




UNDERSTANDING GREENHOUSE GAS BALANCES OF BIOENERGY SYSTEMS

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SUPERGEN Bioenergy Hub

The SUPERGEN Bioenergy Hub aims to bring together industry, academia and other stakeholders to focus on the research and knowledge challenges associated with increasing the contribution of UK bioenergy to meet strategic environmental targets in a coherent, sustainable and cost-effective manner.

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Foreword

There are many reasons why bioenergy appears attractive as a renewable fuel: it can replace over-committed fossil fuel resources; aid biodiversity; help manage wetlands; diversify rural economies; support energy security and support industrial growth and exports. These are all acknowledged as important, but this report focuses on only one aspect: greenhouse gas balances, which is a key driver for the development and deployment of bioenergy.

This report is published as an output from a SUPERGEN Bioenergy Hub workshop held in January 2013. The workshop aimed to provide an open forum for life cycle assessment specialists to discuss some of the issues surrounding greenhouse gas balances for bioenergy systems and to provide an overview of the extent to which bioenergy systems actually reduce greenhouse gas emissions. This report intends to inform stakeholders with wider energy and environmental policy or research interests on issues relating to bioenergy system greenhouse gas balances. Since there is already a substantial body of information focusing on first generation crop use for biofuels, most of the emerging issues discussed at the workshop focused on the use of solid biomass for heat and power from forestry, perennial crops, waste streams and therefore this is the main focus of the report.

Whilst the report is attributed to the authors, they have endeavoured to reflect the diversity of opinions and ideas represented at the workshop. The report has been published by the SUPERGEN Bioenergy Hub, but readers are free to make copies or post the report for their own use, provided that they do not wilfully misrepresent its content and acknowledge its origin as the SUPERGEN Bioenergy Hub.

Glossary of Key Terms

Annex 1 Countries	Signatories to the UNFCCC who were members of the OECD in 1992 plus those with 'economies in transition' in Central and Eastern Europe.
Annex B Countries	Those countries that have binding GHG emissions targets under the 1997 Kyoto Protocol.
Baseline	A projected level of emissions against which to define reductions. A specific component of a counterfactual case.
Bioelectricity	Electricity produced from conversion of biomass.
Bioenergy	Energy from biomass, usually used to provide electricity, heat or power.
Biofuels	Liquid fuels derived from biomass that may be upgraded for transport fuel applications.
Biomass	Hydrocarbon material containing biogenic carbon, often recently sequestered from the atmosphere during plant or tree growth.
Carbon debt	A reduction in the long term carbon stocks of the earth's carbon reservoirs.
Counterfactual	Plausible, defined, circumstances relating to a specific project or locality, that may be reasonably expected to exist in "business as usual" conditions. One or more counterfactual descriptions may be reasonable for a given situation.
GHG balance	The net amount of greenhouse gases emitted by a process or product, taking into account all emissions and sinks along a supply chain.
First generation technology	First generation technologies convert part of a biomass feedstock to biodiesel or bioethanol via well-proven techniques. Most commonly the oily portion of a feedstock is converted via transesterification and the sugary or starchy component via fermentation.
GHG emissions intensity	The net amount of greenhouse gases emitted per unit of product or service.
Global Warming Potential (GWP)	An index used to calculate equivalent warming effect of a unit mass of a given greenhouse gas integrated over a specified time period, usually 100 years, relative to CO_2.
Land-Use Change (LUC)	A change in the use or function of land (e.g. from forest to arable or pastureland to perennial crop) which normally affects the amount of carbon stored in the land and its capacity for future carbon sequestration.
Life Cycle Assessment (LCA)	A methodology to assess the environmental impacts of a product or process over its life cycle.

Land Use, Land-Use Change and Forestry (LULUCF)	Catch-all term for changes in terrestrial biological systems, including agriculture and forestry.
Radiative forcing	Measure of the change in vertical irradiance (in Wm-2) at the tropopause as a result of a change in composition of the atmosphere.
Radiative Forcing Index (RFI)	Ratio of total radiative forcing of a source of warming to that of CO_2 emissions alone over a defined time period.
Second generation technology	Second generation technologies convert the lingo-cellulosic (or fibrous) part of a biomass feedstock to a usable biofuel often using hydrolysis or other pre-treatment techniques prior to fermentation.
Sequestration	Removal of carbon dioxide (CO_2) from the atmosphere to another reservoir either biological or geological.
Sink	A natural or man-made process that sequesters carbon.
Stand	Part of a forest usually containing trees of similar age and type managed in the same way.
Third generation technologies	Technologies that escape the land and resource constraints associated with biomass feedstocks by making use of algae, waste material or other available by-products.
Yield	The amount of biomass produced per unit area of land used.

Abbreviations

ALCA	Attributional Life Cycle Assessment
CCC	The Committee on Climate Change
CLCA	Consequential Life Cycle Assessment
GHG	Greenhouse gas
GW	Gigawatt
GWP	Global Warming Potential
ILUC	Indirect Land Use Change
IPCC	Intergovernmental Panel on Climate Change
LCA	Life cycle assessment
LUC	Land Use Change
LULUCF	Land Use, Land Use Change and Forestry
IPCC	Intergovernmental Panel on Climate Change
Mt	Megatonne, 10^6 metric tonnes
NOx	Generic term for mono-nitrogen oxides NO and NO_2 (nitric oxide and nitrogen dioxide)
RED	Renewable Energy Directive
RFI	Radiative Forcing Index
tCO_2e	Tonnes of CO_2 equivalent
UNFCCC	United Nations' Framework Convention on Climate Change

Executive Summary

Bioenergy systems play a key role in the UK's energy future because they offer the triple benefits of being **renewable**, **sustainable** and incurring **lower greenhouse gas (GHG) emissions** than fossil fuels, such as coal, oil or gas.

When biomass is utilized as an energy source, carbon dioxide (CO_2) that was recently captured from the atmosphere by plant growth is re-released. As this has been recently sequestered, it is often ignored as not contributing to net increases in long term atmospheric concentrations. However, that neutrality is dependent on the biomass growth vegetation recapturing the equivalent over a short time horizon, otherwise the balance between carbon in the atmosphere and biosphere is shifted. In the natural world, every unit of greenhouse gas (GHG) emitted has an impact that needs to be considered and, given the tight carbon budget constraints faced by the UK, this must be considered in assessment.

Bioenergy is expected to deliver 8-11% of the UK's primary energy demand by 2020 and around 12% by 2050 (DECC 2012), playing a key role in delivering policy commitments on greenhouse gas reductions. ***See section 1 – Why is bioenergy important in the future UK energy mix?***

Bioenergy systems achieve GHG reductions by displacing a relatively high carbon intensity existing fuel with a biomass feedstock that has incurred lower GHG emissions along its supply chain than the (usually fossil fuel) incumbent. Verifying GHG reductions therefore requires consideration of the whole supply chain and awareness of the wider impacts of bioenergy implementation. Techniques such as life cycle assessment (LCA) can be used to verify this. When this is done the yield of usable material produced is nearly always important; fertilizer use is often important for annual crops; changes in carbon stocks may be very significant for forestry systems and land-use change can have very large impacts for perennial crops. A summary of which issues tend to be most important for which crops and why is given in ***section 2 – What are the key differences between different bioenergy systems?***

Every bioenergy system is different and their GHG balances must be independently verified. Nevertheless, there are many examples of UK bioelectricity systems achieving substantial GHG savings, while relatively low carbon intensity natural gas is dominant in the UK heating sector, making substantial reductions more difficult to achieve. Biomass-derived liquid transport fuels with existing technologies offer lower potential for savings and there are many reported examples that do not result in greenhouse gas savings. **Section 3 – Can bioenergy systems achieve "real" greenhouse gas reductions?** shows that real GHG savings can be achieved, but certain factors, including land-use and the reference comparison can substantially alter the calculated GHG savings.

Section 4 – How can different reports reach different conclusions about the GHG balances of bioenergy systems? examines and classifies the main drivers of variation in LCA of bioenergy systems. Some variation is "real", where different systems may actually give rise to different physical levels of GHG emissions. Other sources of variation may be methodological – this can often be thought of as using LCA to answer a "different question" about the same bioenergy system.

