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Introduction and key messages

The CCC’s bioenergy review provides an assessment of the potential roles for bioenergy given lifecycle emissions and other sustainability concerns, and also considers alternative uses for bioenergy feedstocks. The main report is available on our website: http://www.theccc.org.uk/reports/bioenergy-review

More detailed analysis on lifecycle emissions is covered in this technical paper. Three further technical papers are available on the website covering:

Technical Paper 2. Global and UK bioenergy supply scenarios
Technical Paper 3. Appropriate use of scarce bioenergy
Technical Paper 4. Biomass in power generation

Bioenergy has been identified as an important resource for meeting renewable energy targets. At the same time it has the potential to contribute to climate change mitigation, but its role here is uncertain and controversial. Bioenergy chains have complex implications for greenhouse gas (GHG) emissions and, in the worst cases, can result in higher emissions than the fossil fuel they are displacing. At its best, growing bioenergy feedstocks can enhance carbon sinks in addition to reducing emissions. Therefore it is important to make a full assessment of emission balances when considering the role of bioenergy in climate change mitigation.

Our focus in this technical paper is on the GHG emissions associated with bioenergy crop cultivation, the use of forest biomass and land use change. These are relevant for global emissions accounting and UK carbon budgets. We examine the complexities in determining lifecycle emissions, which is reflected by the significant variation in the results of different lifecycle studies. The biggest differences arise at the cultivation stage, or ‘up to the farm gate’ due in part to different assumptions about the factors that influence emissions. For example, when looking at the same crop, emissions will vary according to assumptions made about crop yields, fertiliser application rates, the allocation method for apportioning emissions to co-products and the extent to which land use change has been considered.

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1 Other effects on climate include for instance changes to the water cycle and surface reflectance, which can result in strong local warming or cooling depending on the previous land use. See e.g. Loarie et al. (2011) Direct impacts on local climate of sugar-cane expansion in Brazil, Nature Climate Change.
The key messages from our analysis are:

- **Liquid biofuels sustainability.** The Government should argue strongly for extending the European sustainability framework under the Renewable Energy Directive to cover indirect land use change (ILUC) emissions. This should either be through the use of ILUC factors or by capping the use of feedstocks with associated risks of ILUC.

- **Forest biomass sustainability.** The minimum emissions threshold required under the sustainability framework for the Renewables Obligation (RO) should be tightened from the current level of 285 gCO₂/kWh to 200 gCO₂/kWh. Serious consideration should also be given to introducing a sustainability standard to all wood used in the UK (e.g. pulp and paper, construction), which would provide more confidence that RO support for biomass in power does not result in indirect deforestation.

- **Flexibility of targets.** Liquid biofuel targets under the Renewable Transport Fuel Obligation and biomass targets in the Renewable Energy Strategy should be regarded as flexible, and adjusted in the event that there is insufficient supply of sustainable bioenergy.

- **New targets.** No new targets for longer term bioenergy penetration should be set until new regulatory arrangements are introduced to ensure achievement of sustainability objectives.

- **Accounting.** Any new global agreement limiting emissions should fully account for agriculture, forestry and land use change emissions, including those related to the use of bioenergy.

We set out our analysis in 6 sections:

1. Carbon accounting and bioenergy lifecycle emissions
2. Emissions from cultivation, processing and transportation of bioenergy crops
3. Emissions from direct and indirect land use change
4. Use of co-products
5. Emissions from forest biomass
6. Conclusions – is bioenergy low-carbon?

We do not cover lifecycle emissions related to wastes and agricultural residues, as in most cases these are significantly lower than for other feedstocks, especially where there are avoided methane emissions.
1. Carbon accounting and bioenergy lifecycle emissions

Bioenergy could in principle be carbon neutral when used for power, heat and transport; that is, its use does not produce a net increase of emissions because the amount of carbon dioxide (CO₂) released on combustion equals the amount originally removed from the atmosphere during plant growth. Under this assumption, the use of bioenergy will always deliver emissions savings compared to the counterfactual fossil fuel it is displacing.

In practice, bioenergy is not carbon neutral as GHG emissions of CO₂, methane (CH₄) and nitrous oxide (N₂O) are produced across the entire supply chain from the planting of the crop, through to its fertilisation and growth, processing and transportation (Figure 1). Land use change emissions – both direct and indirect – can be significant, especially where there is conversion of carbon-rich land. In the worst cases, combined emissions along the chain can exceed those of fossil fuels.

Whether the use of bioenergy delivers a net GHG emissions benefit has to be determined by comparing its lifecycle emissions, from cultivation to end use, against the lifecycle emissions of the counterfactual fuel. Such comparison would then allow the exclusion of bioenergy chains with high GHG emissions, which can in some cases result in higher emissions than the fossil fuel it is seeking to displace.

![Figure 1: Lifecycle emissions of bioenergy chain](image-url)

*Source: CCC.*
The current accounting framework in the UK reflects these lifecycle emissions only for domestically produced bioenergy feedstock. Imported feedstocks, which account for the majority of total UK bioenergy use, are regarded as zero carbon in the national inventory and hence in carbon budgets. The current international accounting framework has incomplete coverage, with the result that lifecycle emissions of many feedstocks are not accounted for anywhere (Box 1). This issue will become increasingly important as imports increase to meet ambitious renewable energy targets.

