Regulation 543/2009

All arable land included in the crop rotation system, whether worked or not, but with no intention to produce a harvest for the duration of a crop year. The essential characteristic of fallow land is that it is left to recover, normally for the whole of a crop year. Fallow land may be:

- bare land bearing no crops at all;
- land with spontaneous natural growth, which may be used as feed or ploughed in;
- land sown exclusively for the production of green manure (green fallow).

All areas of arable land maintained in good agricultural and environmental conditions as set out in Article 5 of the Council Regulation (EC) No 1782/2003 or, where applicable, in the most recent legislation, whether or not they are part of the crop rotation, are included.

Source: Council Regulation 543/2009

Around 7.4 million hectares of EU agricultural land was recorded as 'fallow' in EU statistics in 2012. Although this area appears to be large, it is far from evenly distributed. The EU average fallow as a proportion of overall arable land is six per cent, ranging from less than one per cent in Ireland to 28 per cent in Portugal. Three distinct country groups have higher than average proportions of fallow. Five Mediterranean Member States[23] have over ten per cent of their arable land recorded as fallow, ranging from ten per cent in Greece up to over 27 per cent in Spain and Portugal. The two Scandinavian Member States of Sweden and Finland, which have relatively low areas of arable land, have six and 12 per cent fallow respectively. Finally, two of the newer Central and Eastern European Member States, Romania and Estonia have around eight per cent each. In absolute terms over 75 per cent of all fallow land in the EU can be found in just five countries[24], with Spain accounting for 46 per cent of all fallow, and 30 per cent of all fallow found in the central region of Spain[25] where it is a well-established part of traditional crop rotations adapted to the low local rainfall. The agronomic need for fallow is often greater in more arid areas.

The distribution of fallow land in the EU is a function of agro-ecological and historical conditions and trends across Member States. Estimating how much of the current fallow area could be considered in some sense 'spare' rather than agronomically desirable and thus suitable for energy crop cultivation is challenging. Even if we assume that the scope for planting on fallow is greatest in countries which now have above average fallow (which may not be the case), the areas which seem likely to become both available and suitable for the

[23] Portugal, Spain, Cyprus, Malta and Greece
[24] Spain, (46%), Romania (10%), France (6.8%), Italy (6.4%) and Poland (5.9%)
[25] When viewed in relation to arable crops in the same year, Portugal (28%), Spain (27%) and Cyprus (19%) have the largest proportions.

production of high yielding crops seem unlikely to be large. For example, if the EU average fallow area (six per cent) became the normal proportion for those Member States with currently higher than average fallow areas, and where agro-ecological constraints, such as severe drought conditions in Spain, are lower, a new area could be realised, in principle, for crop production. If this were to be the case, a rounded figure of approximately 200,000 ha of fallow land could be considered in some sense 'spare'. However, such a change in cropping may be in no sense desirable from an ecological, agronomic, or environmental point of view, as discussed further in Section 3. With fallow land ranging from less than one per cent up to 28 per cent across the EU, determining an economically and agro-ecologically suitable level is impractical without extensive research. It should be recognised also that with the continuing decline of many farmland biodiversity species in the EU[26], fallow land on many farms might be insufficient at current levels to help curb such declines. The 200,000 ha figure should therefore not be seen as an estimate of potential land per se, but more as a marker to identify that some fallow land in the EU could be considered as having potential for energy crop cultivation. In reality, this figure may be lower or even higher but without further information, a greater level of accuracy cannot be achieved.

2.2.2 Abandoned agricultural land

Abandoned: abandonment of agricultural land describes a complex process of reduced farming activity over a continuum ranging from land that is temporarily unused (overlapping here with fallow or former compulsory set-aside) to land that is entirely abandoned for production, and management is withdrawn completely. Three distinct categories are identified by Keenleyside and Tucker (2010):

- *Transitional abandonment* has been observed particularly in Central and Eastern Europe as a result of restructuring and land reforms, and in other Member States as a result of compulsory set-aside, until this was abolished in 2008, or as a result of land use change. Transitional abandonment can be seen also in areas that are economically marginal in production terms. These areas can move in and out of agricultural use depending on market prices for certain commodities.
- *Semi-abandonment or hidden abandonment:* Where the land is used by the farmer but with a very low level of management. The land is not formally abandoned and is subject to some form of management, which might be simply to keep it available for future use, for example for recreation and tourism. Such land may also be subject to the minimum management necessary to meet cross-compliance requirements by those claiming direct payments under the CAP. Very extensive or intermittent farming operations may also fall into this category, not least on semi-subsistence farms and in dry and more mountainous areas, including those characterised as High Nature Value (HNV) farming. Such extensive farming is generally associated with very low or zero direct economic returns, but may be continued for personal or social reasons, to support other farm income streams, for example from hunting and tourism, or for nature and landscape conservation (or simply to maintain a long term family investment).
- *Actual abandonment:* Where the farmland is not used at all. The vegetation may change through natural succession into tall herb, bush and forest ecosystems after a period, depending on climatic and soil conditions. On rich and wet soils the outcome is likely to

[26] Many species associated with agricultural land are continuing to decline, and many habitats remain in unfavourable conservation status, with figures varying across bioclimatic regions (ETC/BD, 2006).

be forest ecosystems but, in contrast, on poor dry soils in southeast Europe, it can be ‘steppe-like’ grassland vegetation that is able to survive for many years without any active management such as mowing or grazing.

Abandonment is only one of the reasons why the declared area of agricultural land use is decreasing. There is also significant afforestation of agricultural land, steady growth in urban, recreational, and infrastructure areas as well as other changes taking place.

There are various causes of actual farmland abandonment in Europe including: geographic, ecological and agronomic factors; demographic and socio-economic drivers; the impact of policy; institutional factors; and, historic circumstances, especially in new Member States. These influences differ between European regions. Farmland abandonment often results from a combination of these factors, with one predominating over the others (Terres and Nisini, 2013; Alcántara Concepción *et al,* 2012; Moravec and Zemeckis, 2007; Pointereau *et al,* 2007). The category of most relevance to this study is the abandonment of agricultural land that leads to the encroachment of semi-natural vegetation. This is different from planned changes in land use, for example for urbanisation or the establishment of forestry which generally makes the land unsuitable for energy crops.

2.2.3 Abandoned cropland and temporary grassland

Between 2000 and 2006, agricultural land use in the EU decreased by around 700,000 ha (as defined by the Corine land cover data nomenclature which is satellite based and which excludes permanent grassland and moorland grazing areas). Over this period, land use change data from this source for certain agricultural land types[27] suggest that the explanatory factors include urban expansion (68 per cent) and the development of scrubby vegetation communities (24 per cent) (see also EEA, 2010). Some of this vegetation growth will arise from temporary or permanent abandonment, some from deliberate forestation. The scale of land abandonment and the precise areas affected are difficult to determine. Within this timeframe, only some of the land passing out of agricultural use could realistically be brought back into agricultural production, eg for energy crops. Some changes, such as urban encroachment are semi-permanent with the land being lost from cultivation entirely. Other changes, such as the encroachment of transitional woodland scrub or other semi-natural vegetation following farming withdrawal could in principle be more easily reversed in the short term if this is desirable, although often at considerable cost. Over this six-year period, it is estimated that around 168,000 ha of certain agricultural land types has been lost to these non-agricultural land uses (see Annex 2).

Whether or not these areas could be brought back into production depends on specific local circumstances, such as ownership of the land, access, potential productivity, size of the plot, the scale of incentives available, etc. More generally it is a question of overcoming the reasons for the decline in management. In some cases these might be economic or social factors, which might respond well to market signals, such as local investment in bioenergy production. In other cases, terrain and soil constraints may pose more significant barriers, making crop production economic only in the most positive of markets. Based on indicators

[27] Including primarily cropland and improved pasture but excluding natural grasslands, moorlands and much of the extensive grazing areas of the EU.

of farmland abandonment risk (see JRC, 2013 and Annex 2), it is estimated that approximately 113,000 ha of land that has come out of agricultural production has been as a result largely of economic or social factors, and the remaining 52,000 ha as a result of severe terrain and soil constraints. However, these figures refer to the position in 2006, before food commodity price spikes in 2007 and 2008, and the implementation of major policy changes such as the abolition of set-aside policy (2007-2008) and the implementation in 2009 of the Renewable Energy Directive. No comparable recent land use change data is available to assess further potential farmland abandonment or its reversal in the EU.

The only reliable statistical information on which to hazard broader conclusions on more recent reported changes is the change in overall Utilised Agricultural Area (UAA) across the EU which draws on data provided by governments. Between 2006 and 2012 there was an overall reported decrease of 5.7 million hectares of UAA but with no pan-European land use change data yet available for this period it is unclear precisely what is being reflected in the UAA data, including those changes that have occurred. Nor is it clear where these changes have taken place and what land uses have grown as the UAA has declined. According to the more recent survey, based on LUCAS 2012 land cover data and which may provide a good signpost to actual change, urban areas have continued to increase significantly by nearly two million hectares and woodland has increased by a dramatic 11.4 million hectares (between 2009 and 2012). All other land cover types[28] have seen a decrease at the EU level, although with significant variation between Member States. Further extrapolation from these data would imply a level of confidence well beyond that which can be assumed from the data. Therefore, we have made a more pragmatic assessment of recent land use and *assumed* that the land use trends seen between 2000 and 2006 have continued at the same rate suggesting an overall area of fairly recently abandoned cropland in the EU in 2012 (which might support commercial energy crop production) equating to a similar figure of around **200,000ha.**

2.2.4 Abandoned grassland

It should be noted that due to the land use classification used in the satellite based Corine data some areas of agricultural land, particularly grazed grassland and moorland areas are not covered under the 'agricultural' classification. These areas are known to be more at risk of abandonment than others and need to be considered here, but are very difficult to identify clearly within EU land use and cover statistics. Here, we rely on recent grassland land cover transitions seen in the LUCAS 2012 dataset, not all of which will be under agricultural use, as a source on which to base some estimates. The LUCAS data suggests that around 1.2 million hectares of grassland have been lost since 2009 in the EU 27. Not all of this would have been under agricultural management and some will have been lost to urbanisation and deliberate afforestation, as well as through the reduction in management and abandonment. Some will have been converted to cropland. Without any further breakdown of the data or means of calculating what proportion of agriculturally used grassland has been lost, it is necessary to simply estimate an area.

[28] Cropland, grassland, shrubland, bare land and water.

In order to provide some guide to this estimate, we can consider the proportion of LUCAS grassland in 2009[29] that was in use for agricultural purposes. For 2009, LUCAS records that approximately 76 per cent of all grassland in the survey[30] was under some form of agricultural use[31]. If we assume that the decrease in grassland area between 2009 and 2012 took place proportionally across all potential grassland uses, we can extrapolate that 912,000 ha of grassland may have transitioned out of agricultural use between 2009 and 2012. Of course some of this will have been converted into cropland, and thus retained in agricultural use under a different land cover heading. With the data available it is not possible to identify this proportion. In this case, it is assumed that approximately one third of the reduction in grassland area has been converted to cropland of some form, and that the remaining ~600,000 ha has been lost from conventional agricultural use entirely. This again is an extrapolation based on a manipulation of existing data and this figure is suggested only to give some level of estimate to the potential grassland area for consideration in this study.

It is highly unlikely that much of this previously grassland area would be suitable for commercial energy crop production as described here on the basis of environmental sustainability and economic viability[32]. A more likely development trajectory for these areas is their gradual transition to forests (naturally or through deliberate conversion). This will produce vegetation that could be harvested for energy biomass.

2.2.5 Marginal land

In addition to the types of land discussed already, the biofuels and ILUC debate has seen repeated reference to the term ‘marginal’ land (for ‘low ILUC’ biofuels). Marginal land has no formal definition and is not included anywhere in either land use or agricultural statistics.

Marginal land is a much more relative and subjective concept relating to the productivity of individual areas. Land can be considered marginal for a variety of reasons, such as economic, environmental, or agronomic limitations or some combination of all of these. Therefore, it is important to be clear from what perspective the land is being assessed as ‘marginal’, whether or not it is marginal in other terms, and whether the relevant considerations are permanent or just temporary (Allen *et al,* 2013). It is a relative term. What might be relatively productive land in southern Spain may be considered to be ‘marginal’ in the Paris basin.

Most discussion of marginal agricultural land refers to the marginal economic returns that are to be had from such land. These arise from the quality, scale and position of the land and its relative productivity or the ease at which crops can be grown (due to slope or accessibility issues, for example). There is no question that there are considerable areas of agricultural land in this category, particularly in the uplands and mountains and in some places where land will come in and out of production in response to market signals (see

[29] The previous survey year, complete with land cover and land use information, not yet available in the 2012 survey.
[30] Covering 23 Member States, excluding Bulgaria, Cyprus, Malta and Romania.
[31] 58,441,600 ha in agriculture compared to 76,867,100 ha total grassland area.
[32] See section 2.2.2 for some of the reasons leading to farmland abandonment, or for more information Terres and Nisini (2013).

transitional abandonment). However, from an environmental perspective this land may not be of 'marginal' use but instead be providing a range of useful environmental and socially valued services to society. These ecosystem services, such as carbon storage, water filtration or providing space for nature are often provided from economically marginal land precisely because these areas are not exploited for another purpose (Allen *et al*, 2013; Hart *et al,* 2013).

There is little information to support any quantitative assessment of the areas of marginal land that exist in the EU. For the purposes of this study 'marginal land' areas are included implicitly within the total of agricultural land rather than identified separately.

2.2.6 Degraded and contaminated land

Degraded and **contaminated** land describes those areas where soil functions have been largely depleted (eg from excessive peat removal[33]) or where the occurrence of pollutants in soil above a certain level has caused a deterioration or loss of one or more soil functions, or where the presence of man-made chemicals or other alteration in the natural soil environment has brought this about (JRC, undated)[34]. Contamination can result from a variety of sources such as infiltration of seawater (salinisation) in coastal areas or the contamination of land resulting from activities such as manufacturing, mineral extraction, waste disposal, or building heavy infrastructure. Statistical reporting considers two further definitions for contaminated land (JRC, 2014):

- Contaminated Sites: 'area where the presence of soil con-tamination has been confirmed and this presents a potential risk to humans, water, ecosystems or other receptors.'
- Potentially Contaminated Sites: 'sites where unacceptable soil contamination is suspected but not verified, and where detailed investigations need to be carried out to verify whether there is an unacceptable risk of adverse impacts on receptors.'