It is therefore absolutely critical that the "LCA question" being asked is clearly and adequately defined. **Section 5 –What should be considered when assessing if bioenergy is delivering real**

greenhouse gas reductions? gives guidance on formulating LCA questions and what needs to be considered by policy makers in defining GHG reduction objectives e.g. it is important to consider which demand is being displaced, from whose perspective "reductions" are framed, when emissions are incurred and whether reduced sequestration can be considered equivalent to increased emissions.

Section 6 – What are the methodological issues that make bioenergy LCA calculations difficult and their results contested? then focuses particularly on the methodological issues that result in different LCA analyses of the same system producing different results and the most appropriate context for applying different methods is outlined. There is particular focus on our understanding of temporal aspects of biomass feedstocks. This issue is most significant for forestry systems and it is noted that often the issue is not one of a carbon debt, but foregone future sequestration, which perhaps should be considered differently when assessing the system GHG balance.

Finally s***ection 7 –What are the implications of our understanding of bioenergy system greenhouse gas balances for policy initiatives or "How can policy frameworks incentivize "real" greenhouse gas reductions?*** synthesizes the policy implications for assessing GHG balances of bioenergy systems and promoting greenhouse gas reductions. It emphasizes the importance of land-use and land-use change for some systems and recognizes the need to better understand the future food-fuel interface for climate policy development. It also identifies a key gap in knowledge surrounding the impact of forest management on carbon stocks and perceives a need for closer examination of carbon dynamics. It notes the fact that importing biomass is effectively equivalent to exporting our carbon reduction obligations, but notes that this occurs in many sectors where the UK imports goods.

Overall several challenges emerge in ensuring bioenergy systems deliver GHG reductions:

1. Analysing with some degree of accuracy what is actually being released and developing a framework that effectively reflects reality. Along with the limitations on our knowledge, it is important to recognize how different parameters vary with location, time and character and estimate the uncertainty in measurements.

2. Taking adequate account of the interactions of bioenergy with other sectors and ecosystem services (including land, food, energy, water) so that the savings or reductions can be fairly presented.

3. Translating our understanding of bioenergy GHG balances into policy mechanisms that actually incentivize GHG reductions – particularly when there is often fragmented ownership or responsibility for the entire supply chain.

1. Why is Bioenergy Important in the Future UK Energy Mix?

When plants grow they absorb CO_2 from the atmosphere and store it as carbohydrate; plant carbohydrates can be harvested and converted to provide us with energy, called bioenergy. This energy source is renewable since the harvested biomass will be replenished as long as land, sunlight, water, nutrients and CO_2 are available.

When the plant is used for energy, CO_2 is released to the atmosphere; but this is the same amount of CO_2 that was originally sequestered. This is effectively equivalent to "recycling" the CO_2 i.e. there are no net additional emissions, although other additional emissions may be incurred in producing the biomass and processing it to provide bioenergy. See box 1: The Carbon Cycle.

Therefore bioenergy is important to the future UK energy mix

1. For renewable energy development to support international commitments, energy security and economic innovation objectives, and
2. For greenhouse gas mitigation.

Box 1: The Carbon Cycle

Climate change is caused by an increase in the long term atmospheric concentration of GHG. This has been driven primarily by releases of stored fossil fuels in the earth, giving rise to releases of "fossil CO_2".

However, even without release of fossil fuels the earth's carbon balance is not static. There are constant exchanges and fluxes of "biogenic" carbon between different "temporary" storage pools on land, in atmosphere, oceans etc. Biomass sequesters CO_2 from the atmosphere when it grows and the CO_2 is returned when energy in the biomass is released either by organisms respiring or when man uses the energy via, for example, combustion.

In principle absorption and re-release will not affect the long term atmospheric CO_2 concentration. However, the immediate effect is accumulation of GHGs over their respective lifetime in the atmosphere and so biogenic carbon has the same global warming potential (GWP) as fossil carbon. From a climate perspective, therefore there are two main reasons why bioenergy could be desirable:

1. If the time lag between release and resequestration is short so that the atmospheric CO_2 does not have enough "time" in the atmosphere to exert significant radiative forcing
2. The bioenergy application results in a greater amount of greenhouses gases being sequestered or emissions being avoided than would otherwise have been the case

1.1 For Renewable Energy Development

The European Commission's Renewable Energy Directive (RED) (EC 2009), promotes the production of energy from renewable resources setting targets for participating Member States. The UK target is, by 2020, to produce 20% of all energy from renewable resources, including a minimum 10% of renewable transport fuels (EC 2009). Bioenergy currently constitutes around 3% of UK primary energy demand (DECC 2013a), but it has growing importance and is expected to deliver 8-11% of the UK's primary energy demand by 2020 and around 12% by 2050 (DECC 2012).

It is envisioned that biomass will deliver 30% to 50% of the UK's RED target (DECC 2011); a significant proportion of which will be via decarbonisation of the UK's heating sector (DECC 2013b). Biomass is therefore vital to achieving renewable energy targets.

While the use of waste and local biomass might be encouraged it is recognized that imports, particularly from countries such as North America, are likely to form a significant part of the UK's future supply.

1.2 For Greenhouse Gas Mitigation

The UK is committed to achieving GHG reductions consistent with limiting the rise in global mean surface temperature to 2^{o}C above pre-industrial levels. Meeting this target is regarded as being sufficient by scientists and policy makers to avoid dangerous climate change (UNFCCC 2009).

This has been interpreted by the UK's Committee on Climate Change as needing an 80% reduction in GHG emissions below 1990 levels by 2050, in addition to a series of short term emission budgets. See box 2: Cumulative Emissions.

The dominant GHG in the UK's national emissions is CO_2 and fossil fuel use accounts for over 97% of CO_2 emissions (DECC 2013c). This amount of fossil fuel use is similar to other industrialized nations across the world, but as it is a finite resource, it cannot continue in the long term. So, replacing fossil fuel use with renewable resources such as biomass makes sense, particularly if the GHG emissions associated with biomass use are lower.

Biomass is unique in the renewable energy sector in that it can deliver lower GHG energy for the heat, transport fuel and electricity sectors. However, it also uniquely requires a physical fuel for ongoing operation, is being pursued in many countries worldwide and the sustainable global resource is inherently limited. Currently there is adequate supply to meet demand, but there is substantial uncertainty related to future availability levels, especially with forecast global population growth (DECC 2012).

There have been suggestions (CCC 2011) that biomass use should be prioritized in areas where other decarbonisation options are more limited and where it has potentially the biggest impact. These include energy intensive industries, the aviation sector and dedicated biomass carbon capture and storage (CCS) plants (CCC 2011). The use of CCS offers the potential of a double benefit with atmospheric CO_2 being permanently sequestered.

However, when considering GHG emissions for biomass supply other gases can be significant, particularly nitrous oxide (N_2O) and methane (CH_4), which must also be taken into account in overall calculations.

Box 2: Cumulative Emissions

The mean global surface temperature is increased by all of the GHG present in the atmosphere at a point in time. Over time these gradually decay but continue to exert a warming effect over their lifetime. Therefore the cumulative amount of GHGs emitted to atmosphere is more important than the releases at a particular point in time. Greenhouse gas budgets have therefore been implemented as a climate mitigation policy in the UK. The budgets are set to reflect the cumulative nature of GHG emissions, as any delay in curbing emissions early on will require a strengthening of longer term targets to remain in line with 2°C.When biomass grows CO_2 is absorbed, reducing radiative forcing. When energy is released from biomass the CO_2 is released to atmosphere and causes a warming effect regardless of whether it is biogenic or fossil in origin.

2. What are the Key Differences between Different Bioenergy Systems?

Bioenergy systems can be categorized in a variety of ways, including by the final use of the energy, the conversion processes or by feedstock type. However, the most significant GHG emissions and complexities tend to occur in the supply chain, and so for this report we have categorized bioenergy systems by feedstocks in the following categories: annual crops; perennial crops; forestry products; waste and residue systems and algae. For each of these feedstock types, different aspects of the supply chain tend to contribute more to the GHG balance; these are the aspects to focus on to deliver improvements in the level of GHG reductions and our accuracy and understanding of those levels. Table 1 summarizes the issues that tend to drive high levels of GHG emissions in systems using different feedstocks.