**Box 1: International accounting rules under the Kyoto Protocol**

Under the Kyoto Protocol of the United Nations Framework Convention on Climate Change, bioenergy emissions should be included in the annual carbon accounts of the country in which the bioenergy feedstock was harvested. Hence, bioenergy emissions should be reflected in the Land Use, Land Use Change and Forestry (LULUCF) or agriculture inventories rather than the energy inventory. In practice, a large proportion of these emissions are not being captured in the inventories or elsewhere:

- **Annex I countries** (developed nations) signed up to the Protocol are required only to report LULUCF emissions arising from deforestation, reforestation and afforestation. In contrast, the cultivation of bioenergy crops or harvesting of forest biomass is usually counted as crop and forestry management, for which emissions reporting is at the discretion of each member state.

- **There are no requirements** on Annex II countries (developing nations) or other countries which have not ratified the Protocol (e.g. the United States) to account for any emissions.

This means that a large proportion of emissions from large producers of bioenergy feedstock in both Annex I countries and those countries not signed up to Kyoto are being ignored.
Emissions from cultivation

Emissions related to the cultivation of bioenergy crops (food and fodder crops and dedicated energy crops) occur for a number of reasons including the use of diesel powered farm machinery, energy emissions from the manufacture of fertiliser and other agrochemicals, and nitrous oxide emissions from the application of fertiliser to soil.

Although these emissions could erode up to around 35% of the potential savings from using biofuels instead of fossil fuels for surface transport use on a lifecycle basis, there are crops with lower associated emissions and increased availability expected in the future (Figure 2):

- **Oil seed rape and wheat:** Temperate annual crops, such as oil seed rape and wheat have cultivation emissions of the order 23-28 gCO₂e/MJ of biofuel, equivalent to between 28-34% of lifecycle emissions from conventional fuels for surface transport. This reflects:
  - The fertiliser intensity, with high emissions associated with both the production (CO₂) and application (N₂O) of nitrogen fertiliser. Combined, these emissions account for around 80% of the total cultivation emissions of these crops.
  - The need to re-establish the plant each year has implications for emissions arising from site preparation and planting (e.g. tractor diesel emits CO₂).
  - Wheat, maize and oil seed rape can also produce useful co-products such as dried distillers grain with solubles (DDGS) and rape meal that are used as animal feed, which will offset some of the emissions of the biofuel (see section 4).

- **Oil palm and sugar cane:** These perennial crops with typical life spans of 20-25 years and 5-12 years respectively require relatively less fertiliser, reflected in associated cultivation emissions of around 14 gCO₂e/MJ of fuel for both crops.

- **Sugar beet:** Despite being a temperate annual crop, cultivation emissions are low (around 12 gCO₂e/MJ of fuel), reflecting lower nitrogen fertiliser requirement. This is due to soil incorporation of the sugar beet tops, which is a nitrogen-rich residue.

- **Emerging oil crops:** Camelina and jatropha are at an early stage of development as biofuels, but recent evidence suggests that they could have relatively low cultivation emissions due to low fertiliser requirements.

- **Dedicated energy crops.** Dedicated energy crops such as miscanthus and short rotation coppice (SRC) have very low fertiliser requirements. This is due to their efficiency in recycling nutrients from the biomass to the root system at the end of each growing season. A large proportion of the emissions are associated with establishment of the plant in the first year. These crops are already used in biomass combustion for power and heat but as advanced conversion technologies become commercially available, they are likely to compete with food and fodder crops as a liquid biofuel feedstock.
There is scope to improve the emissions savings of annual arable crops such as wheat and oil seed rape by reducing their fertiliser requirements. This will be important given that over the next decade at least, biofuels are likely to come predominately from food and fodder crops:

- **Employing better management practices:** $N_2O$ release following fertiliser application arises due to complex biological processes that depend on weather, soil type, and farm management practices (Box 2). By taking these factors into account, fertiliser efficiency can be improved by maximising crop uptake. In the UK, Defra is undertaking work to better understand how biological systems impact on fertiliser use. In addition, employing a good crop protection regime through the use of herbicides and pesticides, which have lower emissions than fertiliser, can boost yields without the need to increase fertiliser.

- **Crop development and breeding:** Looking ahead, there is potential to breed new varieties that are less fertiliser intensive:
  - Non-edible wheat with a higher energy and lower protein content.
  - Perennial wheat crops that have a deeper and denser root system making it better able to fix nitrogen in the same way as a dedicated energy crop such as miscanthus.
  - Potential exists to significantly increase yields of oil rape seed, which is a relatively new crop in the UK, without increasing fertiliser use.

- **Reducing $N_2O$ in fertiliser production:** by the fitting of $N_2O$ abatement systems.
In the longer term, it may be possible to produce biofuels from algae. While this is likely to be beneficial from a land use perspective, the overall lifecycle emissions are difficult to assess at this stage. Algae’s high requirements for fertiliser and non-atmospheric CO₂ during the cultivation stage could potentially make it a higher emitter of carbon than food and fodder crops such as corn². However, co-locating algae ponds by waste water treatment plants, where treated waste water could be recycled to provide some of the nitrogen and phosphorus requirements, and using CO₂ from recycled/waste streams could reduce cultivation emissions.