Very limited quantitative information on national areas of contaminated land is available through EU level data, such as the EIONET-SOIL Data collection exercises, despite its importance for estimating the scale of contamination in Europe (Panagos *et al*, 2013). Between 2001 and 2011, Member States have been asked to report the overall extent of contaminated land as part of several data collection exercises organised by EEA before 2007, and thereafter, by the JRC European Soil Data Centre (ESDAC), in co-operation with the National Reference Centres for Soil belonging to the European Environment Information and Observation Network (EIO-NET).[35]

The reporting on contaminated land by Member States is voluntary. As a result, only 15 member states[36] provided information on their total area of contaminated sites in the most recent data collection exercises (2011), reporting an estimated 198,642 ha of contaminated

[33] It should be noted that peat extraction is excluded from this analysis, again due to lack of pan-EU data.
[34] http://eusoils.jrc.ec.europa.eu/library/themes/contamination/
[35] Joint Research Centre (2014) Progress in the management of Contaminated Sites in Europe, p 5. http://publications.jrc.ec.europa.eu/repository/handle/111111111/30755?mode=full [accessed 20/02/2014]
[36] Austria, Belgium (Brussels and Flanders), Cyprus, Czech Republic, Denmark, Estonia, Hungary, Latvia, Lithuania, Luxembourg, Malta, Romania, Slovakia, and Sweden

land in the EU[37] (ESDAC, 2011). This figure is clearly an underestimate of the current contaminated land area, excluding some of the larger Member States and with some reported data being questionable (such as only 15 ha in Hungary[38]). For further information on contaminated land areas, see Annex 2.

Once land has been contaminated or degraded it takes broadly one of two development pathways, either the land remains contaminated and thus only suitable for certain uses or, alternatively, remediation activities allow the land to become used for other purposes, such as recreational areas and parks, cultivation, growing trees or development. The majority of the land reported as contaminated at the EU level is assumed to be either in use (ie as a landfill area or mineral extraction site) or still contaminated[39] from previous uses, preventing it from being considered available for the cultivation of energy crops.

Further assessment of the available information, such as the total current areas of mineral extraction sites taken from broader land use data, has proved inconclusive. As such, there is little if any reliable information on which to base an assessment of the current area of contaminated or degraded land that could be suitable for energy crop cultivation. The ~200,000ha of contaminated land reported by 15 Member States in the recent survey includes a great many areas that would not be suitable for cultivation, particularly as most are still in some form of existing use. Without better or more detailed data and information we have estimated an area of **50,000ha** in order to acknowledge that it is likely that some existing contaminated or degraded land in the EU could be suitable for energy crop cultivation.

2.3 The land area in summary

The lack of information and the lack of specificity of certain data sources present a significant challenge to the accurate identification of land areas with potential for energy crop cultivation. The estimates set out in section 2.2 above represent what we think are a plausible, although not proven, set of estimates with reasonably transparent assumptions. Table 2 below provides a summary of the different categories of land considered within the scope of this assessment for energy crop production and other tentative estimates of areas where relevant for energy crops. In practice, if the demand for energy crops grew in the EU market, with correspondingly high prices, this is not how the new crops would be allocated, between different land uses. The market and individual landowners' decisions would influence what can and cannot be made available and the economics of a viable production system. Furthermore, the actual area planted would depend on the level of incentives offered and, in our view, energy crops would be more likely to displace food crop production on 'good quality' agricultural land in many places – in order to benefit from reliable yields – than occupy what might be considered by some as 'spare land'.

Together, the figures in Table 2 suggest a hypothetical area of land that could be investigated further for growing energy crops production of around **1.35Mha**. This is a significant area of land amounting to approximately one third of the area cultivated for

[37] Data from 2006 - 2011

[38] With contaminated land covering everything from major industrial pollution events to waste disposal sites, this figure seems too low to be credible.

[39] B Barov, *pers comm*

biofuel feedstock production in 2010. This covers several different categories but altogether is not on a very different scale from those figures set out in reports such as Copa Cogeca's recent position on biofuels (Copa-Cogeca, undated), suggesting that 1.5 – 2 Mha of land (in some form) remains uncultivated since 2009. The figure presented in this report is an aggregate figure formed through a combination of estimates of various land use types and areas and is certainly lower than some estimates that have been in circulation.

Whether or not these areas could or would be cultivated in practice remains a major question. The economic, environmental and social barriers to cultivation would need to be overcome, and the sustainability considered in a rounded sense alongside local investment in collection and processing activities. These additional constraints could further limit the potential areas of land in the categories we have reviewed.

Table 2: Categories of land considered in this study for energy crop production

	Category of land	Area	Exclusion rationale or data source
Natural and forest land			
A	Existing woodland and forest	Excluded	Covered in IINAS *et al*, 2014
B	Existing non-forest semi-natural habitats (including abandoned grazing land)	Excluded (unless C or D)	Excluded on the basis of its environmental importance
Agricultural land			
C	Recently abandoned cropland (<5 years old)	**~200,000ha**	Data highly limited, estimates based on Corine land use changes ***Corine land cover change (2000 – 2006)*****
D	(Recently abandoned) Grassland moving out of agricultural use since 2009, most likely out of production, includes transitions to urban land	**600,000ha**	Some areas excluded on the basis of environmental importance; transition areas unknown, assume most going to urban/forest ***LUCAS land cover data (2009 – 2012)***
E	Current arable land in rotation (including oilseed rape and other industrial crops being utilised as biofuel or other bioenergy feedstocks) excluding fallow (see F)	Excluded	Excluded on the basis of competition with food and feed production
F	Fallow land in agricultural rotation – most of which is needed for agronomic purposes	**200,000ha**	Some areas excluded on the basis of agronomic or environmental importance. ***Farm Structure Survey - Eurostat (2000 – 2012)***
G	Uncropped land within arable farms under environmental agreements or similar eg field corners, buffer strips etc	Excluded	Excluded on the basis of environmental importance. ***No area information***
H	Current grassland under agricultural management (non-arable)	Excluded	Excluded on the basis of competition with food and feed production
I	Other underutilised land within the current UAA but not permanent grassland***	**300,000ha**	n/a
Non-agricultural land			
J	Suitable contaminated sites (excluding areas suited only for afforestation)	**50,000ha**	Excludes areas in use or unsuitable for production or with high biodiversity value. ***JRC 2001 – 2011****
Total			
	Total potentially available land based on optimistic assessments of area		**1,350,000ha**

Source: Own compilation. **Notes:** *= Between 2001 and 2011, Member States have been asked to report the overall extent of contaminated land, as part of several data collection organised by EEA before 2007, and thereafter, by the JRC European Soil Data Centre (ESDAC), in cooperation with the National Reference Centres for Soil belonging to the European Environment Information and Observation Network (EIO-NET). **= no further updated Corine data is available, trends in land use change were estimated to continue at the same rate and distribution between 2006 and 2012; ***= there are likely to be some areas of land that are genuinely unused land ranging from small patches to larger parcels. No data or information is available on which to base this assessment.

3 Sustainability considerations and impacts of cultivation

Each category of land we considered in this study (Table 2) covers land with a wide variety of conditions depending on its geographic location, area, aspect, vegetation, and management history etc. Such variability will affect both the suitability of such land for bioenergy production and its potential natural development[40]. The remainder of this section highlights the potential impacts that could result from the cultivation of energy crops on the types of land identified above (informed in parts by the summary table and energy crop factsheets in Annex 5).

For the most part, the commercial production of energy crops would require more interventions[41] than if the land were left to develop along a natural trajectory. Defining specific site based impacts resulting from cultivation is far from straightforward and much of the literature in this area compares the production of perennial crops to annual crops[42], rather than to the vegetation growth on semi-natural or other land. In most cases, the cultivation of land identified in this study, in particular that which is outside current agricultural areas, will have negative impacts on the environment. However, this will not be the case always, with low level and extensive management in some areas bringing about environmental benefits, or at least no further negative impacts. Certain land types that could be potentially used for energy crop cultivation have been excluded upfront from the scope of the study because of their environmental importance, such as existing semi-natural habitats (including abandoned grazing land) and current grassland under agricultural (non-arable) management (Table 2). The significant environmental benefits associated with maintaining natural and semi-natural habitats are summarised in Poláková *et al* (2011).

3.1 Greenhouse gas emissions

For the most part, the environmental impacts of additional energy crop cultivation will be driven by the type of land use change that is entailed and the increases in management intensity that occur, whether on existing agricultural areas or land currently outside management. In terms of net greenhouse gas (GHG) emissions, changes in land use have a particular influence. The impacts vary in relation to the carbon contained in below and above ground biomass and soils, and the cultivation practices used, including tillage and fertiliser requirements. Positive impacts, through the accumulation of carbon in above ground biomass, have been associated with using *Miscanthus*¸ switchgrass and willow on abandoned land (Baral and Malins, 2014b) when compared to an alternative scenario of reversion to grassland. This is an important caveat to their results, as they point out, since natural reversion to grassland is not common across Europe. Abandoned land reverting to more carbon-rich habitats such as forests or land with some tree cover would alter the GHG balance appreciably – and is a more likely outcome.

3.2 Soil impacts

Changes in soil carbon and soil structure have a further impact on GHG emissions from cultivation, generally with increased emissions that need to be set off against the

[40] Such as the difference between climax vegetation community types across the EU.
[41] Including the use of inputs such as fertilisers, pesticides and water, ploughing, cultivation and harvesting etc.
[42] ie in relation to replacing annual food and feed crops with energy varieties

sequestration achieved. Both the decline of organic carbon and increasing erosion rates are the key risks for European soils associated with agricultural activity. Risks to soil from water erosion are particularly severe in southern Europe, whereas risks are usually more moderate in northern Europe with more variability found in central and Eastern Europe (Winrock, IEEP and Ecofys, 2012). Perennial energy crops have been shown to have beneficial properties in relation to Soil Organic Carbon (SOC) build-up[43] as well as erosion control. In some cases, the planting of certain species of energy crops, such as Poplar, has been shown to recover the soil carbon losses resulting from the conversion of grassland or pasture-land (Baral and Malins, 2014b)[44]. However, this again depends on the counterfactual, the previous land use and the specific local impacts of bringing abandoned land into energy crop cultivation.

3.3 Water and air impacts

Several of the energy crops considered in this study, although associated with different levels of drought tolerance, are known to require considerable volumes of water, making impacts on water availability probably the most serious environmental impact observed currently in relation to energy crops outside the more favoured areas of agricultural production. Miscanthus, though characterised by high water use efficiency, has high absolute water requirements and Poplar, Eucalyptus, Reed canary grass and Willow are water demanding too. Energy crop cultivation will result in increased demand for water, either from irrigation or natural sources. With the majority of abandoned agricultural land in the more arid regions of the EU (Mediterranean and Eastern Europe), impacts of any new cropping there are expected to be significant (EEA, 2013).

Literature on the air and water pollution impacts from energy crop production is relatively limited. Most published assessments are again a comparison between conventional annual crops and perennial energy crops, with reduced impacts commonly observed for the latter – so their relevance, where the comparison is with uncultivated land, is more limited (see Searle and Malins, 2014; Elbersen *et al*, 2013; Ashworth *et al*, 2013). It is furthermore worth mentioning that set-aside has been shown to reduce diffuse pollution as a result of reduced fertiliser and pesticide application (Cumulus Consultants, 2007), a positive effect likely to be reversed from renewed cultivation.

3.4 Biodiversity impacts

Biodiversity impacts vary significantly depending on the counterfactual, with the location of crop plantations, previous land use and crop type and management (eg cultivations, levels of pesticide and fertiliser inputs used)[45] are amongst the key drivers in the biodiversity impacts observed. Specific impacts are uncertain given that research into the impacts of bioenergy crops on biodiversity has been very limited, and most of it has focused on growing energy crops on existing arable land and replacing annual crops, rather than cultivation on abandoned or fallow land areas. Some generalisations can be made and some

[43] In particular, miscanthus and switchgrass (Zimmermann, 2013; Anderson-Teixeira *et al*, 2009; Clifton-Brown et al, 2007; Schneckenberger and Kuzyakov, 2007; Liebig et al, 2008), as well as SRC (Cowie, 2006). See also Elbersen et al (2013; underlying analysis for EEA 2013)

[44] Studies referred to by Baral and Malins (2014b) include Grigal and Berguson (1998), Rytter (2012), Dawson and Smith (2007), and Dowell, Gibbins, Rhoads and Pallardy (2009), the latter having studied the poplar example mentioned above.

[45] Arable versus perennial

likely environmental impacts can be inferred from studies investigating the environmental implications of set-aside or fallow land and land abandonment. Poláková *et al* (2011) present a rather comprehensive compilation of literature focusing on the biodiversity implications of land under different forms of agricultural management, including no-management.

Most importantly, the replacement of any semi-natural habitat (especially those listed under Annex I of the Habitats Directive) by a dedicated bioenergy crop would result in significant biodiversity losses. However, the use of biomass harvested from semi-natural vegetation in such habitats (eg hay meadows or scrub / heathland habitats) might be environmentally acceptable, or even beneficial in some circumstances (Box 4). Such uses would need to be carefully regulated to ensure they are sustainable and with appropriate management (eg no increase in the use of fertilisers and cutting carried out at suitable times and using appropriate machinery etc). Where semi-natural habitats have been subject to, or are at risk of, abandonment then the harvesting of biomass could help to reduce or even reverse the impacts of land abandonment. As noted in several studies, abandonment of semi-natural habitats, particularly in Natura sites but also in other HNV areas, is a major threat to biodiversity in the EU, as the semi-natural vegetation and associated specialist fauna tends to be replaced by lower value dense rank grassland and scrub and generalist species (Poláková *et al* (2011).