2.1 Feedstock Types

2.1.1 Annual Crops

Annual crops tend to be used for higher "quality/value" liquid biofuels. They generally have two components: the seed/fruiting body (a source of oil, sugar or starch, commonly converted to biofuels by first generation technologies) and the lignocelluloses forming the rest of the plant. High levels of agrochemical inputs maintain high product yield and quality but incur significant GHG emissions. Crops with high nitrogen fertilizer requirements (e.g. corn and wheat) also produce high levels of soil emissions, especially N_2O. Good quality agricultural land is required for high yields and so displacement of food crops is likely to be an issue. If bioenergy crops are grown on land previously used to produce food the food production is likely to have been displaced elsewhere and this indirect land-use change (ILUC) may give rise to additional GHG emissions which have been stimulated by the biomass production and therefore should be considered as part of the GHG impact of the supply chain.

The accessible yield of the sugary/starchy/oily component can be relatively low for some crops, effectively increasing the GHG emissions per unit of bioenergy produced. For many crops there is a substantial co-product and the valuation of this can make a substantial difference to the interpretation e.g. the way GHG emissions associated with soy production are split across soy meal and soy oil affects the attribution of GHG emissions to biodiesel.

2.1.2 Perennial Crops

Perennial crops, such as short rotation coppice (SRC) or energy grasses (e.g. Miscanthus) do not require high levels of agrochemical inputs or generate high levels of soil emissions. There are no substantial co-products and the crop yield is high. The main GHG issues tend to be direct and indirect land-use change (ILUC). ILUC is unlikely to be significant when planting energy crops on less agriculturally productive land as this land is less likely to have been used for significant food production; but direct land-use change emissions need to be accounted for and use of marginal land can result in lower crop yields. These crops are suitable for heat and power applications, though there is substantial research effort on developing second generation lignocellulosic biofuels.

2.1.3 Forestry Systems

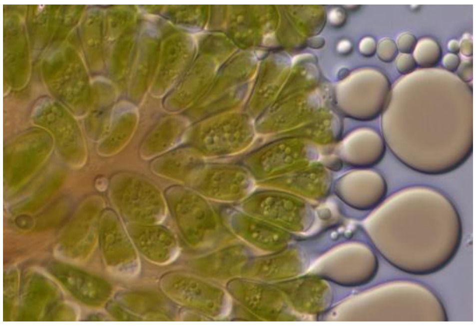
Forestry systems generally involve low agrochemical input, low soil emissions and high yielding systems. Forestry systems are rarely managed solely for bioenergy and so carbon impacts need to be viewed alongside other impacts e.g. on biodiversity, timber production, amenity value etc. Nonetheless, biomass harvesting may affect the stock of carbon stored or future sequestration potential of the forestry system, which needs to be taken into account. Typical forest growth timescales of decades mean that there may be a long time lag between GHG sequestration from the atmosphere and re-release, and current management may impact on future long term sequestration potential. Forests usually produce multiple products so care is needed in linking carbon changes to the bioenergy product.

It is tempting to link production of forest biomass for energy to a particular forest or harvesting cycle, particularly if this gives “real” data on which to base calculations. However, sustainable forest management requires consideration on a larger scale taking account of stands of different ages, species, management and harvesting regimes. While there may be a substantial carbon release associated with a specific harvest, this needs to be assessed in the context of the aggregated carbon stock across the forest holdings.

2.1.4 Waste and Residue Systems

Waste and residue systems are often credited with high levels of GHG savings based on assumptions about the counterfactual i.e. what would have happened to the material if it had not been used for bioenergy. Natural decay or disposal of biomass and wastes may result in releases of greenhouse gases such as methane or nitrous oxide, which have a much higher global warming potential (GWP) than CO_2 so there is potentially a very substantial benefit in using the material for bioenergy. However, there is a need to carefully consider the appropriate counterfactual in order to accurately assess the GHG balance.

2.1.5 Algal Systems



Algal systems are often classified into macro-algae (fast growing sea kelps, which offer high yields with low inputs, but have substantial harvesting challenges) or micro-algae (strains cultured for high oil or chemical yields under controlled conditions and with substantial nutrient inputs). The GHG balance is affected by the emissions incurred during growth, harvesting and processing of the very wet material, including adequate nutrient supply.

High value co-products are often essential for economic viability and allocation of the GHG emissions then needs to be considered.

Table 1: Summary of key issues most likely to influence the GHG balance of different feedstock types *(+ = relevant factor, ++ = can be a key determining factor, -= usually not a dominant factor)*

	Embodied emissions associated with agrochemical inputs	Land emissions	Role of co-products	Carbon stocks	Land-use change emissions	Indirect land-use change emissions	Accessible yield of crop
Annual crops	++	++	++	-	+	+	++
Perennial crops	-	-	-	+	++	++	-
Forestry systems	-	-	+	++	-	-	-
Waste and residue systems	-	++	++	++	-	-	-
Algal systems	++		+				++

3. Can Bioenergy Systems Achieve "Real" Greenhouse Gas Reductions?

Many scientists have examined the GHG reductions achievable by different UK bioenergy systems taking into account their supply chain emissions i.e. over the full life-cycle. This "supply chain accounting" approach to quantifying GHG emissions is quite different to the "territorial based accounting" system used in most GHG policy frameworks, but provides a way of linking remote GHG impacts of bioenergy to the energy provided at the point of use (see box 3). In general, the use of wood for either heat or electricity in the UK achieves very low levels of GHG emissions per unit of energy output. With electricity, this can translate to substantial (~90% reductions in GHG emissions compared to the national grid electricity mix (Thornley et al. 2009)).

The UK energy system incorporates substantial use of natural gas in the domestic heating sector in highly efficient boilers. Achieving significant GHG reductions is therefore more challenging since the gas already has a relatively low level of carbon emissions and the conversion efficiency very high. Nevertheless, substantial reductions are achievable (Thornley & Gilbert 2010).

In the transport sector, if we assume that the existing liquid fuel infrastructure remains dominant, lower levels of GHG reductions are generally achievable than in other sectors, partly because the internal combustion engine used is relatively efficient, partly because the fuel processing required to produce liquid biofuel incurs substantial GHG emissions and partly because most technologies only make use of a small "usable" fraction of the overall feedstock (Thornley 2012). Consequently lower levels of savings or sometimes actual increases in GHG emissions may result in this sector when biofuels displace existing liquid transport fuels. A radically different transport infrastructure could substantially change this, but it will take time to develop because of the inertia of the system and it carries with it the risk, financial and emissions cost of the infrastructure change.

Box 3: Supply Chain Accounting

The UNFCCC conventionally reports global emission on a "territorial basis" so that all emissions within a country's boundaries are attributed to that country. This would mean that all carbon emissions from biomass are registered where the biomass is converted to energy; while all sequestration is recorded where the biomass is grown. However, when trying to determine the "real" GHG balance of a system it is necessary to combine the contributions in different countries by focusing on the emissions along the length of the supply chain. This is often a hypothetical construct since there may not be any direct, tangible link or influence between a unit of energy production in the UK and biomass growth overseas. It can also sometimes be misleading to relate units of energy to particular biomass sources e.g. a forest company may sustainably manage its assets to ensure a spread of ages, species etc. with harvesting carbon being offset by new sequestration, but probing at the micro-level may identify a reduction in carbon stock which is offset at macro-level by other stands in other locations. Alternatively a forest owner may manage some of his holdings in a way that achieves certain minimum standards that allow certification, GHG savings and a certain label to be applied. But the same company could have other holdings in the same region that are not certified, particularly if certification does not confer any (financial) benefit in that market. Therefore requiring minimum carbon management standards for a particular consignment is insufficient to guarantee wider responsible management and carbon conservation.