Emissions from production and transportation

Emissions arising from the production and transport of conventional biofuels produced from food and fodder crops (i.e. excluding cultivation emissions) further erode the emissions savings of biofuels over the use of fossil fuels on a lifecycle basis³:

- Emissions from producing biofuels can exceed 30 gCO₂e/MJ of fuel, eroding over 36% of emissions savings. However, emissions can be significantly lowered by altering the fuel used to power the processing of the feedstock. For example, while processing wheat into ethanol fuelled by lignite can generate emissions of around 32 gCO₂e/MJ, using natural gas will lower processing emissions by around 10 gCO₂e/MJ.

- Emissions from transporting biofuels are of a similar order to those for transporting conventional fuels.

In future, emissions from the use of dedicated energy crops with new technologies (e.g. biofuel derived from ligno-cellulosic conversion) are expected to be significantly lower. We reflect emissions associated with different feedstocks and technologies in our modelling of ‘appropriate’ use of bioenergy (technical paper 3).

² A. Clarens et al. (2010), ‘Environmental lifecycle comparison of algae to other bioenergy feedstocks’
³ Emissions are based on EU-RED typical values
Summary on emissions from cultivation, production and transportation of bioenergy crops

Combined emissions from cultivation, production and transportation could significantly erode emissions savings, and depending on the assumptions used (e.g. on crop yields, production process and transport distance) can vary considerably when looking at the same bioenergy chain (Figure 3). Emissions are therefore material, and should be accounted for when considering the emissions impacts of bioenergy. The aim should be to minimise these emissions, through crop choice, farming practices, production processes, etc.

Figure 3: Range of GHG savings per bioenergy chain compared to fossil fuel

Note: Exhibit based on 60 “well-to-wheel” lifecycle emissions studies and shows a large range for each biofuel. Excludes land use change emissions.
3. Emissions from direct and indirect land use change

Why land use change results in emissions

There are many drivers of land use change, which include amongst other things, bioenergy, agriculture, and urbanisation. As part of a lifecycle analysis, it is necessary to consider how increasing the amount of land to grow bioenergy feedstocks can alter the overall emissions savings of the feedstock in question.

Land use change impacts on the level of carbon sequestered below and above ground – either by directly releasing carbon (loss) or increasing sequestration (benefit) – from two main pools:

- **Soil organic carbon**: on a global basis this equates to about 1,500 Gt of carbon, making it the second largest carbon pool after the ocean. Carbon is captured from decomposing organic matter such as leaves and root tissues and accumulation can take from decades to centuries.

- **Living and dead vegetation (biomass)**: the global total is around 560 Gt of carbon, and is found below ground (e.g. roots) and above (e.g. leaves and branches).

The implications of land use change are important because of the significant quantities of carbon contained in certain land types. These are so large that even a small change in size can have a big impact on the emissions balance of the bioenergy feedstock. For example:

- Peatland is by far the most carbon-dense terrestrial ecosystem with in excess of 2,000 tC/ha (Figure 4). The loss of just 5-7% of UK peat land carbon would be equivalent to total UK emissions in 2009⁴.

- The tallest trees in the world found in the giant conifer forests of the Pacific Northwest hold the largest biomass carbon pool with 606 tC/ha. By way of comparison, agricultural land in Great Britain is estimated to contain just under 50 t/ha⁵ of soil organic carbon, making it a poor sequester of carbon.

There are two types of land use change associated with growing bioenergy crops:

- **Direct land use change emissions** result when conversion of land to grow crops results in direct release of carbon stored in the soil and existing vegetation.

- **Indirect land use change emissions** result when growth of bioenergy crops displaces an existing activity (e.g. agricultural and timber production) to new land which on conversion causes emissions.

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⁵ Countryside Survey (2007).
Direct land use change

International studies

To assess whether converting land to grow bioenergy produces a net benefit or loss in terms of soil organic carbon and plant biomass, it is necessary to consider the previous land type and the bioenergy feedstock being grown on the converted land. Estimates have been made to compare the level of carbon released by the conversion of certain land types to grow biofuel crops against the annual savings achieved by displacing the use of fossil fuels.

At its worst, the ‘carbon debt’ created by releasing such a high level of carbon up-front could take decades, if not centuries, to repay through recapture in the soil and biomass re-growth, depending on the original land type (Figure 5).

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Given the risk of carbon debt, conservation rather than conversion of land with high carbon stocks should be promoted.

The sustainability criteria for biofuels adopted in the EU Renewable Energy Directive (RED) and the UK’s own biomass sustainability criteria aim to achieve this by precluding the use of such land, in addition to growing biofuel crops on land that is highly biodiverse (Box 3).

**Box 3: EU-RED sustainability criteria for biofuels**

The EU attempts to limit lifecycle emissions through employing sustainability criteria under its Renewable Energy Directive (RED). Only feedstock meeting the criteria will be counted towards the RED target:

- The criteria require that biofuels and bioliquids should deliver emissions savings of at least 35% relative to use of surface transport fossil fuels, rising to 50% in 2017 and to 60% in 2018 for new installations.

- There are also general prohibitions on the use of feedstock grown on land that was formerly carbon-rich or highly biodiverse.

The RED also encourages the use of highly degraded and contaminated land deemed unsuitable for food and feed production by awarding a bonus of 29 gCO₂e/MJ to the carbon balance to offset the investment costs of bringing such land into a productive state.