Box 4: Examples of beneficial semi-natural vegetation harvesting

Carefully managed mowing of grassland and scrub clearance could help to mitigate the loss of livestock grazing and hay production where partial or complete abandonment occurs. However, it is important to note that the presence of livestock in such semi-natural habitats is beneficial for many ecological reasons, and therefore the harvesting of vegetation for bioenergy should only be carried out as last resort, where grazing is insufficient to maintain the ecological condition of the habitat.

Many semi-natural grasslands are subject to the deposition of high levels of atmospheric nitrogen, which is causing eutrophication, vegetation change and substantial biodiversity declines (Ellenberg *et al,* 1989; Bobbink and Lamers, 2002; NEGTAP, 2001). Furthermore, this eutrophication is exacerbating the effects of undergrazing. Therefore, the cutting of vegetation for bioenergy purposes could also help to mitigate these impacts, although further research into this is probably required.

Source: Own compilation

A particular concern arises when energy crops are cultivated on less productive land, where most HNV agriculture is concentrated, with a potential loss of semi-natural habitats (grassland, calcareous grassland and heathlands) in the case of abandoned land (BIO IS and IEEP, forthcoming). In other instances, abandoned land usually will be of lower biodiversity value; this is especially the case where large-scale abandonment took place previously with associated declines in habitat heterogeneity and species diversity across the landscape (Poláková *et al*, 2011).

In some areas there is fallow land that may be surplus to current agronomic or environmental requirements. Cultivation of fallow areas with bioenergy crops would lead to significant biodiversity impacts as such areas can provide valuable breeding and feeding habitats for a variety of birds, small mammals and invertebrates, as shown by studies of set-aside (IEEP 2008; Cumulus Consultants, 2007; Hodge *et al,* 2006)[46]. This is particularly important because of the ecological effects of land-use change on farmland birds at the EU scale. This indicates that changes in food resource availability, and to a lesser extent suitable nesting sites, associated with cropped areas within agricultural landscapes are the main cause of declining populations of most common farmland bird species (see Butler *et al,* 2010; Poláková *et al*, 2011).

If carefully designed and regulated, the biomass from some non-crop habitats such as grassland buffer strips, seed-rich crops for birds and flower-rich crops for pollinators could be used to produce bioenergy. However, it would be important to ensure that this does not compromise agri-environment objectives and the basis for payment calculations. Some energy crops could also fulfil the role of certain environmental measures; most notably SRC could play a role as a buffer strip along watercourses as it reduces soil erosion and traps run-off, and when established it creates an effective screen from spray drift. This would result in benefits for aquatic biodiversity, provided that the SRC is not too close to the watercourse so that its shades it out, and is interspersed with other habitats.

The introduction of particular alien species is another potential impact of concern, particularly for species, such as eucalyptus, that support extremely low levels of biodiversity (Forsyth *et al*, 2004; Searle and Malins, 2014).

In summary, most perennial energy crops (eg with exception of eucalyptus and other alien trees), such as those considered in this study are shown in most cases to have fewer negative impacts on existing farmland than annual crops. However, the research into the impact of energy crop cultivation on abandoned, fallow and contaminated land is limited. With the information that is available, and based on our understanding of the ecosystem dynamics, it is certain that cultivation of dedicated energy crops on semi-natural habitats[47] would have significant negative environmental impacts in most places. Environmental impacts are likely to be less pronounced on land that is currently under cultivation, but biodiversity impacts would be significant on fallow areas and, depending on the cultivation approaches taken, this may well have knock on agronomic consequences which may in turn result in further environmental impacts.

[46] see also Sotherton 1998; Henderson and Evans 1999; Henderson et al, 2000a, b; Firbank et al 2003; Vaughan et al 2003; Bracken and Bolger, 2006; Hodge et al 2006; Curry 2008; and Van Buskirk and Willi, 2004.

[47] Either abandoned land or previously uncropped areas

4 Estimated energy from available land

Around 1.35 Mha of land in the EU has been identified as having potential to be investigated further for the purposes of dedicated energy cropping. This section considers the biomass and energy volumes that could be achieved if **all** of this land were to be cultivated.

In addition to land areas, two other factors are needed to make this assessment; these are anticipated crop yields and energy conversion efficiencies. Anticipated crop yields that can be expected at commercial scale on land that is marginal for agriculture were taken (sometimes in adapted form as explained in Annex 3) from Searle and Malins (2014) and Alexopoulou *et al* (2012) for the crops considered here, as set out in Table 1. The following yield ranges were used 4.7 – 11.5 t/ha for abandoned and contaminated land, with inherently lower productivity and 11.5 – 17.5 t/ha on fallow land, reflecting that such land is part of the current crop rotation and likely to be of better quality. These yields appear high, relative to current crop yields in such areas but it should be recognised that these figures are for energy crops, and thus the whole plant is harvested, unlike many conventional food and feed crops.

Energy conversion factors were taken from IINAS *et al* (2014) and Baral and Malins (2014), backed up by data from some biofuel industry sources, and vary according to the processing technology chosen and the nature of the final energy use (ie biofuels, heat, electricity[48]). Further details of these conversion factors can be found in Annex 4. The calculations reflect the assumptions taken regarding yields and conversion factors as outlined in this and the previous Annexes 2 - 4.

On the assumptions made here, a total of between 7.7 and 16.7 million dry tonnes of biomass from energy crops could be produced annually, depending on the yields achieved. This would have an embedded energy content of between 139 and 300 PJ of energy. Table 3 shows the amount of final total energy in absolute volumes and relative to current energy use in Europe that could be generated if all the additional biomass considered here were to be put through a single conversion pathway, eg converted into biofuels or through combustion to generate electricity and/or heat. It is worth bearing in mind that our comparator is final energy consumption, which already accounts for transformation and distribution losses[49].

Comparing the energy potential from this additional biomass to 2012, final sectoral energy consumption in the EU (the blue part of the table) shows that the greatest contribution to final energy consumption can be made if all biomass were to be reserved for dedicated heat generation, replacing between just over five and eleven per cent of final sectoral heat energy consumption. Putting all biomass into biofuel pathways, on the other hand, would

[48] The electricity pathway is a split between co-firing and cogeneration with heat uptake.

[49] Accounting for transformation and distribution losses and own use by energy producing industries is what makes up the differences between final energy consumption (ie the energy that reaches the final consumer) and primary energy consumption. The use of final energy consumption data here is in line with using conversion factors that accounting for losses in the conversion of biomass into usable end-products such as biofuels, bio-electricity and bio-heat. For illustrative purposes, while final energy consumption in the EU in 2012 was 46,198 PJ, Eurostat reports primary energy consumption in the same year to be 66,285 PJ.

replace only around 0.5 – 1 per cent of final EU road transport energy consumption. The electricity generated from the available biomass, if all devoted to this purpose, would amount to between 0.4 and 0.9 per cent of final EU electricity consumption, with additional (and rather substantial) contributions to heat generation.

The lower, orange section of the table shows the proportion of additional energy that could be generated through each individual pathway compared to total EU final energy consumption in 2012. The highest contribution to EU final energy consumption (and hence greatest contribution towards meeting EU renewables targets) could be gained from a heat only pathway, closely followed by electricity and heat generation whereby a large share of co-generated electricity is assumed EU-wide (45 per cent). Such supply conditions currently exist only in a very limited number of countries. The biofuel only pathway shows the lowest proportional contribution at only 0.27 per cent at the upper yield ranges. In all cases, the contributions remain below one per cent. The current production and use of energy crops is excluded from these calculations. The redeployment of land now growing oilseed rape to other energy crops would increase the combined share of final energy consumption.

Table 3: Final energy produced from dedicated biomass utilisation and its share of supply

Assuming all biomass used for:	Lower	Upper	Unit
Biofuel	57	124	*PJ*
Electricity (combustion total)	44	95	*PJ*
- out of which Electricity (co-firing)	*26*	*56*	*PJ*
- out of which Electricity (cogen ST-BP plants)	*18*	*39*	*PJ*
Heat (dedicated)	107	231	*PJ*
Heat uptake (cogen ST-BP plants)	45	98	*PJ*
As a share of *sectoral* EU final energy consumption:			**out of:**
Biofuel	0.5%	1.0%	Road transport (12,021 PJ)
Electricity (combustion total)	0.4%	0.9%	Electricity (10,073 PJ)
+ Heat uptake (cogen ST-BP plants)	*2.2%*	*4.8%*	*Heat (2,022 PJ)*
Heat (dedicated)	5.3%	11.4%	Heat (2,022 PJ)
As a share of total EU *final* energy consumption in 2012 (46,198 PJ):			
Biofuel only	0.12%	0.27%	
Heat only	0.23%	0.50%	
Electricity + Heat (mix of co-firing & cogen)	0.19%	0.42%	

Source: Own compilation **Notes**: The upper, green part of the table shows the final bioenergy production if all available biomass were to be put into a biofuel, electricity (mixture of electricity-only co-firing and cogeneration) and heat only pathway. The middle, blue part of the table shows the share of these production volumes out of sectoral EU final energy consumption in the transport, electricity and heat sectors. The lower, orange part of the table shows the share of the three pathways (biofuels, heat only, electricity assuming a mix of co-firing and cogeneration) out of total final energy consumption in the EU in 2012 of 46,198 PJ.

It is important to keep in mind that the figures presented here may represent an optimistic assessment of the available agricultural land and yields gained from such land and assume no utilisation of existing arable cropland. It is likely, certainly for abandoned land, that these yields would be different in practice depending on a range of factors, as may be the overall areas of energy crops. However, even if one were to consider double or even triple the areas set out above, the overall energy volumes would remain limited. These figures show clearly that the overall energy potential from dedicated energy crops on 'spare' land in Europe is low. While important contributions can be made to sectoral components of total energy consumption, overall numbers are modest and the potential from growing energy crops on these land types should not be overestimated.

5 Discussion and recommendations

Deploying 'spare' land for energy crops

This brief review has shown that that there is some scope for additional energy crop cultivation in Europe outside existing cropland or longer term abandoned land. Defining the precise extent and nature of the land on which this cultivation could occur is challenging, limited for the most part by the availability and specificity of information. Based on our assumptions and our assessment of some of the more reliable sources of information and our own expert judgement where this is lacking, around 1.35 million hectares of largely agricultural land could have potential for cultivation of energy crops, around one per cent of the current UAA for the EU-28[50]. This land in question would consist of primarily recently abandoned agricultural land (both cropland and grassland areas), some of the existing fallow land areas, other unutilised areas and a small proportion of contaminated land. It should be made clear at this point that any cultivation of such land will have environmental consequences and would need careful assessment and implementation in order to avoid significant adverse environmental impacts. The displacement of semi-natural vegetation and the reduction of space for wildlife within the current agricultural landscape would be particularly detrimental in some scenarios. The areas and figures indicated in this study seek only to set out the broad scale of potential without committing to a specific area or land type.

Assessing the distribution of this land is again limited by the data. Potentially available fallow land on existing arable areas is largely found in Eastern Europe (mostly Romania), and abandoned cropland is expected across much of central and southern Spain and Portugal, the Czech Republic and Hungary, Croatia and elsewhere). It is unclear whether or not these areas are suitable for conversion to bioenergy, except perhaps in specific patches in appropriate locations, given their importance for biodiversity and carbon sequestration. Grassland abandonment is expected across the EU, but largely in upland and mountain regions and the distribution of contaminated and other unutilised land is unclear. Where spatial information does exist, such as for the potentially abandoned cropland areas (Figure 4), we see that the patches of land with potential for cultivation are small and highly fragmented across regions. A similar picture is expected for other areas of land with no indication that significant blocks of land are sitting idle and awaiting cultivation.

Limits to cultivation

The 1.35 million hectares referred to here may be higher than desirable when taking into consideration economic, environmental and social sustainability, and is in this sense optimistic. The categories of land considered are diverse and may not be brought into cultivation in practice, even in response to much stronger incentives. Decisions about how land is used, including the intensity of the production system, rest almost entirely with millions of individual landowners and land managers. Their decisions have profound consequential effects for other ecosystem services both in terms of demand (for irrigation water for example) and production capacity (of biodiversity, unpolluted water, carbon

[50] Using a UAA figure of 182Mha from Eurostat. NB: Not all of these energy crops in this case would be on land types which officially are within the current agricultural land area.

sequestration). Most of these individuals rely on market returns for the major part of their income, although aid through the CAP is also significant (Hart *et al*, 2013).

Across the EU, land remains out of cultivation for a wide variety of reasons. These can include: economic and market factors where the price of commodities is driven below that at which they can be produced, and thus the land becomes unprofitable to farm; topographic, bio-climatic or edaphic factors which reduce the productivity of or ready access to land; contamination or pollution factors which would require neutralisation before being brought into use; or areas under statutory or other forms of protection and so not available (see Annex 6). Added to this, there are institutional reasons why some land is kept out of production which are unlikely to be wholly eliminated. These include disputed ownership, transitional arrangements (death of owner, acquisition of land for development) bankruptcy and lack of credit, individual management preferences, etc. These factors limit the economic viability, legal availability or agro-environmental suitability of the land for production; significant interventions would be required in order to make some land economically attractive for commercial products.

In most cases the question about why land is or is not likely to be in energy crop production is one of economics, ie can a suitable return on investment be made if energy crops are cultivated on such land and will individual land owners and managers make the decision to cultivate? Larger areas of land could be utilised for energy crops if production cost was not a consideration, and of course there will always be some cases of production continuing in parts of Europe, which is not economic in conventional terms, as occurs with livestock. But **if real world considerations apply it will not be cost-effective to establish commercial energy crops on areas where conditions are too unfavourable, water supplies are limited, or the distance to the processing plant is too far etc.** This is an important dimension of the constraints on utilising 'spare' land. Economic interventions or incentives on a significant scale can help to overcome some of these constraints. However, not all structural barriers will be surmountable within reasonable levels of intervention (such as where many small patches of unused land are distributed over a wide area).