So real reductions in greenhouse gas emission are possible with bioenergy systems, but there is a need to be careful that the particular system being adopted is delivering reductions. Two issues that are particularly important in establishing whether "real" reductions have been achieved are whether or not land-use change is considered for the supply chain and what the realistic comparison point should be when evaluating reductions. Both of these are very relevant to the question of whether or not bioenergy delivers "real" greenhouse gas reductions and are discussed below. Other issues that may cause variations in GHG balances of bioenergy systems are considered in section 4.

3.1 The Importance of Land-use Change

Most of the above assessments ignore any GHG emissions associated with either direct or indirect land-use change. These can make a significant difference to the overall GHG balance of a bioenergy system i.e. making the difference between one that reduces carbon emissions and one that actually increases them. This is particularly the case with biofuel systems, since the yield of usable feedstock per unit area of land tends to be lower and so the land areas involved tend to be larger.

It could be argued that this land-use change is, in fact, not a "bioenergy" issue. The UK imports many materials, such as food, which have been produced using land and therefore have incurred GHG emissions, direct land-use change and indirect land-use change in other countries. The UNFCCC framework requires countries to declare their GHG emissions on a territorial basis so that GHG emissions may be incurred in one country, while the product or service is being delivered in another. This protocol is widely accepted as part of our global trading system, although there is increasing awareness that it delivers, at best, an incomplete picture (UK parliament 2012). However, with bioenergy we are importing biomass specifically to reduce "GHG emissions" and so if "real" GHG reductions are to be achieved it is essential to ensure a framework is in place that corroborates that implementing the bioenergy solution reduces overall GHG emissions, regardless of the country or sector in which the emissions are incurred.

3.2 The Importance of the Comparison Point – Reductions Compared to What?

It is important to realize that the concept of "real reductions" is dependent on many different things, not all of which are "knowable" with any degree of certainty and may be outside the scope of the bioenergy system itself. For example, one of the most significant factors influencing the assessment of bioenergy GHG reductions is what is being replaced e.g. If bioenergy displaces coal-fired electricity the "savings" are greater than if it replaces electricity averaged across the grid system, illustrating the influence of the reference or comparison point on the GHG "savings" delivered from bioenergy.

So, overall, bioenergy can achieve real GHG savings, but every bioenergy system is different and therefore a divergent set of results is to be expected – there is no reason why the huge variety of feedstocks, conversion processes and end user demands bound together by the concept "bioenergy" should always necessarily deliver consistent GHG reductions. If a biomass feedstock is produced in a way that requires very GHG intensive input, is converted very inefficiently to bioenergy and displaces an incumbent that already had relatively low carbon intensity, then it is not reasonable to expect that it would always deliver GHG reductions. Such systems may indeed result in increased levels of GHG emissions e.g. corn production requires substantial agronomic inputs with associated high carbon intensities and this, coupled with a low conversion efficiency to ethanol can result in corn-based ethanol systems with much higher energy demands than petrol. See box 4:US corn-based ethanol production.

Box 4: US Corn-based Ethanol Production

Biofuel production targets in the US were originally intended primarily to increase energy security and reduce air pollutants from vehicles, rather than GHG emission mitigation. As a result, corn bioethanol plants were fuelled with average grid electricity, of which, in the US, nearly 50% of which is generated from coal (Wang et al. 2011). First generation food crops are also associated with high levels of nitrogen-based fertilizers to guarantee sufficient yields. This leads to the production of N_2O, which is a potent GHG. Therefore, based on this, the overall GHG balance of corn-based bioethanol was shown to be poor, or even negative i.e. that the corn-derived ethanol produced more GHG than the gasoline it replaced (Marland & Turhollow 1991; Shapouri et al. 2002, Pimentel 2003).

When dealing with systems that may on the one hand make a valuable contribution to reducing GHG emissions, but on the other hand may actually exacerbate climate change it is important to consider very carefully how and why different assessments can reach different conclusions about the GHG balances of bioenergy systems. This is considered in detail in section 4.

4. How can Different Reports Reach Different Conclusions about the GHG Balances of Bioenergy Systems?

As discussed in section 3, bioenergy systems can deliver real GHG reductions. However, in recent years there have been many different publications, reports and papers reaching apparently diverging conclusions about apparently similar bioenergy systems. This has contributed to some unease that incentivizing bioenergy systems as part of a GHG mitigation approach may be counter-productive and also considerable confusion as to how one group or report can "show" that bioenergy reduces GHG emissions and another "show" that it increases them.

Life cycle assessment (see box 5: What is Life Cycle Assessment?) is commonly used to determine greenhouse gas balances for bioenergy systems, as it allows a holistic assessment of the impact of the conversion system and supply chain across a number of impact categories, including global warming potential.

Box 5: What Is Life Cycle Assessment?

Life cycle assessment (LCA) is a technique which systematically accounts for the environmental impacts that arise during the production, use and disposal of a product (Plassmann et al. 2010). Originally developed for application to industrial processes it has dominated the area of environmental impact assessment (EIA) of bioenergy, since the impacts of the upstream supply chain are so important and there are few other established approaches designed to incorporate this. Standards ISO 14040:2006 (CEN 2006a) and ISO 14044:2006 (CEN 2006b) exist to provide a common framework for, and promote good practice in, carrying out LCA assessment. However, all LCAs should start by defining the goal and scope of the study. This includes critical consideration of the actual question being asked and the LCA practitioner will then use this understanding to adapt the LCA methodology accordingly. This flexibility is essential to allow practitioners to address subtly different LCA "questions". However, it makes standardization and cross-comparison very difficult as it may not always be appropriate to apply the same procedures to different systems. For example, standards may define what is within the scope of the system being studied, but the LCA practitioner must consider whether that standard and scope is appropriate for the particular question they are trying to address.

4.1 How is Life Cycle Assessment Applied to Bioenergy Systems?

There are 2 main ways in which LCA is applied to bioenergy systems:

1. Assessing the performance of specific supply chains
2. Assessing the impact of bioenergy adoption

In the first case there is a specific goal: to assess whether a biofuel or bioenergy source has a lower GHG balance than another fuel. This requires a snapshot of the environmental impacts that are attributed to the production of a given product or service and the technique used is called an attributional LCA (ALCA) (Brander et al. 2009). This method is best used in regulation of GHG emissions from bioenergy suppliers (Nuffield Council on Bioethics 2011).

In the second case the goal is more general e.g. to assess whether adoption of bioenergy can lead to GHG savings in the UK (Nuffield Council on Bioethics 2011). This requires a broader assessment, known as a consequential LCA (CLCA), which considers the larger-scale implications of a bioenergy source, including how it may interact with other industries and sources of GHG emissions and is best suited for policy analysis (Sanchez et al. 2012). For example, this method could be used to examine how the RED policy of a 20% target for renewable energy generation will provide realistic GHG savings.

It is important to understand that ALCA and CLCA are not “better” or “more detailed” approaches; they are simply different techniques developed to address different questions in the most appropriate manner. They therefore follow different methodologies and will provide different results. There are, however, other reasons, why apparently similar LCA assessments may deliver different results and these are outlined in section 5.