The EU RED does not fully take into account carbon debt, instead annualising carbon emissions from land use change over a 20 year period. However, even this partial accounting for carbon debt suggests that converting many natural ecosystems to grow food crops would not meet...
3. Emissions from direct and indirect land use change

the 35% biofuel sustainability threshold (Figure 6). Some biofuels above the black dotted line in Figure 6 produce higher emissions from land use change alone (ignoring all other emissions in the lifecycle chain) than the fossil fuel comparator over a 20 year period:

- Clearing tropical rainforests, deciduous forest and scrubland always produces more emissions than using fossil fuel, irrespective of the bioenergy crop being grown.

- Conversion of certain grassland types (e.g. managed) can produce a net increase in carbon accumulation if perennial crops such as oil palm and sugar cane are grown. This reflects the ability of perennial crops to increase carbon sequestration in the soil and plant biomass.

- For all crops, converting degraded grassland produces a net benefit in terms of carbon accumulation, with the largest increase achieved by perennial crops.

However, an unintended consequence is that by minimising direct land use change emissions, the RED could potentially increase emissions arising from indirect land use change (see below) by incentivising the use of agricultural land. Data compiled under the Renewable Transport Fuel Obligation⁷ shows for example that 44% of all biofuels supplied between April 2010 and January 2011 had been grown on land previously defined as ‘cropland’.

Questions have also been raised as to whether current approaches fully account for all the effects of land use change, including the foregone sequestration of the vegetation that has been replaced by the bioenergy crops⁸. More research is needed to establish the significance of this issue and to ensure there is no double-counting (i.e. sequestration vs carbon stocks).

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⁷ Suppliers obligated under the RTFO are required to provide data on the volumes and source of biofuel brought to market in the UK.
⁸ T. Searchinger (2010), ‘Biofuels and the need for additional carbon’

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Figure 6: Net annual land use change emissions per land and crop type

![Figure 6: Net annual land use change emissions per land and crop type](image-url)

Note: Calculation of land use change emissions based on EU-RED guidelines, and represent average annualised values over a 20 year period.
UK studies

In the UK, dedicated energy crops have been found to have lower direct land use change emissions than arable crops such as wheat and oil seed rape. Furthermore, miscanthus and SRC can result in negative emissions if grown on arable land, by increasing the amount of carbon sequestered in the soil and vegetation (Figure 7).

Based on work undertaken by TSEC-Biosys\(^9\), in order to mitigate land use change emissions the following rules could be applied in deciding what type of bioenergy crop could be grown depending on the land type being converted:

- Converting arable crop land with either miscanthus or SRC increases the rate of soil organic carbon sequestration to an average equilibrium of around 100-110 tC/ha, which is approximately double that of oil seed rape and wheat.

- There would appear to be no change in soil organic carbon when converting managed grassland to either dedicated energy crop, while growing oil seed rape would result in a mean annual decline of over 0.60tC/ha. In general, the conversion of less disturbed lands and managed grasslands to grow arable crops will reduce the carbon contained in the soil.

- Conversion of a broadleaf forest, which would also contain a significant level of carbon in the trees in addition to the soil, should be avoided.

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\(^9\) The TSEC BIOSYS project is a UK multi-disciplinary team with expertise in bioenergy research.

Figure 7: Annual soil carbon changes of arable crops and dedicated energy crops

Note: Change in mean soil emissions and error bars for the soil emissions represent 2 x standard deviation. It can be interpreted that 95% of the data points lie between the two extremes.
Work suggests that how arable land is managed can significantly minimise soil organic carbon losses following conversion of certain land types such as grassland to grow food crops. However, there is some debate as to whether the practice of reduced or no tillage has any benefit (Box 5).

**Box 5: Reducing soil organic carbon losses by sustainable land management practices**

Modelling work\(^{10}\) suggests that how land is managed after converting it to grow food and fodder crops for bioenergy is important in reducing the emissions associated with direct land use change:

- The loss of soil organic carbon arising from the conversion of grasslands to grow arable crops (e.g. corn) is reduced by employing sustainable management practices such as no-till farming and the planting of winter cover crops (e.g. winter wheat planted in the autumn after the bioenergy crop is harvested).

- Following an initial decrease in soil organic carbon after grassland conversion, levels increased each year due to the carbon sequestered by the cover crop, so that after 100 years soil organic carbon increased by 35%. Combined with no till-farming, the carbon debt could be reduced to three years for grassland conversion.

Evidence\(^{11}\) elsewhere suggests that reduced or no tillage has little impact, if any, on soil organic carbon losses especially in temperate climates. The key difference is the distribution of carbon throughout the soil profile, which will accumulate near the top in untilled soil carbon, and be mixed more evenly in soil that is tilled. Overall, the quantity of soil organic carbon was found to be similar between the two systems to a depth of 35cm. The main benefit from reduced or no tillage will be CO\(_2\) savings from conserved fuel use, although this could be offset from increased N\(_2\)O emissions if soil compaction occurs, a particular issue for heavier soils.

**Indirect land use change (ILUC)**

Indirect land use change occurs when land for an existing activity (e.g. food or timber production) is converted to grow bioenergy feedstock or a food crop is used for bioenergy (e.g. divert maize to ethanol), which results in the relocation of that displaced activity to another area. The conversion of land to grow the relocated crop can produce emissions.

This issue is of concern because as discussed earlier, regulations to minimise emissions from direct land use change may inadvertently lead to increasing emissions from indirect land use change. At present, most lifecycle assessments tend to ignore ILUC because of the complexity in trying to quantify and determine these emissions (Box 6).