Energy potentials

Given such land constraints, the energy potentials available from energy crop cultivation are also limited. Even with optimistic assessments of yields, areas and conversion efficiencies, the 1.35 million hectares of land considered in this study is unlikely to yield significant contributions to Europe's energy future, although undoubtedly they do have some role to play. The contribution to biofuel demand for example would deliver one per cent or less of final transport energy consumption[51]. The most efficient use of these crops would be to displace sectoral heat generation (up to around eleven per cent of final consumption). However, when compared to total overall EU energy consumption (in order to give a comparison with EU renewable energy targets for 2020), the contribution is marginal, 0.5 per cent or less in all cases. Even with a doubling or tripling of the land area considered here the overall energy potential remains limited.

[51] Based on 2012 final energy in transport figures.

Recommendations for policy makers

Based on the assessment set out in this study and our understanding of land use dynamics and EU energy policy the following recommendations are made:

- More should be done by national and EU institutions to provide up to date and accurate data, in particular that on land uses that fall outside of the main economic sectors, in order to base assessments and provide recommendations for robust policy making in this sphere. The majority of the data sources available at the pan-EU level lack the specificity, focus and rigour on which to determine accurately the types of numbers on which to base policy.
- The lack of information in relation to land use and potential areas for energy crop cultivation should not, however, be a reason to delay the development of policy in this area. Rather, policy makers should approach with caution claims around the availability of land for energy (and other) uses in Europe and bear in mind the need to set out appropriate environmental safeguards for the use of this land. Embedding better data collection infrastructure in existing policy would be a step forward.
- Without further guidance and information, broad-brush incentives for additional energy crop cultivation at the EU level should be approached with care as they have a limited role in delivering a sustainable renewable energy future for Europe. There is a clear need for better guidance and information, which could be set out at the EU level and implemented in Member States, to guide the development of energy crops, avoid detrimental land use change and take into account local and site-specific conditions.
- The actual potential for and usefulness of energy crop cultivation in medium to long-term energy strategies needs to be assessed at the regional level. Such assessments should take into consideration the regional availability of different biomass resources as well as other forms of renewable energy in order to facilitate a more holistic assessment of potential renewable energy mixes.
- Energy crops are only part of a much wider spectrum of sources of biomass that need to be considered together in a wider frame embracing uses of bioresources beyond the energy sector as well as within it.

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Annex 1 Examples of set-aside transitions

Box 5: Set-aside transitions in Germany

In Germany, there has been a strong decline in the previously set-aside areas since the abolition of the policy, decreasing by 531,600 ha between 2007 and 2010 (from 784,000 ha to 252,400 ha). This land has mostly been recultivated to become arable land. Since 2010 the decline has been less dramatic but former set-aside areas continue to decrease (228,700 ha in 2011, 214,600 ha in 2012 and 198,600 ha in 2013). The decline of set-aside has occurred to a lesser extent in east Germany, with substantial areas of former set-aside still in place there (albeit also in decline) (Statisches Bundesamt, 2012; Statisches Bundesamt, 2013). The decline in set-aside in Germany is linked to declining farmland bird populations (pers comm, R Oppermann). There are concerns that growing energy crops in Germany displaces biodiversity and species rich grassland, but also organic farming as it increases competition for land, driving the prices up so that organic farmers cannot pay the rent (pers comm, R Oppermann).

Box 6: Set-aside transitions in Poland

In Poland, there was a strong decline of set-aside areas in the immediate years following its accession to the EU. Between 1999 and 2001, on average, set-aside amounted to 1.6 Mha (12 per cent of arable land). The largest areas of set-aside were located in Mazowie (central) (172,000 ha), Warm. Mazurskie (168,000 ha) (north), and Zach.-pomorski (north-west) (168,000 ha), with the least located in Opolskie (south) (22,000 ha). However, by 2007, the year that set-aside was abolished and four years after Poland's accession to the EU, the area of set-aside in Poland had fallen to 366,700 ha (amounting to just over 3 per cent of arable land).

This trend is explained by the growth in agricultural production that followed on from the Polish accession to the EU. It is thought that the subsidies to farmers (particularly direct payments and payment to farmers in LFAs), and investments in agriculture, which came as a result of joining the EU, enabled farmers to bring previously set-aside land into agricultural production. Since 2007, the area of fallow land has remained relatively stable indicating that little change to set-aside has occurred since 2007 despite the abolition of set-aside regulation.

Source: Szczerbiak (2012); FAO, 2003

Box 7: Set-aside transitions in England

Following the abolition of set-aside in England, the area of uncropped land fell from 423,500 ha to 159,000 ha between 2007 and 2008 following the abolition of set-aside (with some 50,000 ha discrepancy due to different recording of margins and corners under agri-environment schemes which were in fact maintained uncropped). The area of former rotational set-aside fell by 83 per cent between 2007 and 2008 whereas non-rotational set-aside areas decreased by slightly less than 50 per cent.

Moreover, in 2009, 75 per cent of former non-rotational set-aside areas had been out of production for over 10 years indicating that former non-rotational set-aside areas typically remained out of production following abolition of the policy.

Source: (Defra Agricultural Change and Environment Observatory, 2009)

Annex 2 Land area estimates

Abandoned agricultural land

Determining the extent of farmland abandonment in the EU is challenging, primarily as a result of the lack of a widely agreed definition (Moravec and Zemekis, 2007) and a consistent measurement across the EU (Pointereau *et a*l, 2008). One of the key issues preventing a consistent indicator to measure farmland abandonment results from data availability and resolution. Farmland abandonment is widely recognised as 'a local specific phenomenon', thus requiring high resolution data in order to appropriately assess farmland abandonment that is not available through the Farm Structure Survey or the Farm Accountancy Data Network (Eurostat[52]; Keenleyside and Tucker, 2010). More recently, work has been carried out to develop indicators based on available data to assess areas at risk of farmland abandonment. These indicators consider natural constraints (such as soil and climatic conditions), farm stability and viability (in terms of farm income, investment levels, farmer's age and farm size) and the regional context (such as the land market, remoteness and population density) (Terres *et al*, 2013); Eurostat[53]). Such indicators are useful in pinpointing the areas most likely to have abandoned farmland and for identifying the factors driving abandonment, if not the extent of abandoned farmland present to date.

Estimates typically consider the extent of abandoned farmland in the EU based on land use change data, although how much of this land, which has transitioned out of agriculture is abandoned is not always clear. Moreover, the range of available estimates varies greatly, in both the timeframes considered and the extent of abandonment. For example, one study estimates that over the course of 42 years (1961 to 2003) there has been a total loss of 30 million hectares UAA (Pointereau *et al*, 2008) whilst another shows that between 1990 and 2000, 510,376 ha were withdrawn from farming (EEA, 2006)[54]. The difference in time series makes data comparison, challenging. More detailed work has also been carried out at the Member State level to determine the extent and causes of farmland abandonment through case studies in France, Poland and Spain (Pointereau et al, 2008). These rely on national datasets again with variable timeframes. Overall, the case studies show that 936,555 ha of farmland were abandoned in France (between 1988 and 2000), that 759,902 ha in Poland (between 1996 and 2002), and 1,986,335 ha in Spain (between 1989 and 1999). Estimates and causes of farmland abandonment have also been discussed in literature with varying detail and timeframes for the Czech Republic, Estonia, Finland, Germany, Greece, Italy, Latvia, Lithuania, Romania, Slovakia, and the UK (Pointereau *et al,* 2008; Keenleyside and Tucker, 2010; Feranec *et al*, 2010; Corbelle-Rico *et al,* 2012).

Abandoned land is not recorded formally in any agricultural or other land use statistics. The only pan-European dataset that includes a reference to abandoned land is LUCAS. Under the

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[52] http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Agri-environmental_indicator_-_risk_of_land_abandonment [last accessed 7 February 2014]

[53] Farmland abandonment is defined as land where agricultural activities have stopped resulting in undesirable changes in biodiversity and ecosystem services. The EU agri-environmental indicator designed to determine the risk of farmland abandonment derives from key farmland abandonment drivers combined into a composite index indicator.

[54] It is inappropriate to compare these estimates because of structural changes which occurred in this timeframe.

agricultural land use category, land is further divided into: Agriculture (excluding the following two categories); Fallow land and abandoned land in agriculture; and Kitchen gardens. The fallow and abandoned land category is defined as: '*Agricultural land not used for the entire year for crop production, as part of the field rotation. Also, all agricultural land which is set aside long-term is included. Crops growing in naturally vegetated areas are a sign of land been in the past in agricultural use.*'[55]. The visual survey carried out by LUCAS does not allow for a further disaggregation between fallow land in agricultural use and that land which has since been abandoned.

Other, proxy sources of data are available on which to estimate the loss of agricultural land through abandonment (Table 4).

Table 4: Data sources for abandoned agricultural land

Source	Year	Notes
Farm Structure Survey (Eurostat)	- 2012	Using UAA, arable and other agricultural land areas to identify broad trends that may result in or from farmland abandonment
Land Use Cover Aerial Frame Survey (LUCAS) (Eurostat)	2009	Fallow and abandoned land in agriculture
Corine Land Cover change data (EEA)	1990, 2000, 2006	Estimating land abandonment through changes from agricultural land uses to semi-natural vegetation communities

Source: Own compilation

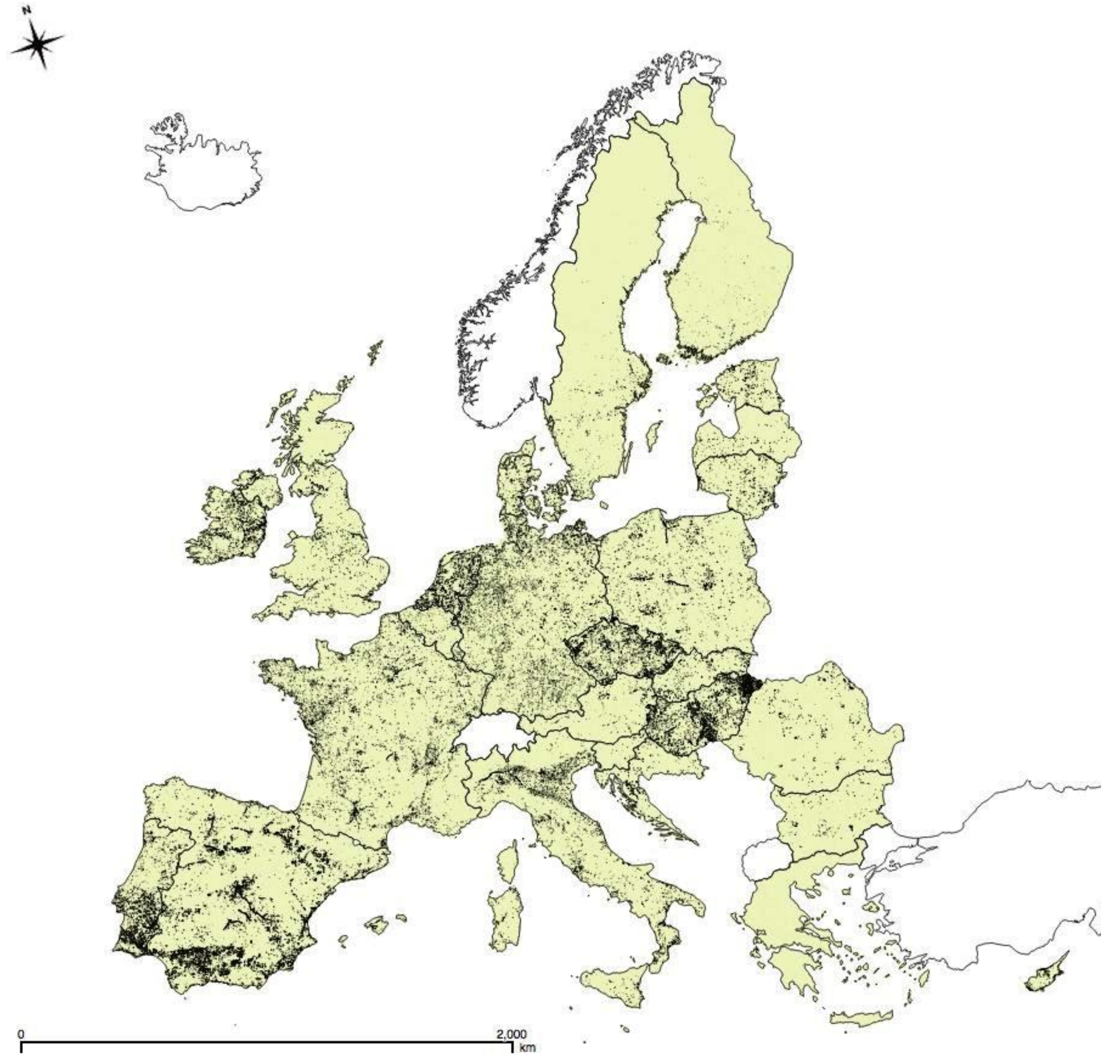
Areas

Across the EU 28 the area of agricultural land is decreasing. Between 2000 and 2006 the Utilised Agricultural Area (UAA) has decreased by three million hectares (FSS). In order to estimate at the broad level, the area of abandoned farmland in the EU we first determined the land cover flows from agricultural land to other types of land cover using Corine data (2000 and 2006)[56]. Corine uses a mixed nomenclature of land cover and land use, separating clearly defined agricultural use of land (Classes 211 – 243) from land covers, such as natural grasslands and moorlands that may or may not be under agricultural use. Our approach considers the change from the agricultural land use classes in the year 2000 to other land cover types within the Corine dataset in 2006. Over this time period just under 700,000 ha of agricultural land has undergone a transition to some other form of land use[57]. The majority (68 per cent) of this transition has been to urban development, with the next most significant change being to transitional woodland scrub (23 per cent). Within this timeframe, only some of the land use changes could realistically be brought back into agricultural production for energy crops. Some changes, such as urban encroachment are semi-permanent with the land being lost from cultivation entirely. Other changes, such as the encroachment of transitional woodland scrub or other semi-natural vegetation could be the result of farming withdrawal and more easily overcome in the short term. Five land cover types were identified as those most likely to occur when farming ceases to take place and could be reversed. These are: Sclerophyllous vegetation; Transitional woodland-shrub;

[55] Eurostat, (2009) LUCAS 2009 (Land Use / Cover Area frame statistical Survey) 2009
[56] http://www.eea.europa.eu/data-and-maps/figures/land-cover-2006-and-changes-1#tab-documents [last accessed 26 February 2014]
[57] Not including changes between different agricultural land uses, such as from arable to permanent grassland.