4.2 How can LCA Analyses of Similar Systems Give Different Results?

In recent years some researchers have focused on the causes of variation in LCA calculations (Cherubini 2010, Rowe et al. 2011). Rowe et al. identified three main causes of variation in GHG and energy balances of bioenergy production systems:

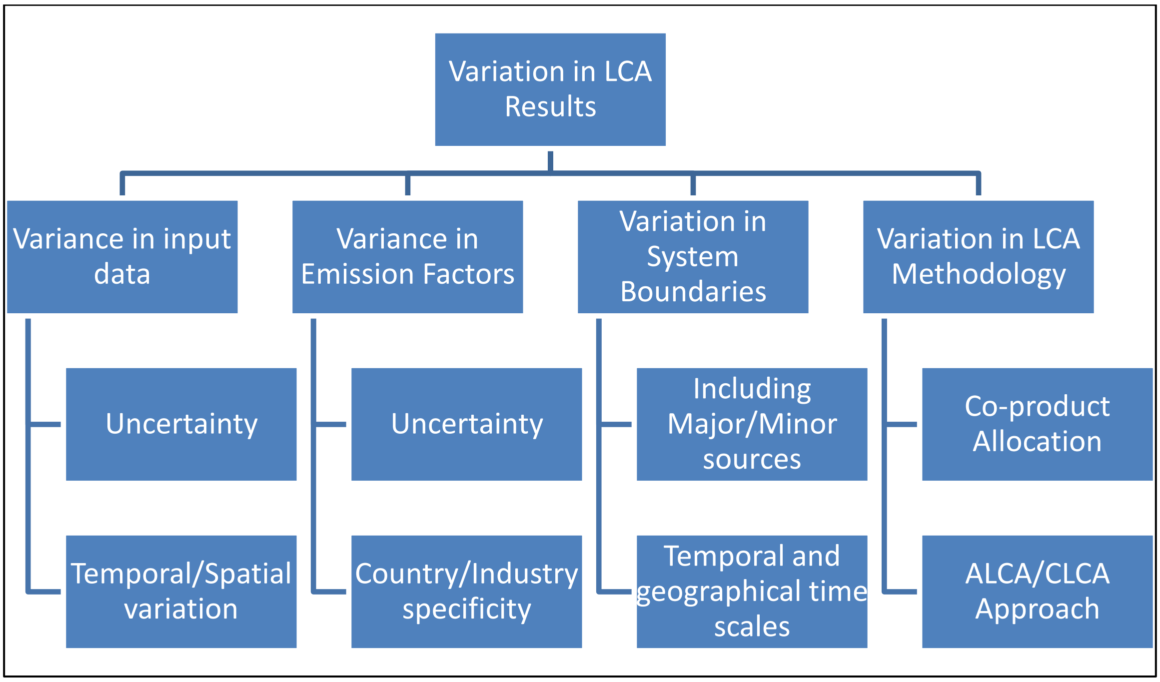
1. ‘real’ variation in input data due to varied cultivation practices and production methods
2. ‘uncertainty’ in input data due to limitations in the knowledge base or contentious input data
3. ‘methodological variation’ e.g. system boundaries and co-product allocation

These are shown diagrammatically in figure 1 and discussed in sections 4.2.1, 4.2.2 and 4.2.3.

4.2.1 Real Variation

Calculating GHG balances for bioenergy by LCA requires collation of huge amounts of data and assumptions to be made concerning crop cultivation, yields and conversion methods etc.. Variations in these assumptions can occur for a variety of reasons and will inevitably contribute to differences in calculations of GHG reductions, even within bioenergy systems based on the same feedstock. For bioenergy from annual and perennial energy crops key sources of ‘real’ variation have been identified as crop yield, fertilizer application rate and type, transportation distance to the power plant, conversion efficiency of the power plant and co-product utilization (Whitaker et al. 2010, Rowe et al. 2011). For example, in the cultivation of energy grasses, GHG emissions associated with fertilizer production spanned two orders of magnitude ranging from 0.06 to 3.95 g CO_2 eq $MJ^{-1}{}_{wood}$ fuel. The conversion efficiency of the power plant can also have a significant effect on the overall GHG balance of bioenergy production chains, for example a single feedstock converted to electricity using different technologies (e.g. co-firing or gasification), can result in a GHG balance ranging from 9 to 21 g CO_2 eq $MJ^{-1}{}_{electric}$ (Rowe et al. 2011). These are “real variations” in GHG emissions that actually make a difference to the level of GHG reductions as experienced in the atmosphere and contributing to climate change. Understanding the sources of this variation can allow areas for efficiency improvements to be highlighted.

Figure 1: Sources of variation in LCA calculations



When considering LCA calculations it is vitally important to assess the realism of the scenario presented e.g. fertilizer is a relatively expensive commodity and assessment at international level confirms that using fertilizer is more efficient from a GHG perspective than not using it (Brentrup & Palliere 2008). Fertilizer (and carbon) intensive bioenergy systems often make less commercial sense and so may be reported on in theoretical papers but are much less likely to be implemented in practice.

So, real variation may occur because two apparently similar bioenergy systems actually involve different steps or equipment which result in different levels of GHG emissions. In addition we are dealing with a natural system and so there will be a level of natural variation, even for a system that is apparently well-defined e.g. yields or soil emissions may be different for two apparently similar systems at different times or locations. This is a real variation in GHG emissions that cannot be completely eliminated by more or improved knowledge.

4.2.2 Uncertainty in Source Data

In addition to real variation in bioenergy production chains, “uncertainty” may arise because there is insufficient knowledge about GHG emissions from certain process steps to accurately define assumptions. Recourse is often made to data that already exists for another production chain, which may not be accurate. In addition there is uncertainty due to lack of knowledge which is particularly important for land use change (LUC) effects, and soil N_2O emissions. This is exacerbated when considering global supply chains, where cultivation, harvesting, transport and land-use change are inherently uncertain. In addition it can be difficult to “know” what the appropriate counterfactual is for a consequential LCA when considering the emissions displaced or avoided.

The modeller needs to choose a value or make an assumption that they believe to be representative or likely, but that may not be accurate for the particular bioenergy supply chain being considered.

For example, in the small number of studies estimating soil carbon sequestration under dedicated energy crops values used ranged from -0.1 to -25 g CO_2 eq $MJ^{-1}_{woodfuel}$ (Whitaker et al. 2010).

Where knowledge is lacking, reliance on published typical values is common and particular values may get used, repeated and reused with little verification of their appropriateness or validity. Work that is recognized as good quality may get used repeatedly as a reference source even when more appropriate/up-to-date data becomes available. For example, a paper published in 2003 "Carbon and Energy Balances for a Range of Biofuels Options" (Elsayed et al. 2003) has been referenced over 100 times and is still being used for data on biomass gasification emissions (Wu et al. 2013), despite the significant technical development of those systems that has taken place in the interim. These data sources become ingrained in LCA databases, but inevitably contain historical, rather than contemporary data. Consequently GHG balances may be based on parameter assumptions that are not representative of the real system being assessed; results generated will not be an accurate reflection of reality. The effect can be minimized by careful data collation, review and sensitivity analysis; but this may require substantial effort and in some cases the effort required may not be justified by the increase in confidence or reduction in GHG emissions achieved.

For example, emissions of N_2O from soils vary spatially and temporally with climate and soil type. Most LCAs default to IPCC values which assume a linear relationship between N fertilizer application and soil N_2O emissions, which may take high-level cognisance of agro-ecologic zone, but not weather or application method. Accuracy in this parameter matters because for biofuel production N_2O emissions can constitute between 65% and 85% of the overall GHG balance from cultivation.

Bioenergy systems are part of the natural environment and that entails a natural variability that makes extrapolation of results very difficult e.g. nitrous oxide emission or soil carbon contents can vary spatially and temporally. So shifting an industrial bioenergy system in time or space will change the GHG balance. These are "real" changes from an atmospheric perspective and careful consideration needs to be given to the most appropriate way of managing and reducing them e.g. perhaps by considering or restricting the most appropriate geographical zones for feedstock production.

4.2.3 Methodological Variations

As discussed above, LCA of bioenergy systems is often carried out in line with particular standards e.g. ISO or PAS 2050. However, most standards are still relatively flexible and the onus remains on the practitioner to choose appropriate system boundaries and allocation procedures etc. relevant to the question being asked. Variations in results arise from methodological aspects including:

1. How the **system boundaries** are drawn
2. Using different **allocation procedures**
3. Using different **emission factors**

As explained earlier these methodological variations are not arbitrary decisions made by individual practitioners but should be informed by consideration of the actual question being asked. Section 5 of this report considers in more depth the importance of correctly framing the "LCA question" and how this may affect the methodology and ultimately the "answer" produced.

Section 6 then considers the implications of this framing for the methodological approach adopted in LCA analysis.

5. What Should be Considered when Assessing if Bioenergy is Delivering Real Greenhouse Gas Reductions?

As stated in section 4, LCA methodology can be adapted to suit the goal and scope of the assessment. It is therefore vitally important to be clear at the outset what question we are actually trying to address. This section illustrates the importance of this understanding and how it may affect the LCA methodology applied when assessing if bioenergy is delivering ***"genuine carbon reductions"*** (DECC 2012).