A number of studies (including several commissioned by the EU Commission) have attempted to assess ILUC emissions. Most studies use agro-economic models which simulate global agricultural markets, trade, intensification etc. These models try to predict the land use effect of using particular crops for biofuels.

The studies all agree that ILUC emissions are significant, although they vary considerably in their results for different feedstocks (Figure 8). In most cases, ethanol feedstocks are shown to have a lower ILUC risk than biodiesel feedstocks.


Box 6: Complexity of calculating Indirect Land Use Change emissions

There is substantial complexity in trying to quantify and attribute ILUC emissions to bioenergy due to a number of factors, including that ILUC:

- can occur across national boundaries (e.g. displaced agricultural production in the EU can relocate to another continent)
- can entail significant time lag
- cannot be observed/measured directly (relies on complex global modelling)
- is dependent on assumptions made about global trade
- is dependent on assumptions made about current and future agricultural yields
- is not specific to bioenergy as other types of economic activity can cause ILUC (e.g. agriculture, urbanisation and timber production)

The RED and the EU Fuel Quality Directive require the EU Commission to propose a methodology to control ILUC emissions. The Commission is currently looking at a number of options to reflect ILUC emissions within the RED sustainability criteria. In addition to a ‘do nothing’ approach, the options being considered are:

- **Attribute a quantity of greenhouse gas emissions to biofuels reflecting the estimated indirect land use impact:** this would represent a best estimate of the expected emissions from indirect land use change that results from the production of the individual biofuel feedstock. The ILUC factor would be an additional number added to the lifecycle emissions, and could be calculated as a single uniform factor applied to all crops representing the average land use change of all feedstocks, or a crop specific factor.
• **Introduce additional sustainability requirements on certain categories of biofuels:** although the details of what this option could entail are vague, possible examples proposed could include mitigation of ILUC risks from certain types of biofuels (e.g. use of degraded land to grow the feedstock, integrating bioenergy crops as a rotation crop, and the production of co-products). Under this option, producers would have to demonstrate compliance with the requirements in order to be able to supply biofuels to the EU market.

• **Higher sustainability criteria:** e.g. bring forward the date for increasing the emissions savings threshold from 35% to 50%.

Another option, given the uncertainty around ILUC factors, would be to cap the use of certain feedstocks which have a particularly high ILUC risk.

Given the importance of ensuring emissions reductions from biofuels produced from food and fodder crops, it is imperative that lifecycle emissions are fully accounted for, and that the EU introduces indirect land use emissions to its framework in the near term, in order to avoid damaging indirect land use change that might occur under the current framework.

Therefore we recommend that the UK Government should strongly support either the use of crop specific ILUC factors (i.e. adding estimates of ILUC emissions by crop, (Figure 9)), or as an alternative to the options under consideration, the setting of caps on the use of feedstocks with associated risks of ILUC at levels consistent with sustainable supply.

In support of these approaches, positive incentives could be included for feedstocks with low ILUC risks. For example, in a framework with ILUC factors, these could be reduced if it can be demonstrated that crops are grown on degraded land with low ILUC risk.

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**Figure 9: Addition of crop specific ILUC factors to EU-RED typical emission values**

![Graph showing ILUC emissions, RED typical value, 35% and 50% GHG savings thresholds for various crops and fossil fuels.](image-url)

**Source:** IFPRI (2011), EU-RED.

**Note:** ILUC is central scenario based on biofuel target use by 2020 under the NREAPs.
In view of the uncertainties over ILUC emissions, the introduction of ILUC factors or capping the use of feedstocks with ILUC risks would necessarily be imperfect. However, both would be preferable to simply increasing the emissions savings thresholds (which could restrict potentially sustainable supply) or ignoring ILUC emissions altogether (which could allow unsustainable supply).

Reflecting ILUC impacts could significantly reduce the supply of sustainable bioenergy to what is available under the current criteria with implications for the 2020 liquid biofuels target. For example, the Gallagher Review suggested that a lower level of ambition may be appropriate, without ruling out that current targets could be achieved sustainably.

If it were to become clear that current targets cannot be achieved when indirect emissions are accounted for, then these should be adjusted. The imperative should be to deliver sustainable bioenergy, rather than to deliver current targets which may go beyond sustainability limits.

The first four legislated carbon budgets build in lower transport biofuels penetration than assumed by the Government (i.e. 8% in 2020 rather than the Government’s 10%). A reduction in biofuels ambition of this order of magnitude or slightly higher would therefore not jeopardise meeting carbon budgets, assuming full delivery on other measures to reduce emissions across the economy.

We also note that increased use of biomass for power and heat could have implications for ILUC. Therefore it is imperative that action is also taken to address ILUC arising from use of woody biomass (see section 5).
4. Use of co-products

In considering lifecycle emissions account also needs to be taken of co-products. The production of bioenergy can involve the generation of co-products during cultivation, harvesting and the processing of the crops into biodiesel and bioethanol (Box 7).

**Box 7: The main co-products and their traditional uses**

Some bioenergy feedstocks are better than others in generating co-products:

- Broadly, food and fodder crops offer more co-products than dedicated energy crops where most of the crop is currently used as feedstock for power. In the future, the generation of co-products from food and fodder crops may decline once the lignocellulosic process which uses more of the plant for the production of biofuels develops commercially.