Sparsely vegetated areas; Natural grasslands; and Moors and heathland[58]. Over this six-year period it is estimated that a potential 165,000ha of certain agricultural land has been lost to these land types. In reality much of this land may still be in agricultural ownership, possibly even agricultural use in some instances, part of a designated site, area of nature conservation importance, or undergoing deliberate afforestation.

Figure 4: Agricultural land use change between 2000 and 2006



Source: Own compilation based on Corine Land Cover Change data between 2000 and 2006 **Note:** Due to the scale and resolution of the map care should be taken when interpreting the distribution of the changes seen. A large number of changes (such as in the Czech Republic) shows equally as prominently as a large area of changes (such as in Hungary).

[58] **Sclerophyllous vegetation:** Defined as evergreen woody bushes and scrubs, which compose maquis, garrigue, mattoral and phrygana; **Sparsely vegetated areas:** Defined as scattered vegetation is composed of gramineous and/or ligneous and semi-ligneous species for determining the ground cover percentage, excluding cryptogams. Includes steppes, tundra and bad lands, and scattered high-altitude vegetation; **Natural grasslands:** Defined as areas where herbaceous vegetation (maximum height is 150 cm and gramineous species are prevailing) cover at least 75 % of the surface covered by vegetation; **Transitional woodland-shrub:** Defined as bushy or herbaceous vegetation with scattered trees. Can represent either woodland degradation or forest regeneration / recolonisation; **Moors and heathland:** Defined as temperate shrubby area vegetation: includes dwarf forest trees with a 3 m maximum height in climax stage.

	AUSTRIA	BELGIUM	BULGARIA	CYPRUS	CZECH REPUBLIC	GERMANY	DENMARK	ESTONIA	SPAIN	FINLAND	FRANCE	GREECE	CROATIA	HUNGARY	IRELAND	ITALY	LITHUANIA	LUXEMBOURG	LATVIA	NETHERLANDS	POLAND	PORTUGAL	ROMANIA	SSWEDEN	SSLOVENIA	SLOVAKIA	UNITED KINGDOM
All	1%	0%	1%	1%	2%	9%	2%	1%	18%	0%	12%	0%	1%	9%	6%	7%	1%	0%	0%	6%	5%	10%	1%	1%	0%	1%	4%
Aba	0%	0%	0%	0%	2%	1%	1%	1%	6%	1%	2%	0%	0%	25%	12%	1%	2%	0%	1%	3%	11%	29%	0%	0%	0%	2%	1%

Whether or not these areas could be brought back into production is a question of overcoming the reasons for their decline. In some cases, these might be economic or social factors, which might respond well to market signals and investment for biofuel production, in other cases terrain and soil constraints may pose more significant barriers making crop production economic only in the most positive of markets. Based on indicators of farmland abandonment risk (see Terres *et al*, 2013 and summarised in Table 5) it is estimated that approximately 113,000 ha of land that has come out of agricultural production has been as a result largely of economic or social factors the remaining 52,000 ha as a result of sever terrain and soil constraints. However these figures show only the state of land in 2006, before food price spikes in 2007 and 2008, and the implementation of major policy changes such as the abolition of set-aside policy (2007-2008) and the implementation in 2009 Renewable Energy Directive. No recent land use change data is available to assess further potential farmland abandonment or cultivation in the EU.

Table 5: Indicators of farmland abandonment risk for Member States with significant areas where withdrawal of farming has occurred (H – high; M – medium; L – low)

MS	Natural constraint	Value of rent per ha	Ratio of income to national GDP	Level of investment	Farmer's age	Population density	Likelihood of bringing back into production
ES	Severe	L/M	M/H	L	H	L	L
FI	Moderate (north); Slight (south)	L (north) M (south)	L	H	L	L	H (South) /M (North)
FR (southwest)	Moderate	L/M	L/M	M	L	L	H
HU	Slight	L	M	L	M	L/M	H
IE	Severe (west); No constraints elsewhere	M/H	L	M/H	M	L	H (except for west IE)
PL	Moderate	L	L/M	L/M	L	M	H
PT (south)	Slight	L	L	L	H	L	H
SK	Combination of severe and slight	L	L	L	M/H	M	H
UK (Sc)	Severe/moderate	M	M/H	L	M/H	L	L

Source: Own table based on maps from Eurostat and FAO/IIASA

Fallow land

Fallow land is described in a number of different data sources particularly agricultural survey statistics. Table 6 shows highlights the main data sources used to identify fallow land.

Table 6: Data sources for fallow agricultural land

Source	Year	Notes
Farm Structure Survey (Eurostat)	2000 C 2003 SS 2005 SS 2007 SS 2010 C 2011 SS 2012 SS	FSS is carried out as a sample survey (SS), and once in the ten years as a census (C); The FSS covers all agricultural holdings with a utilised agricultural area of at least one hectare (ha) and also those holdings with a UAA of less than 1 ha where their market production exceeds certain natural thresholds.
Land Use Cover Aerial Frame Survey (LUCAS)	2009 2012 (land cover only)	Since 2006, EUROSTAT carries out a survey on the state and the dynamics of changes in land use and cover in the European Union called the LUCAS survey. The surveys are done every three years. The LUCAS surveys are carried out in-situ; this means that observations are made and registered on the ground all over the EU. The latest LUCAS survey (2012) covers all 27 EU countries and observations on more than 270 000 points.

Source: Own compilation

Contaminated land

Industrial contamination

The Core Set Indicator 'Progress in the Management of Contaminated Sites' (CSI 015) of the European Environmental Agency has been used in the soil data collection surveys in order to estimate contamination levels. It considers five specific policy questions. The most relevant, for the purpose of this study, looks at assessing the scale of local soil contamination, according to two main parameters: the estimated number and area of Potentially Contaminated Sites (per country); and the estimated number and area of Contaminated Sites (per country)[59].

EU level information does exist for contaminated sites, with an estimated 198,642 ha of contaminated land being reported in the EU at present (for 15 Member States) (Table 7, with a further disaggregation of contamination by type in Table 8).

Table 7: Available Areas of Identified Contaminated Sites per EU member state

Country	Year Surveyed	Identified Contaminated Sites Area (ha)
Austria	2011	5,000
Belgium (Brussels)	2006	200
Belgium (Flanders)	2006	57,000
Cyprus	2011	340
Czech Republic	2006	50,794
Denmark	2006	45,800
Estonia	2006	4,545
Hungary	2011	15
Latvia	2006	2,184

59 Data Collection on Contaminated Sites 2011, 2011

Lithuania	2011	2,501
Luxembourg	2006	19
Malta	2006	63
Romania	2006	25,481
Slovakia	2011	1,700
Sweden	2006	3,000
	Total area	**198,462**

Source: European Soil Data Centre (ESDAC) (2011) CSI-015 "Progress in the management of contaminated sites". http://eusoils.jrc.ec.europa.eu/library/data/eionet/2011_Contaminated_Sites.htm [Last accessed 20/03/2014]

These area figures provide some estimate of the extent of contaminated land in the EU, however they should be approached with caution. For example Hungary, reported only 15ha of contaminated sites in 2011. With contaminated land covering everything from major industrial pollution events to waste disposal sites, this figure seems too low to be credible. Furthermore the kind of information provided does not allow an identification what type of land was reported as contaminated (i.e. polluted industrial sites in urban areas, areas of semi-natural pollution in rural areas, etc).

Table 8: Area of contaminated land by pollution type in the EU

		Waste disposal and treatment		Industrial and commercial activities				Military		Storage				Transport spills on land		Nuclear	Others *	Site Identification
Member State	Year	Municipal waste	Industrial waste	Industrial and commercial services	Mining	Oil extraction and production	Power plants	Military operations	Oil storage	Oil extraction and storage sites	Obsolete chemical storage	Storage of manure	Other storage	Oil spills	Other hazardous substance spills			Total Area (ha) per Identified Sites
AT	2011	1600	750	2050	0	0	0	0	0	0	0	0	600	0	0	0	0	5000
BE – BXL	2006	20	20	8	0	0	0	0	20	0	20	0	40	0	0	0	0	200
BE -Fl	2006	399	3648	23085	0	18354	3819	0	0	0	0	0	513	0	0	0	7239	57000
BG	2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	:
CR	2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	:
CY	2011	187	34	34	51	0	7	0	17	0	7	0	0	3	0	0	0	340
CZ	2006	26718	3149	9143	762	1270	2032	1575	2438	0	254	0	305	152	1676	15	1371	50794
DK	2006	8244		0	27480	0	0	1832	0	5496	0	0	0	0	0	2748	0	45800
EE	2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	:
FI	2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	:
FR	2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	:
GR	2001	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	:
HU	2011	0.5	0.2	2	0.3	0	0.3	0.6	2	0	0.6	0	0.2	6	0.5	0	3	15
IE	2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	:
IT	2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	:
LC	2001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	:
LT	2011	125	0	150	0	25	200	25	825	0	900	0	100	25	0	0	125	2501
LV	2006	330	0	467	0	9	100	63	1000	0	37	0	37	28	28	0	55	2184
LU	2006	0.1	0.7	15	0	0	0	0.0	0.2	0	0	0	0	2	0.0	0	0	19
MA	2006	20	20	5	0	0	0	0	9	0	0	0	5	5	0	0	0	63
NL	2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	:
RO	2006	6370	5096	1274	3058	1784	1274	0	255	0	0	0	0	0	0	0	5096	25481
SK	2011	391	272	340	85	34	17	119	204	0	34	0	17	119	34	0	34	1700
SL	2003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	:
SP	2011	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	:
SE	2006	210	150	1350	360	30	30	90	240	0	0	0	30	180	30	0	300	3000
UK	2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	:
Total																		

Source: Own compilation on the basis of EIONET Data Survey 2011. Data from Portugal and Poland were not included in the Survey. **Notes:** : = no available data; * = shooting ranges, waste water treatment plants, other activities (like harbours, railway areas, airports)

An alternative approach we considered was to look at existing data on the extent of contaminated land at the national level. However, one of the limitations preventing us from pursuing this path is due to the fact that no soil quality standards have been established at EU level (JRC, 2014). Thus, the progress in the prevention of new contamination and the management of land already contaminated, as well as the knowledge base, is highly variable among EU member states (EEA, 2000). National targets exist in several European countries (JRC, 2014) yet establishing a rough estimate of the extent of contaminated sites is hampered by the lack of harmonisation in national datasets and the inconsistent quality of information on contaminated land. Further consultation of national and regional data inventories on contaminated land was beyond the scope of this report.

Beyond considering those areas known to be contaminated, we considered the area of certain land uses known to result in some form of land contamination, such as mining, quarrying and waste disposal. The LUCAS 2009 data provides figures for land use for mining and quarrying activities covering 1,439,400 ha of the EU, a further 761,100 ha is associated with waste and water treatment. The Corine 2006 land use data provides information for similar categories, mineral extraction sites, covering 610,099 ha and dump sites covering 104,616 ha[60]. Heavy extraction industries and waste processing areas (such as landfill sites) may have some area of land potential suitable to accommodate energy crops. However, the land use information provided by pan-European datasets does not provide a further disaggregation to allow such an assessment.

Having contacted individuals from the mining industry, and considering the variety of different mineral extraction, and quarrying activities that take place in the EU, it was not possible to estimate further what proportion of these areas could be cultivated if any.

Once mining is complete or landfill sites are full the land use changes depending on the remediation activities carried out, farming or forestry are common on such sites or, depending on their location, recreational areas (Box 8).

Box 8: Land contaminated by mineral mining and extraction activities

On average, the mining industry exploits an area of land (which, in the majority of cases, was previously used for agricultural purposes) for 30-50 years. The main activity undertaken on the land is excavation. Once the activities in the mine have come to an end, the following scenarios are envisaged:

- The mining company is requested to restore the site. In the great majority of cases, the process of restoration makes the land suitable for agricultural and forestry purposes. Once it is restored to farmland, the areas of land is then absorbed by agricultural statistics (ie EEA Statistics)
- The ex-mining land is not restored, and is automatically excluded from production because it is still contaminated from a previous use (in most cases, it is used for water management purposes).

Source: Personal communication, B Barov

[60] Detailed descriptions of the different Corine Land Classes are available at http://sia.eionet.europa.eu/CLC2000/classes/index.html [Last Accessed, 31 March 2014] Detailed descriptions of the different LUCAS Land Classes are available from Eurostat (2009).