The UK Government's bioenergy strategy recognizes that incentivizing certain types of bioenergy may actually result in increases in GHGs, while aiming to promote bioenergy that achieves "real GHG reductions". It is therefore extremely important to understand exactly what we are trying to achieve underneath that headline objective. LCA is the right tool to address this issue. However, subtly different questions require different approaches in terms of LCA scope of system, methodology etc. and therefore it is vitally important to ensure that adequate consideration is given to the question being asked when considering bioenergy GHG balances. This section examines the relevant considerations in translating that policy principle into an appropriate "LCA question", how those considerations would affect the LCA methodology chosen and ultimately the answer obtained.

5.1 Reductions for Whom?

As explained in section 1.2, GHG reduction targets specified by the UNFCCC are reductions in national, territorial emissions compared to a particular reference year. This reporting framework is founded on the assumption that reducing the carbon emissions of different contributing national sectors will reduce national emissions, which will contribute to global GHG reductions. However, reduced emissions in one country may often be linked to an increase in emissions in another country. This is particularly problematic when emissions reductions are achieved in countries with targets (Annex 1 countries) linked to increases where there are no national emission targets in place (Non-annex 1 countries). Therefore we must be clear which emissions are included in the scope of assessment: all emissions on UK soil would normally be included; including sequestration or emissions incurred in other countries may give a more complete picture but makes no difference to the UK's UNFCCC targets; emissions incurred in non-annex 1 countries are likely to be much less accurate than in other countries.

Consideration of this issue is critical when defining the scope and boundary of the LCA calculations, discussed further in section 6.1.

5.2 Reductions to Service which Demand?

5.2.1 Type of Demand

The energy system is not static with a fixed demand. In realty demand is dynamic, varying by time of day and seasonally. Different types of generating capacity are more or less appropriate for serving different types of demand. In the electricity sector bioenergy is best suited to delivering base-load demand, but may also service heating or transport fuel demands.

5.2.2 Level of Demand

The UK does not have a fixed energy demand and installing new electrical generating capacity is not guaranteed to displace existing fossil-fuel generating capacity. Depending on the overall supply-demand balance generation of "green" energy may be additional to current energy generation, rather than directly displacing it.

5.3 Reductions over what Timescale?

Anthropogenic climate change is predominantly caused by the long term changes in atmospheric GHG concentrations since the industrial revolution and many policy frameworks focus on 2020 and/or 2050 objectives compared to 1990 reference levels. However, the long lifetime of CO_2 in the atmosphere means that cumulative accounting (see box 2) with different GHG 'budgets' in different time interval is argued to be the most appropriate way of considering emissions (Allen et al. 2009). This emissions longevity also means that near term reductions are more valuable than longer term ones i.e. saving one unit of GHG this year is more valuable than saving it in five years' time since the GHGs continue to exert a radiative forcing effect for the whole time they are in the atmosphere. Bioenergy generally involves re-release of previously sequestered carbon and so the extent to which this contributes to long term concentrations of CO_2 in the atmosphere may depend on when the sequestration and re-release take place.

5.4 Are Reduced GHG Emissions as Important as Increased Sequestration?

Greenhouse gas balances aim to "balance" all the GHG emissions and sequestration along a chain to arrive at a net figure for GHG emissions. Often this is simplified by assuming that the CO_2 released on combustion or use of the biomass is equivalent to that originally sequestered. However, bioenergy deployment may, in some cases, change the total GHGs sequestered e.g. incentivizing bioenergy may result in additional plantations that sequester more carbon (e.g. in soil) than that contained within the harvested biomass or harvesting forest biomass may change the future sequestration potential of the forest. Identifying causal links between these effects may not be possible and so it may not be appropriate to assess this on a narrow supply chain basis; but effects may be manifest at larger scales when considering the cumulative impact of development.

Box 6: Balancing Bioenergy Sequestration and Releases

Using biomass for energy releases biogenic carbon which contributes to climate change and is counted as an emission under the UNFCCC framework and the UK's GHG budgets.

Sequestering additional carbon by growing biomass in the UK for energy in the UK reduces climate change, counts under the UNFCCC framework and the UK's GHG budgets.

Sequestering additional carbon by growing biomass overseas for energy in the UK reduces climate change but is not counted under the UK's GHG budgets and may or may not register within the UNFCCC framework depending on the country of origin. In particular where biomass is grown in a country with no binding target it will be more difficult to be confident that sequestration by biomass growth has not been offset by other increases in that country. Key issues that cause complications here include land-use and land-use change. These are difficult to assess since they require consideration of the dynamics of two global markets with multiple products, linked by a common land, water and energy resource pool.

Supply chain accounting is an attempt to trace the GHG impact of products globally across national boundaries. It is effective in isolating the impact of a particular product but is not appropriate for dealing with cumulative impacts in global markets and so can confirm that good/best practice is being effective in achieving certain benchmarks but cannot guarantee net reductions in global emission because it cannot take account of the impacts in related sectors.

Changing forest management patterns to produce additional biomass for energy releases a certain amount of direct CO_2, which will be similar to the levels released from other woody feedstocks. Impacts on the forest's sequestration capacity over different timescales, depending on the species, management change and alternative pathway that is assumed. Since forests are usually a mix of ages, species etc. it is more important that the holistic management is sustainable with respect to GHG balance than a particular, traceable supply chain. This would be most effectively accomplished using forest certification schemes, many of which have only limited explicit consideration of the carbon pools in a forest. Incorporating this would protect against apparently sustainably material having incurred actual GHG increases and prevent accounting anomalies where GHGs are "ascribed" to forest fractions depending on their mass, value or energy content. This may help or hinder a particular product stream form appearing to deliver reductions, but it does nothing to ensure global GHG reductions. Normally certification balances impacts across a number of sustainability categories, but it may make sense for bioenergy use to mandate minimum carbon performance criteria judged across the whole forest. Note this would not prevent development of a "black market" for non-certified material for other uses. In addition there uncertainty of varying degrees attached to all these carbon assessments. However, overall it is more important to encourage good practice than to set minimum standards of mediocrity.

5.5 Reductions over what Scope of System?

Often the scope of system must be tailored to the policy objective, but this can lead to misleading results e.g. most international accounting frameworks, including the UNFCCC ignore international aviation and shipping which can be a significant contributor to some GHG balances. A key issue is whether or not direct and indirect land-use changes are included, particularly when these are incurred in other locations. The UK would not normally include emissions from overseas land-use changes in its national emissions inventory (e.g. when we import food that has been produced on forest land cleared for agriculture). However, incentivizing bioenergy may contribute to land-use change and associated direct and indirect emissions. As with sequestration it can be difficult to identify causal links for specific supply chains and so recent attempts to address this have focused on attribution of ILUC factors to certain supply chains. This is highly uncertain and it may make more sense to apply consequential analysis on a large scale rather than attempt to allocate large-scale macro effects to individual supply chains.

5.6 Reductions Compared to what Reference System or “Counterfactual”?

If we are evaluating how bioenergy systems are reducing GHGs, it must be assumed that bioenergy is displacing some other form of energy that would otherwise have been in place or may otherwise be developed in future. This is important as different bioenergy systems are likely to displace different existing energy supply systems. For example in the UK, wood fuel for heating might displace kerosene or heating oil in rural areas, anaerobic digestion might displace natural gas, co-firing is likely to displace some use of coal. The reference system needs to be clearly defined so we can compare the emissions from the bioenergy system with the likely energy generation technology which has been displaced.

Similarly it could be argued that if emissions associated with land-use are taken into account then the reference case against which reductions are measured should also take into account the emission associated with a counterfactual “land-use”. This brings additional complexity in terms of determining what that counterfactual should be e.g. pasture or food production. Establishing the present day counterfactual land use is often feasible, but projecting what might have happened to a piece of land under other circumstances is inevitably uncertain and subjective, so that different opinions on the feasibility of alternative uses may result in different projections for GHG reductions.

In the case of waste products, consideration needs to be given to what appropriate disposal or use would have been implemented if the material were not used for bioenergy. This can be difficult e.g. ‘wood waste’ might sometimes be left to decompose or might be utilized in panel board production if it were not used for bioenergy.