- Differences also exist amongst food and fodder crops (see Figure B7). For example, most of the oil palm in the processing stage is used to produce biodiesel, whereas approximately 30% of the wheat is left over from the bioethanol production process in the form of protein, fat and fibre. This can be used to make animal feed. Therefore, there is a trade-off between using most of feedstock for bioenergy and the loss of a co-product.

**Agricultural residues & main uses:**
- Straw: soil incorporation, animal bedding and power generation.
- Bagasse: power/heat for sugar mills and pulp & paper production.
- Corn stover and sugar beet tops: soil incorporation.
- Others: corn cobs, nut shells & husks, palm kernel expeller, all of which can be used for combustion.

**Process by products from biofuel production:**
- Rape meal: animal feed competitive with soy meal.
- Dried Distillers Grain with Solubles (DDGS): animal feed competitive with soy meal
- Glycerine: chemical feedstock
- Soy beans are primarily grown for animal meal, while the cooking oil and biodiesel are the co-products.
Box 7: The main co-products and their traditional uses

Figure B7: Share of co-products per unit of crop feedstock

The extent to which the co-product can determine the GHG savings of the main bioenergy product depends on the allocation method chosen to apportion resource inputs and upstream emissions between the co-product(s) and main bioenergy product e.g. ethanol (Figure 10).

Allocation based on energy content is the method employed by the RED biofuel sustainability criteria. Under this approach, co-products such as DDGS are allocated emissions according to energy content. However, agricultural wastes and residues such as straw are deemed to be zero carbon and thus some of the emissions associated with the cultivation and harvesting of wheat is apportioned to the biofuel, some to DDGS and none to the straw.

The method of substitution credits takes into account indirect emissions avoided by displacing the use of another product with the co-product. This could have positive implications by saving emissions from avoided land use and production.

For example, the production of biofuels from food and fodder crops such as wheat, maize and oil seed rape provides valuable co-products such as animal feeds (e.g. DDGS and rape meal) that can be used to displace existing animal feeds such as cereal grains and soy meal. According to the US Environmental Protection Agency, one tonne of DDGS (produced from either maize or wheat grain fermentation) can displace 0.45 tonnes of wheat grain and 0.55 tonnes of dry soy meal. Given that the EU is a large importer of South American soy meal, its displacement by cheaper rape meal and DDGS could have a beneficial emissions impact:

- Soy is cultivated primarily for the feed market constituting the world’s largest animal protein source.

Note: Soya in this exhibit corresponds to the soya meal which is the main product accounting for over 80% of the crop. Biodiesel from soya is the co-product. Calculation based on mass basis.
• Soy as a protein rich crop tends to be more land intensive for a given output compared to the growing of cereal crops.

• Increased production of soy could trigger the expansion into lands with high carbon stocks in South America, where Brazil, Argentina and Paraguay are the world’s largest soy bean producers after the USA. However, while Brazil’s soy moratorium\textsuperscript{12} has proved successful in reducing direct primary forest conversion since 2006, there is evidence that the moratorium has inadvertently lead to increased indirect land use change by displacing cattle ranching from existing pastures to areas deeper in to the forests.

Any co-product that needs drying such as DDGS could fare worse under the substitution method because the co-product needs to be comparable to the feed it is displacing (soy meal is dry). Thus emissions associated with the drying process will be allocated to the main crop, giving maize bioethanol a lower emissions savings compared to allocation based on energy content.

Other valuable co-products include straw which if incorporated into the soil reduces the requirement for fertiliser, while bagasse (a fibrous residue of the sugar cane plant) is used to generate heat to displace the use of fossil fuels and also to produce steam for electricity production, and CO$_2$ from fermentation.

\textbf{Figure 10: Impact of co-product allocation method on GHG savings of current biofuels}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure10.png}
\caption{Impact of co-product allocation method on GHG savings of current biofuels}
\end{figure}

\begin{itemize}
\item Bioethanol from US maize/corn (DDGS)
\item Bioethanol from UK sugar beet
\item Bioethanol from UK wheat (rape meal)
\item Biodiesel from US soy bean
\item Biodiesel from UK oilseed rape (rape meal, crude glycerine)
\end{itemize}

\textbf{Source:} North Energy Associates (derived using modified version of BEAT2 workbooks).

\textbf{Note:} Processing with a natural gas-fired combined heat and power unit.

\textsuperscript{12} An agreement was signed in 2006 not to trade soy from areas in the Amazon Biome that were deforested after 2006.
5. Emissions from forest biomass

Bioenergy sourced from solid biomass such as forestry and woodland products has limited cultivation emissions, mainly associated with diesel fuel use in forest operations and some application of fertiliser and pesticides for short rotation forestry (SRF). However, forests are very important carbon reservoirs. Thus intensified harvesting and deforestation driven by bioenergy demand could result in a very significant loss of forest carbon stocks and increased emissions relative to burning of fossil fuels that could take decades if not centuries to repay. Therefore, in addition to reducing the risk of deforestation, maintaining forest carbon stocks through well managed forestry practices are crucial if increased use of biomass feedstock for heat and power is to deliver emissions savings.

The issue of carbon debt is of particular concern given that the expected growth in imported biomass could potentially come from countries that currently have less robust forestry regulations in place to prevent deforestation and unsustainable harvesting. These supplies could come under further pressure once second generation technology to process woody biomass into biofuels has developed on a large commercial scale.