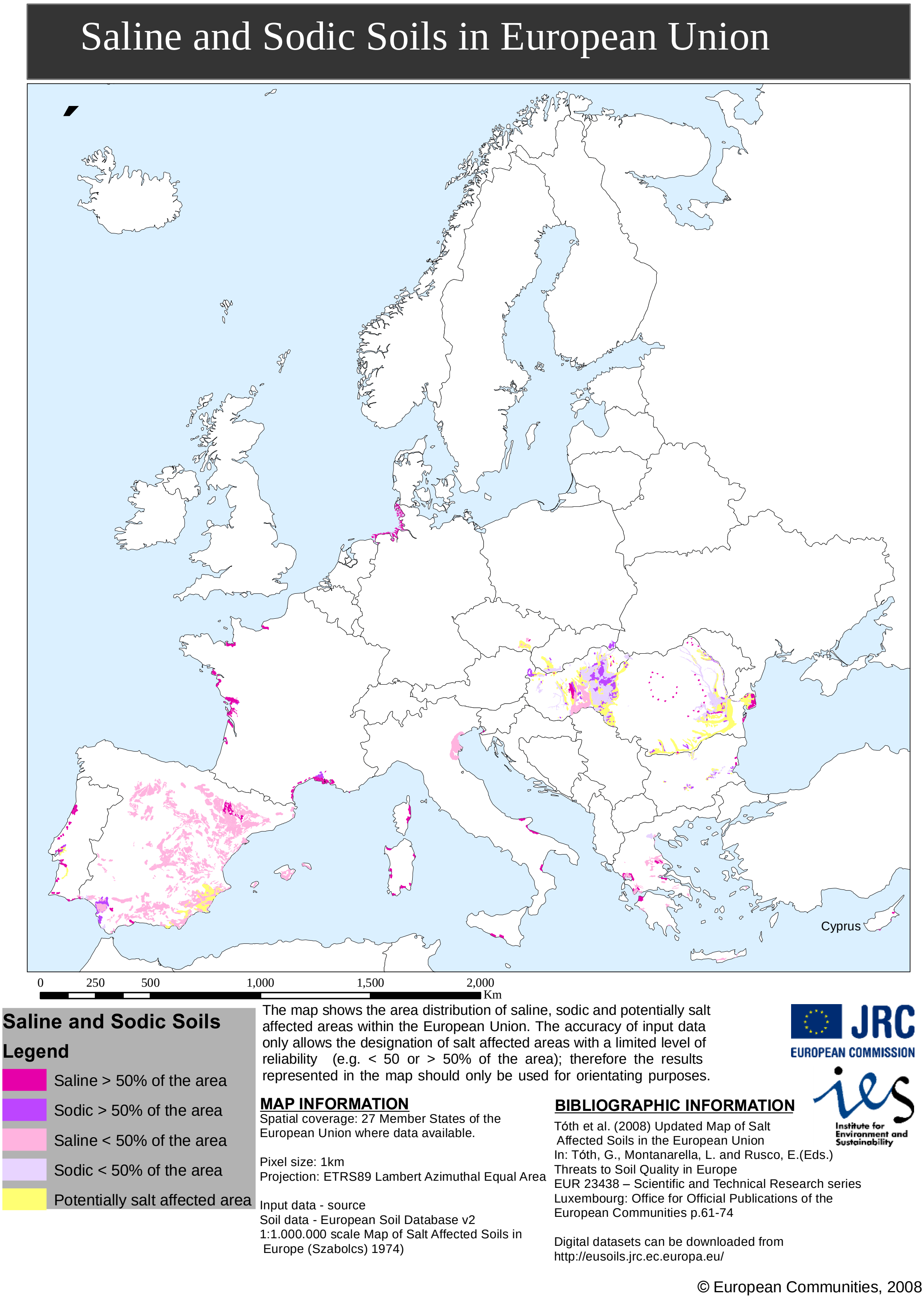
Salinisation and sodification

Another form of soil contamination considered in this review relates to salinization and sodification, the process whereby the accumulation of soluble salts of sodium, magnesium and calcium in soil increase to the point where soil fertility is severely reduced. It is regarded as a major cause of desertification and therefore is a serious form of soil degradation. Salinisation and sodification are among the major degradation processes endangering the potential use of European soils. Information available through the European Soils Data Portal from the JRC suggests that soil salinisation affects an estimated one to three million hectares in the EU, mainly in Mediterranean countries, as can be seen in Figure 5.

Salinisation, is often associated with irrigated areas where low rainfall, high evapotranspiration rates or soil textural characteristics impede the washing out of the salts which subsequently build-up in the soil surface layers. In coastal areas, salinisation can be associated with the over exploitation of groundwater caused by the demands of growing urbanisation, industry and agriculture. Over-extraction of groundwater can lower the normal water table and lead to the intrusion of marine water. Natural disasters such as tsunamis or localized processes such as de-icing of roads with salts can cause salinization also.

Despite some information on the extent and distribution of salinisation in the EU, it is not possible to determine the current use of these areas of land without further spatial analysis. A visual assessment of Figure 5 suggests that these salinized areas cover a variety of uses from agricultural production, urban fringe areas and bare and unused land.

Figure 5: Distribution of saline and sodic soils in the European Union



Source: Toth *et al*, 2008; Panagos *et al*, 2012

Annex 3 Energy crop yields

Yield assumptions are a key parameter when estimating energy potential from crops. Yield developments and responses have been a major point of discussion in relation to the ILUC impacts of conventional biofuels; they are no less important in the context of perennial energy crops. Given the (temporal) scope of the study focuses on current potentials, we do not make use of projected future yields for energy crops. But even assumptions about current yields are difficult to make given widely ranging estimates available in the literature (see also summary table in next annex). Some of the high-end figures reported in the literature represent single data points for yields achieved in very particular settings and are therefore of no use for a study that attempts to make an EU wide estimate of energy crop potential.

For our yield estimates, we rely predominantly on a literature review by Searle and Malins (2014), which systematically compiled, categorised and analysed information on yield estimates. The motivation of this literature review was to test the substance behind often extraordinary yield expectations for energy crops underlying policy targets and roadmaps. The review finds that current expectations need to be moderated to be realistic. Three points stand out from their analysis:

- Searle and Malins explain that (review) studies on yields of energy crops often refer to plot-level yields; yields obtained for commercial, field-scale are often considerably lower, however, due to biomass losses through mechanical harvest and from drying; and due to the presence of beneficial edge effects in small plots driving up yields in such settings;
- Yields are clearly lower on 'marginal' than on good quality land, a result that is not very surprising but important to underline given frequent calls for growing energy crops on 'marginal' land to avoid competition with existing agricultural production;
- The potential for future yield improvement is limited and it would be unreasonable to expect a similar rate of yield increases as have been observed for example for wheat in the past. This is due to relatively low investments in energy crops and their improvement; long breeding periods hence making it simply slower to test eg improved breeds; a relatively low yield response to fertiliser input for most energy crops; not being able to manipulate the harvest index in order to raise yields[61].

We make use of the compilation of yields to be expected on commercial-scale, marginal land in order to inform our yield estimates for growing energy crops on abandoned and contaminated land. Both of these can be expected to be of lower quality, hence 'marginal' in the sense of the word as used by Searle and Malins (2014). Fallow land can be assumed to be of better quality, which is why we use different yield assumptions in this case as set out below. Table 9 is taken from Searle and Malins' review (2014) and adapted for the purpose of this study. In particular, we add figures for reed canary grass as an example for an energy crop that is suitable in colder, Northern European climates.

[61] This refers to the fact that part of the historic yields improvements for conventional crops, such as wheat, have been achieved by improving the grain-to-stalks ratio. Given that the whole plant is processed in the case of energy crops, such manipulation is not an option.

Table 9: Yields of energy crops that can be expected at commercial scale on land that is marginal for agriculture, by climatic zone (dry tonnes per hectare and year)

	Cold temperate	Temperate	Warm temperate	Tropical/ subtropical	*Average per crop*
Miscanthus	3-5	**7-15**			*7-15*
Switchgrass		2-7	**5-10**		*5-10*
Willow SRC	0-10 ***[2-10]***	**4-13**			*3-12*
Poplar SRC	3-8	**4-10**	**4-10**	**4-10**	*4-10*
Eucalyptus		**5-15**	**5-15**	**5-15**	*5-15*
Reed canary grass	***4-7***				*4-7*

Source: Table 2 in Searle and Malins (2014, p5), adapted as explained in notes; range for reed canary grass taken from Alexopoulou *et al* (2012)

Notes: Figures in *italic* added for the purpose of this study; ranges in **bold** used to calculate average range (last column). Willow range for cold temperate: Upon inspection of the Searle and Malins (2014) supporting online material, we discarded the lower-end value of 0, precisely 0.37 found by Tahvanainen and Rytkonen (1999) and caused by weed failure (assuming that such problems would be addressed before commercial scale planting) and used instead the next lowest value of 2 for marginal land from the study by Mitchell (1995).

In order to calculate average yields per crop (last column in Table 9), we excluded the lowest yield ranges per crop. This is based on the assumption that farmers would choose the crop suitable for the climatic conditions they operate in, eg a farmer located in a cold temperate climate zone would not grow miscanthus. Given that yields ranges across the energy crops considered are reasonable similar, we also average across crops and **ultimately work with a single range across all five crops and all climate zones of 4.7 – 11.5 dry t/ha** (this is for abandoned and contaminated land). This is a practical assumption also in light of considerable uncertainties regarding farmers' decisions for or against certain energy crops in certain regions as well as the absence of spatially disaggregated data on available land. Fallow land can be assumed to be higher-yielding, partly in line or close to arable land. We therefore scale up energy crops yields by using the **11.5 dry t/ha** from above as the lower-end yield estimate and assume a 50 per cent higher upper-end yield estimate, ie **17.25 dry t/ha**.

Annex 4 Energy conversion factors

In order to convert biomass yield in tonnes (see previous annex) into a calorific unit, we used conversion factors from the ECN Phyllis2 database for the lower heating value (LHV) of biomass[62]. Calorific values across the crops considered are broadly similar and range between 17 and 19 MJ per dry kilogram, we therefore assume an **average calorific value of 18 MJ per dry kilogram for all crops**.

The next step is the conversion of the embedded energy in biomass into usable energy, whereby we distinguish different conversion routes for the electricity, heat and transport sectors. For the first two, we make use of information provided by IINAS from the GEMIS model[63]. The relevant conversion factors for **heat and electricity pathways** chosen for this study are summarised in Table 10. Worth noting are the assumptions with regard to electricity generation and heat uptake. We assume a split of biomass going into co-firing versus co-generation of 55-45. This is highly optimistic and assumes that all countries would move towards the co-generation shares out of total gross electricity generation achieved by the best performers[64].

Table 10: Conversion factors for heat and electricity generation (all 2010 values)

Bio-electricity systems	**eta conv (fuel processing)**	**eta-el**	**el-to-heat ratio (effective)**
Co-firing in coal plants (wood pellets, various sources)	0.975	0.35	0
Cogeneration ST-BP plants (wood chips and pellets, various sources)	0.95	0.3	0.4
Bio-heat systems	**conversion efficiency, fuel to heat**		
Bio-heat direct (wood chips and pellets, various sources)	0.8		
Bio-district heat (wood chips and pellets, various sources)	0.8		

Source: IINAS et al (2014)

Notes: "eta conv" corrects for upstream conversion (e.g. losses from chipping, pelletizing); "eta-el" is the (net) conversion efficiency of fuel input to electricity output.

The following summarises assumptions applied when using the conversion factors from IINAS as represented in the above table:

- All efficiencies refer to the **lower** calorific value of the input;
- We assume an average upstream conversion factor "eta conv" of 0.96 (average of the 0.95 and 0.975 values reported in the table) and apply this to all heat and electricity pathways;

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[62] https://www.ecn.nl/phyllis2

[63] IINAS is part of a consortium that at the time of writing conducted a parallel study for the same group of NGOs to evaluate the biomass and energy potential from the European forestry sector (IINAS *et al*, 2014). In order to ensure consistency, we used the same conversion factors for heat and electricity conversion to their study.

[64] Based on data from COGEN Europe, the EU wide co-generation share is at 11.2% (Eurostat figures for 2011). Shares across MS range from zero to 47.4%, with the greatest shares in Latvia (47.4%), followed by Denmark (46.2%), http://www.cogeneurope.eu/what-is-cogeneration_19.html.

- Electricity output is hence calculated as biomass volume expressed in terms of its lower calorific value (Joules) multiplied by 0.96 and by “eta-el” (from Table 10);
    - Heat output from cogeneration is calculated as the electricity output divided by the electricity-to-heat ratio (“el-to-heat ratio (effective)” in Table 10)
- Dedicated heat output is calculated as biomass volume expressed in terms of its lower calorific value (Joules) multiplied by 0.96 and by 0.8 (Table 10).
- All conversion factors provided by IINAS for co-firing, cogeneration and heat conversion are for woody biomass (pellets and chips). In the absence of more comprehensive information we assume these for our mix of biomass sources, which includes energy grasses.

For **converting biomass into biofuels**, we chose to use a single figure for biofuel conversion efficiency. In other words, no distinction between ethanol and biodiesel pathways is made and no distinction is made for different conversion efficiencies when using different crops. We chose this pragmatic approach in order to keep the number of ranges for different parameters within reasonable limits; given the focus of the study, it was found more important to work with uncertainty ranges for land availability estimates. It should also be noted that based on data available, differences in conversion factors between different crops are not apparent in a robust way.

Table 11 shows a collection of conversion factors for biofuel pathways from different sources. Based on this, **we chose a uniform conversion factor of 0.23 tonnes fuel per dry tonne of biomass**, *to be applied to all feedstock and pathways*. This is based on the following considerations:

- The average of ethanol yields for grassy and woody crops based on industry data (from the cellulosic ethanol plant in Crescentino, Italy, run by M&G) is 0.20;
- The considerably higher yield from the US GREET model was dismissed as overly optimistic (not backed by industry data from Europe);
- The mid-point of a range of yields reported by Baral and Malins (2014) for an FT biodiesel pathway is 0.20. This value is confirmed by another industry source operating FT processes;
- The average pyrolysis fuel yield of 0.30 based on Baral and Malins (2014) estimates used;
- The average of those estimates gives the yield of 0.23 chosen. This compares well with the single figure yield estimate of 0.25 chosen by Searle and Malins (2013), which according to the authors represents an optimistic value accounting for some technical progress. As we are interested in **current** potential, our chosen value is justifiably lower.

This approach means that we do not form any particular assumptions about the likely mix of advanced biodiesel and ethanol pathways. This seems reasonable given very limited investments currently that do not allow for weighting one pathway higher than the other.