Additionally it could be argued that counterfactual land use makes no difference to “real” GHG reductions since these do not constitute a “real” reduction from an atmospheric perspective, merely less than the anticipated increase.

It is critical that these counterfactuals are realistic. This is important both in considering the existing fossil fuel which bioenergy will displace and when considering other future energy options. For example some bioenergy options, such as co-firing in coal-fired power stations, can be deployed very rapidly, while deploying the same level of nuclear or wind capacity could take substantially longer. There is a general expectation in the UK that more low carbon energy will be deployed in future so that the GHG intensity “benchmark” against which renewables capacity should be delivering reductions will decrease in future. However, rapid deployment of bioenergy could deliver more low carbon energy in an earlier time frame than longer term or longer lead-time options. This is particularly important given that the UK is not on track to meet its medium term objectives (CCC 2013).

So, different conclusions about the value of bioenergy for greenhouse gas mitigation may be reached depending on whether the bioenergy system is judged relative to other systems at a specific point in time or whether long term projections of cumulative emissions over system lifetime are considered (when it becomes important whether or not we make assumptions about the likely change in carbon intensity of non-bioenergy alternatives in future.)

On one hand these may seem like pedantic questions if “all” we want is to ensure that there are genuine global GHG reductions. However, they are important as they determine the calculation methodology that should be used in providing an answer to the question and highlight the fact that the objective of achieving “real GHG reductions” does not necessarily correlate with existing legal and policy targets. It is vital that there is clarity about what we are actually trying to achieve/measure at the outset of an LCA and the above issues must be considered at the outset for bioenergy. These considerations will then influence how the LCA should be carried out and the next section of this report discusses specific methodological issues that tend to arise in bioenergy LCAs explaining the rationale for different approaches to dealing with them.

6. What are the Methodological Issues that make Bioenergy LCA Calculations Difficult and their Results Contested?

LCA is a useful tool for analysing the GHG balance of bioenergy systems, but using it also highlights a number of issues, some of which are unique to bioenergy, that require careful consideration. Section 4 highlighted the following key methodological issues that arise when applying LCA techniques to bioenergy systems:

1. How the **system boundaries** are drawn
2. Using different **allocation procedures**
3. Using different **emission factors**

Each of these are examined in more detail below to highlight the complexity involved in bioenergy system GHG analysis and how failure to transparently manage this complexity can lead to misleading results.

6.1 How the System Boundaries are Drawn

System boundary selection determines the processes and activities included in a LCA study. The boundaries should be justified on an objective, repeatable, and scientific basis. ISO 14040 standards recommend that the decision to select "elements of the physical system to be modelled" be based on the goal and scope definition of the study, its intended application and audience, the assumptions made, constraints, and cut-off criteria that is "clearly understood and described" (CEN 2006a). The cut-off criteria can vary substantially between studies and this leads to variability in results since it often depends on what constitutes a "material" emission source to the LCA practitioner. As discussed in section 5.5 it is key to identify the scope of the GHG we are trying to reduce and selecting inappropriate boundaries risks producing results that may either not reflect reality well enough, leading either to incorrect interpretations and comparisons or weakening confidence in the results (Reap et al. 2008). One problematic area is the inclusion or exclusion of direct land-use change (discussed in more detail below in 6.1.1) and indirect land-use change (discussed in section 6.1.2); while another is the temporal scope of the assessment (discussed in section 6.1.3).

6.1.1 Direct Land-Use Change

Emissions associated with land-use and land-use change are often excluded in LCAs, sometimes because it is assumed that no change has occurred or because specific data is not available or because it is difficult to causally link bioenergy to any land-use change. Including direct land-use change emission in an LCA better reflects reality and there is evidence for some supply chains that the GHG emissions associated with direct land use and land-use change (LUC) are potentially large (Smith et al. 2012, Haberl et al. 2012, Searchinger et al. 2008), so that inclusion of different possible land-use changes has a very significant impact on the overall GHG balance (Upham et al. 2009,).

Land-use change to bioenergy crops can produce immediate changes in the GHG balances in response to the disturbance event itself e.g. the burning of biomass or ploughing to clear land, releases GHGs to the atmosphere. However, in the medium term the establishment of woodland growth has high sequestration levels in early years and conversion of land may change soil nitrogen cycles, altering nitrous oxide emissions. Field CO_2 assimilation may be altered by changing the land-use/vegetation/crop and disturbance may reduce carbon storage in soils but it may accumulate later in the life cycle of the crop.

Overall, while the shorter term responses to land use change are important they must be contextualized into the longer term GHG balance of the crop life-cycle. The long term carbon balance of bioenergy crops is sensitive to changes in soil and vegetation carbon stocks which vary with crop and management intensity. In general, annual cropland conversion to perennial crops or forestry results in increased carbon stocks while carbon is lost through conversion of perennial crops or grasslands to annual crops. In some cases monitoring results have been reported over a relatively long period (Powlson & Jenkinson 1981, Smith et al. 1998, Powlson et al. 2005) but in other cases we do not know the long term effects of land-use change to bioenergy on soil GHG emissions or soil carbon stocks.

A final consideration is that the economic lifetime of perennial energy crops is between 20 and 30 years, so land-use reversion will occur at the end of this period and there is little data on the GHG implications of this.

6.1.2 Indirect Land-Use Change

In addition to emissions associated with direct land-use change there are concerns that increased bioenergy land-use could displace agricultural land in a cascade onto other land uses or increase the intensity of management of remaining agriculture so having an ‘indirect' effect (Fargione et al. 2008, Witcover et al. 2013). This “indirect land-use change" (ILUC) could have devastating consequences in terms of increased GHG emissions (Fargione et al. 2008; Searchinger et al. 2008).

ILUC works well as a concept, but is difficult to assess at a global scale (Fritsche et al. 2010, Kim et al. 2011 and Kim et al. 2012). In some contexts, indirect land-use change may have a large impact on bioenergy GHG balances; in other contexts (even where land-use change has taken place) it is insignificant or may even enhance GHG savings (Stephenson 2013).

Sometimes it is possible to examine a “real" chain and see if there is likely to be a significant problem, but this is often undermined by the global connectivity of food, energy and commodity markets. ILUC factors are seen as an answer by some, but the integrity of the results will rely on appropriate choice of ILUC factor. This requires a much deeper understanding of the land interface between food and fuel production and other land uses.

6.1.3 Scope of Temporal Assessment

Key international policy commitments seek reductions in GHG emissions compared to a 1990 reference level. Therefore planting or changing forest management to increase carbon sequestration after 1990 are considered beneficial from a policy perspective. However, the reality today is that all carbon emissions that have already been incurred from that date are essentially non-reversible and will contribute to climate change. It could therefore be argued that all historic releases are irrelevant and only changes from the present should be considered in assessing bioenergy GHG balances, so the timescale considered in LCA assessments should start from the present day. This decision essentially depends on whether the LCA is intended for particular policy reporting purposes or not.

However, there are also issues associated with the timescales adopted in LCA analysis. Originally LCA was intended to examine cradle to grave emissions for industrial processes and so it is always clear where the temporal start point (pre-construction) and end-point (post disposal/decommissioning) should be drawn and the impacts are averaged over the functional unit, which is normally only relevant during the operational phase. However, bioenergy systems rely on natural plant growth which is often independent of the energy conversion/utilization and there can be a discrepancy between the temporal scale of the plant growth (from one year for an annual crop, to 70 years for a commercial forest) and that of the conversion facility (typically 20-30 years). This can make it difficult to determine the most appropriate timescale over which to consider the net impact of a bioenergy system.

Additionally LCA is a static tool that considers only the net impact over the defined period. However, biomass growth is dynamic and some GHG balance calculations on bioenergy systems have been carried out which have claimed that production of biomass incurs a "carbon debt" which may take a long time to be repaid. This is particularly an issue for forestry where life-cycles and harvest intervals are significantly larger than for perennial crops.