Woody biomass can come from three main sources, existing forests and woodlands, short rotation forestry plantations and dedicated energy crops. The emissions from dedicated energy crops have already been discussed in sections 2 and 3. There are potentially significant carbon risks attached to the other two main sources.

**Existing forests and woodlands**

The biggest concern lies with imported biomass sourced from mature forests, which have accumulated high carbon stocks over a substantial period of time and are anticipated to become the largest supplies of biomass to the UK. While UK biomass sustainability criteria (Box 8) and other standards are expected to discourage deforestation, the more immediate risk is that biomass demand could intensify the harvesting of forests (e.g. shorter rotations, stump removal) that are already under continuous management. There is also a further risk that harvesting could expand to areas that have previously not been subject to continuous management, and into previously unmanaged forests (e.g. boreal forests) where carbon stocks are higher compared to managed forests. Under any of these scenarios, a reduction in forest carbon stocks would occur, and resulting emissions could be very significant.
Box 8: UK biomass sustainability criteria

In early 2010, the European Commission reported on the requirement for sustainability criteria for solid biomass and biogas used for power, heat and cooling. It was left to member states to decide whether to introduce sustainability criteria. In April 2011, the UK did so under the Renewables Obligation for solid biomass and biogas used in power. To be eligible for Renewables Obligation Certificates from April 2013, large generators over 1 MWh capacity will have to ensure that feed used:

- Meets a minimum GHG lifecycle emission savings of 285 gCO$_2$e/KWh. This is equivalent to a 60% emissions savings relative to the EU grid average (712.8 gCO$_2$e/KWh)
- Has not been sourced from land that is highly biodiverse or carbon-rich (e.g. peatlands and wetlands), consistent with the definition set out in the EU-RED Directive.

To encourage its use, waste (e.g. sewage gas, municipal solid waste) is exempt from the criteria but the use of non waste residues such as straw and grain husks is not.

DECC is currently working on specific guidance with respect to forestry harvesting.

In a well managed forest, carbon stocks remain in steady state where the rate of removal of carbon during harvesting of individual stands does not exceed the rate of sequestration of the remaining stands in the forest. This equilibrium is disturbed if the level of harvesting for production is intensified, which is influenced by the type of forest management practice employed (e.g. the extraction and regeneration method):

- Clear felling and stump removal are the worse methods of extraction as the soil contains the largest share of carbon for many forest types. One study suggests annual emissions of 25 tCO$_2$/ha following soil carbon disturbance in Sweden comparable to that experienced during stump harvesting$^{13}$.
- Analysis undertaken by the Environment Agency shows that in Russia clear felling of trees followed by unmanaged regeneration (where carbon recapture will be slower than under a managed regeneration system) will produce over a 20 year period annual emissions of around 1,333 gCO$_2$/kWh (Figure 10). This is almost double the carbon intensity of the EU grid average. Over a 100 year period, carbon recapture from the growing forest allows for annual emission savings of 61%.
- Using a less intensive practice of periodic thinning and felling in the same region could achieve emission savings of 71% versus the use of fossil fuels for both the 20 year and 100 year periods.

While sustainability certification schemes for forests do exist, these do not necessarily account for carbon impacts. For example, Swedish targets to increase wood fuel use have led to increased clear felling and growing interest for stump removal in Forest Stewardship Council certified forests$^{14}$.

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$^{13}$ P.G Jarvis et al (2009), ‘The role of forests in the capture and exchange of energy and greenhouse gases’

$^{14}$ Swedish Society for Nature Conservation (2011), ‘Under the cover of the Swedish forestry model’
For existing forestry in the UK, we can be reasonably confident that bioenergy supplies will be low-carbon. The UK Forestry Standard specifies when stump removal may be acceptable, and strategies are in place to encourage the management of neglected woodlands which has carbon benefits:

- In previously unmanaged woodland, low intensity management can help young and better quality trees to thrive. This is important from a carbon perspective as younger trees sequester carbon at a faster rate than mature ones. In addition the use of selective thinning to produce biomass for power generation can deliver emission savings of 83% (Figure 11).

- Such management can also be useful for minimising the risk of carbon release arising from natural disturbances such as wildfire, wind and insect infestation, which is expected to become more frequent given the changing climate. Although forests overseas are at greater risk of such disturbances (e.g. mountain pine beetle infestation in British Columbia and fires in boreal Eurasia), one particular issue in Scotland is of storm felled unmanaged conifers. In this scenario it may be better to harvest the trees at risk for bioenergy and replant.

There is also a carbon impact from using forest residues, albeit a smaller one, which may not always be captured in lifecycle analyses if the use of residues is assumed to be carbon neutral:

- Compared to an immediate release of carbon on combustion for energy, residues if left uncollected on the forest floor continue to store carbon until released over a period of time through decomposition, some of which is sequestered into the soil. Therefore failing to take account of residues in lifecycle analysis may overestimate net GHG savings.
• For example, residues collected and used as pellets to displace coal produces net emissions savings only after 16 years as the reduction of forest carbon stocks slows to a steady state. Taking account of forest carbon loss reduces net emissions savings by 12 MtCO₂e at year 20 (Figure 12). If residues are used to displace gasoline, the period extends to 74 years before net emissions savings occur due to the lower carbon intensity of the transport fossil fuel.