Table 11: Conversion factors biofuels

<table>
<tr><th>Variable</th><th>Ethanol yield</th><th>Ethanol yield (M&G)</th><th>Fischer Tropsch-diesel yield</th><th>Combined diesel-petrol yield (pyrolysis)</th><th>Biofuel yield</th></tr>
<tr><td>Unit</td><td colspan="5">tonne fuel/dry tonne biomass</td></tr>
<tr><td>Miscanthus</td><td rowspan="2">0.26</td><td rowspan="4">0.22</td><td rowspan="6">0.16-0.22</td><td rowspan="6">0.28</td><td rowspan="7">0.25</td></tr>
<tr><td>Switchgrass</td></tr>
<tr><td>Reed canary grass</td><td></td></tr>
<tr><td>Giant reed</td><td></td></tr>
<tr><td>willow</td><td rowspan="2">0.26</td><td rowspan="2"></td></tr>
<tr><td>Poplar</td></tr>
<tr><td>Wood/ woody crops</td><td></td><td>0.17</td><td>0.22-0.23</td><td>0.32</td></tr>
<tr><td>Forest biomass</td><td></td><td></td><td>0.2</td><td>Baral and Malins reasonable</td><td></td></tr>
<tr><td>Source:</td><td>GREET model 2013[65]</td><td>Sandro Cobror, pers comm</td><td>Baral and Malins (2014) (for ag and forestry residues); forest biomass: industry source</td><td>Baral and Malins (2014) (for ag and forestry residues); forest biomass: industry source</td><td>Searle and Malins (2013) (based on M&G 'optimistic' value)</td></tr>
</table>

Source: Own compilation

[65] GREET model developed by Argonne National Laboratory, https://greet.es.anl.gov/

Annex 5 Energy crop factsheets

This annex includes a summary of the agronomic requirements and environmental impacts associated with energy crops and energy crop factsheets.

Table 12 summarises a range of ***agronomic requirements of energy crops***. Energy crops considered are characterised by varying tolerance to **growing conditions**. Some are adaptable to different climatic zones found in Europe, such as miscanthus and switchgrass. Both willow and reed canary grass can be grown in colder, Northern European climates, whereas giant reed and eucalyptus need warmer climates to thrive. Water availability can be considered a limiting factor to some of the crops' development, with miscanthus, giant reed, willow, poplar, eucalyptus reported to need moist soils or good water availability. Some of the crops considered are reportedly adaptable soil types, such as reed canary grass, willow, poplar and eucalyptus. **Nutrient requirements** tend to be lower for the perennial crops considered here compared with conventional annual crops, remaining equivalent or below 100 kg per hectare for several crops.

Regarding likely ***environmental impacts*** of the crops considered here, the factsheets following the table list both positive and negative environmental impacts. Crop-specific information was difficult to find, given the little experience in growing most of the crops considered. The main report sets out general trends that can be observed from the crop specific information, in line with other studies looking into environmental impacts associated with energy crops, such as EEA 2013, BIO IS and IEEP (forthcoming) and others.

Table 12: Summary of energy crop agronomics, impacts, yields and distribution

Energy crop	Yield	Growing conditions	Nutrient requirements	Main EU cropping areas*	Environmental implications
Eucalyptus	**4 to 24** t/ha (Searle and Malins, 2014)	Well adapted in mild temperate climates, in Europe mostly in the Mediterranean; north-western coast of ES and PT particularly suitable (high precipitation levels, short dry season, minimum temperature >-7° C). Best on sandy clay soils, can be grown on marginal and poor soil and on deep soils with available moisture (ie South-western Spain).	N fertilisation rate varies from 60-125 kg/ha	Portugal and Spain	Drought-tolerant; high water requirements; native to Australia, New Guinea, Indonesia; has been categorised as invasive in several countries
Giant reed	**6-7 t/ha** (Scordia *et al*, 2009)	Mainly growing in warm temperate or subtropical climatic zones, but can survive in areas with short period of frost. Prefers soils with moisture abundance	N fertilisation from 50-100 kg/ha	Mediterranean area	Impacts uncertain. High resistant to drought (can grow without irrigation); Originated in Asia but considered a native in the countries surrounding the Mediterranean sea,; pest resistant.
Miscanthus	**5-13t/ha** on poor marginal land, **7-44t/ha** on sufficient irrigated arable land; **13-44t/ha** in warm temperate regions (Greece); **7-9t/ha** at field scale (Searle and Malins, 2014). Low yields after establishment, progressive increase after the 3rd year.	Very adaptable to all climatic zones in Europe; sensitive to extremely cold weather conditions and when supplementary irrigation is needed (Nemoral and Mediterr. South, respectively). Easier to establish on lighter soils, but higher yields on heavy soils (higher water availability)	High nitrogen-use efficiency; nitrogen and nutrient requirements very low	UK, France, Ireland	High water requirements, risks to groundwater; however high water use efficiency. Biodiversity impacts uncertain. Potential increase in SOM and limited water retention, potential erosion risk in first year, increase soil carbon. Poor performance again weed; Native to Asia and Africa
Poplar	Mostly between **5-10** t/ha; **2.2-11.4** t/ha in a former landfill site in Belgium, **3.6** t/ha in a former mining site (Searle and Malins, 2014)	Suitable for temperate regions, requiring abundant irrigation/precipitation. Tolerates poor soil conditions	Low fertiliser needs	Italy, Germany, Denmark	Some genotypes are drought tolerant; High water requirements.
Reed canary grass	**4-7t/ha** (Alexopoulou *et al*, 2012)	Well adapted in cool temperate climate. Good winter hardiness and survives well in North Scandinavia. Most soil types suitable, particularly suitable for poorly drained soils with good tolerance to flooding		Finland; Sweden; Denmark	Drought-tolerant; high water requirements; native to the temperate regions of Europe, Asia, and North America.
Switchgrass	**5-10 t/ha** (temperate areas, arable and moderate quality soils); **10.9 t/ha** grown in monoculture vs. **4.4 t/ha** grown in mixtures, unless legumes part of mixture (Searle and Malins, 2014). At least 3 years to reach full yield potential	Many varieties, adaptable to many climatic zones, less so to far north latitudes	In general no nitrogen (N) is needed the establishment year; afterwards low N need of 0-70 kg/ha	Negligible at present, apart from high estimate for Romania	Little experience hence impacts rather uncertain; reduced nutrients run-off losses, limited gully erosion, increase soil carbon; biodiversity unclear (higher yields in monoculture); native to North America
Willow	**5-10 t/ha** (Searle and Malins, 2014); **5** (Ireland), **8-10** (Sweden), **8-20** (UK), **15-20** (Italy) t/ha (all in odt).	Mainly in continental climate zones, best in Northern Europe; can be grown on a wide range of soil types, light as well as loamy soils; not suitable for cold climates or dry locations	Sweden: no N applied in the 1st year of establishment; 45kg/ha applied in 2nd year, 100-150 kg/ha in 3rd year	UK, Poland, Denmark	Water demanding (irrigation not viable); Provides an habitats for animals and plants (for example, butterflies, invertebrates and birds); Increased SOC, low soil erosion; Potential negative visual impacts; Native to Europe (particular, the UK)

Source: Own compilation based on sources cited here and in the detailed factsheets following **Notes:** * mainly from AEBIOM (2013)

Factsheet Eucalyptus

Eucalyptus *(Eucalyptus* spp.*)*	
Harvest and cultivation methods	Established by stem cuttings and planted in double rows. When cultivated in very short rotation cycle plant density is 2 plants/ha (Alexopoulou *et al*, 2012).
Sensitivity to growing conditions	Well adapted in mild temperate climates and at high elevation in cool tropical regions. In Europe mostly found in the Mediterranean countries; particularly suitable conditions are found in the north-western coast of Spain and Portugal, with high levels of precipitation, a short dry season and minimum temperature above -7°C (Rockwood *et al*, 2008). Best production in sandy clay soils, but has the ability to grow in marginal and poor soil (Campinhos, 1999). Able to grow on deep soils with available soil moisture (south-western Spain) (Alexopoulou *et al*, 2012).
Nutrient requirements	Nitrogen fertilisation rate varies from 60-125 kg N/ha (Alexopoulou *et al*, 2012).
Typical yield range	Range of yields between 4 to 24 t/ha (Searle and Malins, 2014).
Current EU distribution	Portugal and Spain (Rockwood *et al*, 2008).
Water requirements and (quality) impacts	Benefit: • Drought-tolerant (Searle and Malins, 2014). Risks: • High water requirements leading to significant impact on water storage (Searle and Malins, 2014). • Very sensitive to moisture stress (Alexopoulou *et al*, 2012).
Biodiversity implications	*No crop-specific information found.*
Soil implications	*No crop-specific information found.*
Other environmental implications	Native to Australia. Although some species are native to New Guinea, Indonesia and the Philippines (Forsyth *et al*, 2004; Searle and Malins, 2014).

Factsheet Giant Reed

Giant Reed *(Arundo donax* L.*)*	
Harvest and cultivation methods	It can be harvested every year or every second year. Two harvests per every period are sustainable (Lewandowski *et al*, 2003). Average plantation is 1 to 2 plants per square meter (Alexopoulou *et al*, 2012).
Sensitivity to growing conditions	Mainly grown in warm temperate or subtropical climatic zones, but can survive in areas with short period of frost (Alexopoulou *et al*, 2012). Prefers soils with abundance of moisture (Alexopoulou *et al*, 2012).
Nutrient requirements	If nutrient status of soil is poor, a sufficient amount of K and P should be applied. Nitrogen fertilisation from 50-100 kg N/ha (Alexopoulou *et al*, 2012).
Typical yield range	Increasing yields from the first to the third year (Lewandowski *et al*, 2003). Yields reported in Europe are between 6-7t/ha (Scordia *et al*, 2009).
Current EU distribution	Currently found in the Mediterranean area (Christou, 2013).
Water requirements and (quality) impacts	Benefit • High resistance to drought due to strong root • Grows without irrigation under semi-arid southern EU conditions (Lewandowski *et al*, 2003).
Biodiversity implications	*No crop-specific information found.*
Soil implications	*No crop-specific information found.*
Other environmental implications	• Originated in Asia but considered a native species in the countries surrounding the Mediterranean sea (Alexopoulou *et al*, 2012). • Pest resistant crop (Searle and Malins, 2014).

Factsheet Mischanthus

Miscanthus *(Miscanthus spp.)*	
Harvest and cultivation methods	10 years productive life, the yield increases annually (Searle and Malins, 2014). Preferred way of planting is by rhizome division (very costly). Average plantation is 1 to 2 plants per square meter (Lewandowski *et al*, 2003). Preferred harvesting conditions are during the spring (February to April), when M. is well dried. Alternatively, harvested wet and dried artificially (Lewandowski *et al*, 2003).
Sensitivity to growing conditions	Very adaptable. Cultivated in all climatic zones of Europe, whereas very sensitive to extremely cold weather conditions and when supplementary irrigation is needed (e.g. Nemoral and Mediterranean South zones respectively). Highly sensitive in the first winter following establishment (Elbersen *et al*, 2012). Easier to establish on lighter soils, but higher yields on heavy soils because of higher water availability (Schwarz *et al*, 1993).
Nutrient requirements	High nitrogen-use efficiency (nitrogen and nutrients requirements very low) (Biomass Energy Centre, 2011; Searle and Malins, 2014). Reported Nitrogen leaching of 3-30 kg/ha (from third year onwards) (Lewandowski *et al*, 2003).
Typical yield range	Low yields after establishment, progressive increase after the 3rd year. From 5-13t/ha on poor marginal land, and from 7-44t/ha on sufficient irrigated arable land. Highest yields (13-44t/ha) in warm temperate regions (such as Greece). Another review found yields of 7-9t/ha found at field scale. (Searle and Malins, 2014).
Current EU distribution	Main cropping areas (2011): UK, France, and Ireland (AEBIOM, 2013).
Water requirements and (quality) impacts	Risks • High water requirements (between 750 – 800mm) • Decrease of groundwater (Alexopoupou *et al*, 2012). Benefits • High water use efficiency (272L/kg dry matter) (Elbersen *et al*, 2012).
Biodiversity implications	Risks • Reduced biodiversity if semi-natural habitats are replaced • Losses of some rare species if grown on some post-industrial sites • Open-field could be negatively affected, especially by large-scale planting (Kretschmer *et al*, 2011; Tucker *et al*, 2008; Gove *et al*, 2010). Benefits • Potential increases in the abundance of some birds and butterflies • Less disturbance, more weed and structural diversity • Potential benefits if grown on contaminated land that does not hold rare species (Kretschmer *et al*, 2011; Tucker *et al*, 2008; Gove *et al*, 2010).
Soil implications	Benefits • Potential increase in soil organic matter and soil structure, due to soil cover and the high inputs of organic matter from shed leaves (10-20 t/ha of rhizomes in the top soil and 6-8 t roots) • Potential increase in humus content, cation exchange capacity (number of cations a soil can hold, a measure of soil fertility) • Limited water retention (Lewandowski *et al*, 2000). • Increase soil carbon (Searle and Malins, 2014). Risks • Potential erosion during the first year since plants remain small and do not provide ground cover

	• Negligible risk against the release of pesticides into the environment, and diseases (Lewandowski *et al*, 2000).
Other environmental implications	• Poor performance against weeds in the first year. Once fully established, weed control is no longer necessary (Lewandowski *et al*, 2000). • Perennial grass native to Asia and Africa (Searle and Malins, 2014).