• The level of emissions savings will also vary according to the rate of residue decomposition, which differs according to climatic conditions and the diameter size of the residue. This suggests that for bioenergy it would be preferable to prioritise use of certain forest residues such as branches over stumps\textsuperscript{15}.

The Government should ensure that plans to incorporate good forestry management for imported and domestic biomass into the biomass sustainability criteria minimises the risks of unsustainable forest management and degradation.

**Short rotation forestry**

While the UK biomass sustainability criteria should reduce the risks of deforestation, they could result in an increased demand for SRF. Bioenergy demand is expected to drive expansion of new SRF plantation (e.g. eucalyptus) in South America and South East Asia, where favourable climatic conditions produce faster growing plantations with higher yields than Europe. The main carbon concern is the potential impact on land use change emissions (see section 3), where plantations driven by other uses in South East Asia have been established by clearing

\[\text{Reference: A. Repo et al. (2011), ‘Forest bioenergy climate impact can be improved by allocating forest residue removal’}\]
secondary tropical forests. However, there are positive benefits to soil organic carbon if planting on degraded, over grazed land or cropland, although the latter land type could be at the risk of leading to indirect land use change.

**Ensuring biomass sustainability: current framework under the RO**

As discussed (Box 8) from April 2013, ROCs will only be issued to generators that meet sustainability criteria for land and GHG emissions. However, the current GHG criteria provide limited confidence that significant emissions savings will ensue, and leave open the possibility that using biomass will actually increase emissions:

- The 60% saving threshold is relative to the EU grid average carbon intensity, which is much higher than that of the UK (i.e. around 700 gCO₂/KWh for the EU compared to around 500 gCO₂/KWh for the UK).
- As a result, emissions could be significantly higher than alternative forms of low-carbon generation, and only slightly lower than those from gas-fired generation.
- When risks of indirect deforestation are accounted for (see below), use of biomass could actually increase emissions relative to gas-fired generation (i.e. from a carbon perspective, it would be preferable to invest in gas generation rather than biomass, notwithstanding that gas generation is carbon intense).

We therefore recommend that the threshold for use of biomass to meet the RO should be tightened to 200 gCO₂/KWh. This would represent a significant enough saving relative to gas-fired generation, allowing a margin for emissions from possible indirect deforestation. In addition, we recommend that this should be enforced by operators reporting on actual lifecycle emissions, rather than use of the EU default values, which are potentially inaccurate.

**Limiting risks of indirect land use impacts**

Although the UK biomass sustainability criteria cover emissions from direct deforestation and forest management, they do not mitigate risks of indirect deforestation related to potential displacement of demand from other wood consuming industries (e.g. construction). There are also potential indirect land use impacts if dedicated energy crops and SRF for use in biomass power and heat generation are grown on agricultural land and grasslands (e.g. displacement of agricultural production to carbon rich land).

Therefore ways should be found to provide confidence that there will be no direct or indirect deforestation, nor other land use impacts as a result of forest biomass use:

- Given that there is generally more certainty about the sustainability of UK grown biomass, the aim should be to maximise UK supply without threatening supplies to other industries that use wood, through enhanced forest management, new woodland planting and growth of dedicated energy crops.
The Government should include in its forthcoming bioenergy strategy an assessment of the global wood industry, with a view to understanding the demand-supply balance associated with increasing use of bioenergy in the UK and other countries. The key issues of interest here are whether there is currently enough supply from sustainably managed forests to meet demand for biomass in power and heat generation and from other industries which use wood, and whether in the event of excess demand there is scope for rapid expansion of sustainable supply.

There should be close monitoring of wood industry developments with a focus on supply expansion, and flexibility to change the biomass power ambition depending on the extent to which increased supply is or is not likely to be sustainable.

Consideration should also be given to introducing a sustainability standard for all wood consumed in the UK, which would provide more confidence that the UK biomass strategy was not resulting in indirect deforestation.

Indirect land use change emissions due to the growth of energy crops and short rotation forestry should be included in the UK’s biomass sustainability framework.

The risk of indirect land use impacts and deforestation through the increased use of biomass remains an important issue, and should be fully addressed in the Government’s forthcoming bioenergy strategy, to be published early in 2012.
6. Conclusions – is bioenergy low-carbon?

The evidence set out above suggests that bioenergy could be low-carbon in principle, but may not always be the case in practice:

- **Lifecycle emissions from energy crops.** The evidence above has highlighted the risk that near-term targets for liquid biofuels result in only small, or even negative, emissions savings when accounting for lifecycle emissions. This risk could be mitigated through limiting the types of crop and land used for bioenergy, which could be achieved through enhancing the EU’s current sustainability framework to include indirect land use impacts, and in the longer term through a comprehensive global agreement to reduce emissions.

- **Lifecycle emissions from forest biomass.** Very ambitious targets for the use of biomass in the UK and the EU to 2020 could put pressure on sustainable supply, and result in direct and indirect land use impacts including deforestation. This risk could be mitigated through extending the UK's sustainability framework under the RO in the near term, and through a comprehensive global agreement to reduce emissions in the longer term.

Therefore the challenge is to ensure that regulatory frameworks are strengthened to provide confidence that bioenergy supply will be low-carbon. If sufficient low carbon feedstock can be sourced, bioenergy has a potentially useful role in meeting carbon budgets and targets subject to other sustainability constraints being met.