Factsheet Poplar

Poplar *(Populus* spp.*)*	
Harvest and cultivation methods	Planted in spring from cuttings. Planting density typically 10-12,000 per ha; cut back takes place the following winter (Biomass Energy Centre, 2011).
Sensitivity to growing conditions	Suitable for temperate regions, requiring abundant irrigation/precipitation. Tolerates poor soil conditions (Searle and Malins, 2014).
Nutrient requirements	Low fertiliser needs (Alexopoulou *et al*, 2012).
Typical yield range	Yields mostly range between 5-10t/ha. Yields between **2.2-11.4** t/ha has been found in a former landfill site in Belgium, and **3.6** t/ha in a former mining site. (Searle and Malins, 2014).
Suitability on different land types	Tolerates poor soil conditions. For example, yields between 2.2t/ha and 11.4t/ha in a former landfill site in Belgium. (Searle and Malins, 2014).
Current EU distribution	Main cropping areas (2011): Italy, Germany, Denmark (AEBIOM, 2013).
Water requirements and (quality) impacts	Benefits • Some genotypes are drought tolerant (ie Populus polularis) (Chen *et al*, 1997). Risks • High water requirements (Searle and Malins, 2014).
Biodiversity implications	*No crop-specific information found.*
Soil implications	*No crop-specific information found.*
Other environmental implications	N/A

Factsheet Reed Canary Grass

Reed Canary Grass *(Phalaris arundinacea* L.*)*	
Harvest and cultivation methods	Preferred way of planting is by seed. 10-15% of moisture content at harvest time (Alexopoulou *et al*, 2012). It can be harvest once a year during late fall to early spring (Lewandowski *et al*, 2003).
Sensitivity to growing conditions	Well adapted in cool temperate climate. Good winter hardiness and survives very well in North Scandinavia (Alexopoulou *et al*, 2012). Grows well in most types of soils (Østrem, 1987). Particularly suitable grass species for poorly drained soils with good tolerance to flooding. Even though it grows mostly in wet places, it is fairly resistant to drought (Lewandowski *et al*, 2003).
Nutrient requirements	*No crop-specific information found.*
Typical yield range	Yields vary between 4-7t/ha for ten or more years (Alexopoulou *et al*, 2012).
Current EU distribution	Main cropping areas (2011): Finland, Sweden, and Denmark (AEBIOM, 2013).
Water requirements and (quality) impacts	Risks: • High water requirements when established (Missouri Botanical Garden). Benefits: • Drought-tolerant (Missouri Botanical Garden).

Biodiversity implications	*No crop-specific information found.*
Soil implications	*No crop-specific information found.*
Other environmental implications	• Native to the temperate regions of Europe, Asia and North America (Lewadowski *et al*, 2003). • Potentially affected by rusts, mildew and other fungi (TSEC-Biosys, 2006).

Factsheet Switchgrass

Switchgrass *(Panicum virgatum* L.*)*	
Harvest and cultivation methods	10-20 years productive life; one-cut (after November or first killing frost) or two-cut (1st cut in June/July, 2nd at end of season usually after first killing frost) system (Genera Energy, 2012). Easy and cheap establishment made by seed at a rate of 200-400 pure live seeds/meter (PLS/m). Plant density varies from 100 to 200 plants per square meter (Alexopoulou *et al*, 2012). At the harvesting time the moisture content varies from 15 to 40%, according to the specific site of cultivation. It grows to a height of about 2 m, has a deep and fibrous root system (Skinner *et al*, 2012).
Sensitivity to growing conditions	Very adaptable to wide range of climatic zones of Europe, mainly because there are many varieties available (approx. 20 identified) (ATO-BV *et al*, 2001).
Nutrient requirements	In general no nitrogen is needed the establishment year; afterwards switchgrass has a low nitrogen need (0-70 kg N/ha) (Alexopoulou *et al*, 2012).
Typical yield range	5-10 t/ha in temperate areas and on arable and moderate quality soils. Yields of switchgrass grown in monoculture (10.9 t/ha) expected to be greater than those in mixtures (4.4 t/ha), unless legumes are part of the mixture. It takes at least 3 years to reach full yield potential. (Searle and Malins, 2014).
Current EU distribution	Negligible at present, apart for high estimate for Romania (AEBIOM, 2013).
Water requirements and (quality) impacts	Benefits • Limited irrigation needed (low compared to Miscanthus) • Reduced nitrate contamination in surface and groundwater (as for other energy crops, eg Elbersen *et al*, 2013)
Biodiversity implications	Benefits • When grown in mixtures with other native grasses, potential for some biodiversity support (at the expense of lower yields compared to monoculture) (Searle and Malins, 2014) Risks • Little experience hence impacts are uncertain
Soil implications	Benefits • Reduced soil splash • Reduced nutrients run-off losses • Reduced rills • Limited gully erosion • Increase soil carbon (Searle and Malins, 2014)
Other environmental implications	Perennial C4 grass native to North America (Searle and Malins, 2014)

Factsheet Willow

Willow *(Salix* spp.*)*

Harvest and cultivation methods	Established by stem cuttings which are planted in double rows at a density of 0.5 – 2 per square meter. Cutback in its first winter (Biomass Energy Centre, 20122). First harvest is in winter, typically after three years from first cut. (Alexopoulou *et al*, 2012)
Sensitivity to growing conditions	Mainly in continental climate zones, best in Northern Europe; can be grown on a wide range of soil types, light as well as loamy soils, pH range from 6.0-7.5. (El Bassam, 2013) Not suitable for cold climates (Searle and Malins, 2013) or dry locations (El Bassam, 2013).
Nutrient requirements	Mainly in Sweden, no nitrogen is applied in the first year of establishment. In the second year 45kg N/ha are applied, 100-150 kg N/ha in the third year (Alexopoulou *et al*, 2012).
Typical yield range	Yields between 5-10 t/ha (Searle and Malins, 2014); 5 (Ireland), 8-10 (Sweden), 8-20 (UK), 15-20 (Italy) t/ha (all in odt) (El Bassam, 2013).
Current EU distribution	Main cropping area (2011): Sweden, Poland, and Denmark (AEBIOM, 2013).
Water requirements and (quality) impacts	Risks • Water demanding. The water use is similar to that of a cereal crop, higher than permanent grass and lower than that of mature woodlands (RELU, 2009). • Irrigation not economically viable in short rotation forests (Alexopoulou *et al*, 2012).
Biodiversity implications	Benefits • Providing a habitat for animal (small mammals and invertebrates) and plants uncommon in the area (Rowe, 2011). • Field margins of willow can host more butterflies of conservation interest, while pest species of butterflies were less abundant • More weeds and a greater range of invertebrates, compared to miscanthus • Likely to have a positive impacts on the abundance of both farmland and woodland birds (RELU, 2009).
Soil implications	Benefits • Increase in soil organic carbon and lower soil erosion risks, similar to other energy crops (eg Elbersen *et al*, 2013 and others, as per main text)
Other environmental implications	Native to the UK (RELU, 2009). Risks • Potential negative visual impacts (RELU, 2009).

Annex 6 Limits to cultivation

When EU wide area figures are presented there is a tendency to think of these as large swathes of land that could be managed or cultivated coherently to feed large-scale energy or biofuel generation plants. In reality, the majority of the different land types described above exists in small patches dispersed across the EU. The dispersal of such land areas raises questions about suitable transport distances for low energy density biomass (such as energy crops), and therefore whether these land parcels can provide economically competitive biomass at suitable volumes.

Bio-climatic factors, such as climate, soil and terrain constraints influence the proportion of land suitable for different uses. The spatial distributions of such limitations have been assessed using soil and terrain maps. These have been used to identify the areas of EU terrestrial rural land that experiences various constraints on agricultural production in relation to temperature, slope, wetness and soils (FAO - IIASA, 2007)[66]. These are expressed spatially in Figure 6.

For agricultural production, the map shows that only around nine per cent of EU land in 2007 was subject to no constraints on production, with a further 23 per cent subject only to slight constraints. Conversely, almost a quarter of all EU-land was considered to be subject to severe constraints, with the largest proportion of this area constrained by limited soil quality. The distribution of these constraints is not even. Thirteen Member States have over 40 per cent of their land area facing no or only slight constraints[67] whilst six were shown to have more than one fifth of their land area subject to poor soil quality, including a number of Mediterranean regions, but also the UK and Ireland[68].

The spatial distribution of these land use constraints can also be applied beyond agricultural production to other types of land use. The distribution of severe terrain constraints correlate with high alpine areas, with the Pyrenees, Alps, Dolomites and the Carpathian mountain ranges. These areas and the majority of northern Scandinavia, all tend to be dominated by forests. Severe soil constrains are apparent in the Mediterranean Member States, particularly from thin mineral soils suffering from drought conditions in Spain, central Italy and Greece where bareland and shrubland are significant proportions of land cover and where irrigated cropland is common. Other soil constraints are seen in northern UK and Scandinavia, particularly upland areas, with acidic and often waterlogged soils. These areas tend to be dominated by semi-natural vegetation such as upland blanket bog

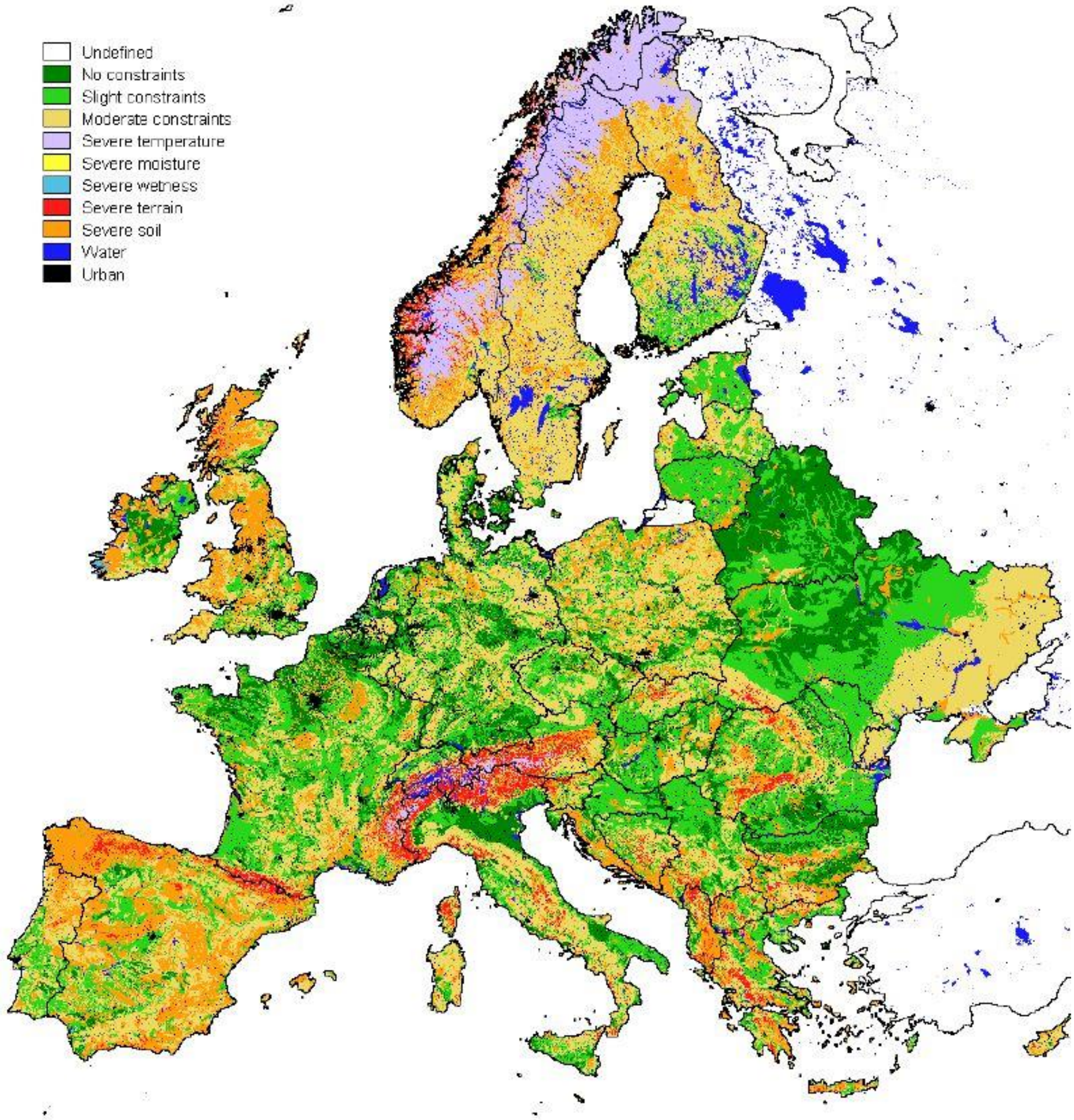
[66] ***Severe temperature*** – less than 120 days length of growing period (2.9% of land); ***severe wetness*** – less than 60 days length of growing period due to drought (<0.1% of land); ***severe terrain*** – greater than 30 per cent slope (3% of land); ***severe soil*** - soil depth less than 50 cm, poorly drained, low natural fertility, coarse texture and stones, or severe salinity or alkalinity (18.7% of land); ***moderate*** – with a growing season of fewer than 190 days (due to temperature and drought) or fewer than 180 days (due to temperature), a slope of 16-30%, a soil depth of 50-100 cm, a medium rather than a high level of natural fertility, or the soil comprised a heavy cracking clay (37% of land); ***slight*** – 8-16% slope (23% of land); and ***no constraints*** – less than 8% slope (9.1% of land). Source: FAO/IIASA, 2007

[67] SK (42%), DE (45%), FR (49%), BE (48%), the CZ (48%), DK (49%), NL (50%), BG (52%), RO (52%), HU (54%), EE (65%), MT (67%), and LT (76%)

[68] GR (21%), CY (22%) PT (25%), IE (38%), the UK (39%), and ES(43%)

on peat soils. In contrast the dominant arable production regions of the EU also stand out, generally those areas of no or only slight constraint[69].

Figure 6: Map of climate, soil and terrain constraints for rain-fed agriculture in the EU



Note: The constraints are derived using the Global AEZ methodology[70] applied to European datasets (FAO/IIASA, 2007, quoted by Eliasson, 2007). The slight and moderate constraints include climate, soil and terrain constraints.

Perhaps the most interesting parts of this map to consider are those areas in between these two extremes, those with moderate constraints. These tend to represent more extensive arable or mixed farming areas, particularly in western and some north-eastern Member States as well as the grassland and pasture areas in Scandinavian and more central and eastern Member States. Given the marginal economic nature of farming and the natural

[69] For example, the lowland and plain areas such as the Carpathian basin, the East Anglian fenlands and the Paris basin; or the areas of southern Romania and northern Bulgaria surrounding the Danube.

[70] Global Agricultural Ecological Zone Methodology (Fischer *et al,* 2002)

constraints faced, these areas may be more at risk from changes in land use, particularly from agricultural abandonment (Laurent, 1992; Keenleyside, 2004; Pointereau *et al,* 2008). Soil type, slope and exposure are important factors to explain farmland abandonment, but their relevance varies according to the type of agricultural system that characterises the production (Gellrich and Zimmerman, 2006).