"Carbon debt" describes three different, though related, phenomena:

(i) the time delay between the reduction of carbon stocks on a site due to harvesting, and its replacement by new growth

(ii) the permanent reduction in carbon stocks within a forest because of increased levels of harvesting

(iii) the theoretical potential for managed forest to sequester more carbon if left unharvested

(i) can be a significant issue if viewed from a local/supply-chain perspective, but it must be remembered that sustainable forests are generally managed at large scales. Local perturbations in carbon stocks of particular stands are to be expected as part of the normal harvesting routine and are not usually significant in the aggregated carbon stock of the entire forest holding. Therefore it is important that carbon stock is assessed at an appropriate scale.

The impact of increased harvesting of bioenergy on long term carbon stocks in a forest should be taken into account in the overall GHG balance. This has been assessed for some forestry systems (Schlamadinger et al. 1995, Burger 2009, Nave et al. 2010, European Environment Agency 2008, Lattimore et al. 2008) but more analysis and evidence is required to be confident that forest harvesting is not having a negative impact on forest carbon stocks.

It should be noted that (iii) does not involve direct emissions of fossil GHGs or an immediate reduction in carbon stock, but reduced levels of potential future sequestration and so could perhaps more accurately be described as "foregone sequestration" than "carbon debt" (Matthews 2013). It is particularly important when considering "foregone sequestration" to consider the appropriate counterfactual and the alternative land-use that would prevail if forests were not supplying wood for bioenergy. In regions where forestry is a major source of income, this could be an alternative crop or perhaps even by residential or leisure developments. It could be argued that forest growth and continued sequestration is only likely if it provides a financial income stream and there is usually no explicit financial compensation for continued carbon sequestration from existing land-use.

It is also important to remember that carbon sequestration is only one of many purposes of forestry and forest management. There are many reasons why forest management may switch to a mode that reduces the potential for future sequestration. A very strong demand for bioenergy/wood products could drive this if a growing market for the smaller forestry fractions were to encourage more residue harvesting; but equally carbon stocks could be reduced by management changes to increase/improve woodland habitats and biodiversity. Carbon sequestration and storage is an important function of forestry systems, but not the only one.

6.2 Using Different Allocation Procedures

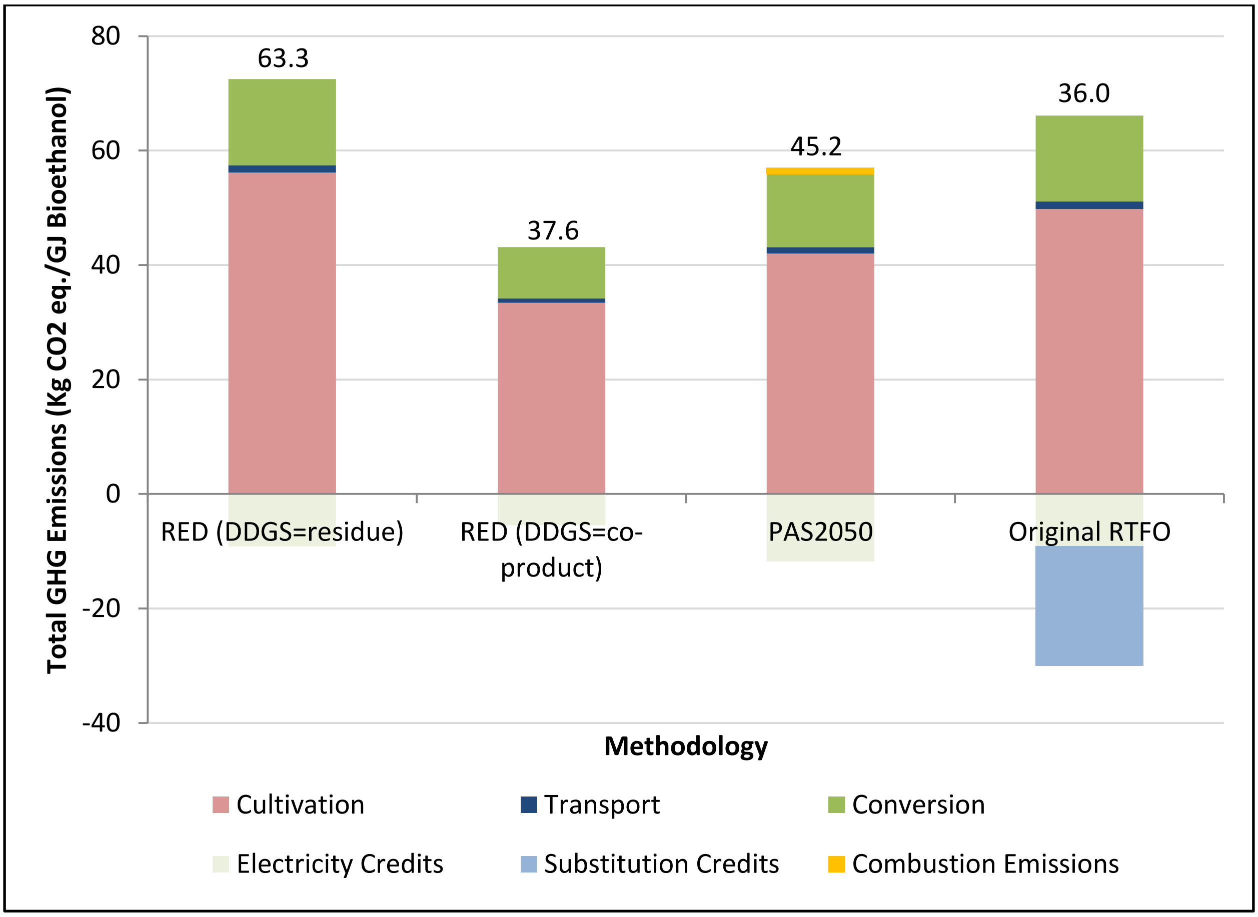
When carrying out a consequential LCA (appropriate for analyzing the policy or wider impact of bioenergy production) and there is more than one product it is normal to deal with this by expanding the system to consider the consequences associated with production of the co-product e.g. if soy produces oil for biodiesel and meal for animal feed the GHG calculation would take into account the GHGs that have been avoided by displaced meal production. However, for attributional LCAs (appropriate for considering the impact of a particular supply chain) a procedure called allocation is commonly used, which involves appropriately allocating the GHG emissions of a multi-functional process amongst its products.

Allocation is one of the most controversial issues in LCA methodologies (Reap et al. 2008). The ISO Standards recommend that, if possible, allocation should be avoided by system expansion. This assumes that the co-product can displace another product, which now no longer needs to be produced, and the avoided emissions are credited to the main product (Whittaker et al. 2011). Alternatively, emissions can be allocated between the main product and the co-products according to physical relationships such as mass or energy content, or by economic relationships, such as cost. Different allocation methods can generate significantly different results and this was examined by Whittaker et al. (2011) and illustrated in figure 2, which shows the GHG balance for bioethanol production with a "dried distiller's grain with solubles (DDGS)" co-product. When DDGS is considered to be a co-product this allocates emissions away from bioethanol, hence reducing the overall GHG emissions. If it is considered to be a residue, and not allocated emissions, the GHG emissions from bioethanol are almost twice as high (See figure). The original Renewable Transport Fuel Obligation (RTFO) methodology would assume that DDGS can substitute animal feed production, hence is awarded a credit for avoided production.

Problems are frequently encountered, particularly when these approaches fail to reflect the inherent "value" that different stakeholders may attach to one product or function over another.

The forestry industry produces multiple products and it does not make sense to consider biomass or bioenergy as independent from that industry (Sanderson 2013). The most valuable portion of the tree is the sawlog, particularly for furniture and construction use. Other parts of the harvested tree have other markets, including biomass for energy, pulp and paper. The value derived from these different products combines to determine whether or not it is commercially viable to harvest a particular stand. The harvested biomass (or carbon) then finds its way into a range of products. The extent to which the carbon remains sequestered beyond harvest depends on the use to which the material is put. It can be hundreds of years for sawn timber in the construction industry to relatively short time spans as tissue paper or bioenergy. Therefore the carbon that is sequestered by a whole tree or whole forest needs to be "allocated" across these different products.

Figure 2: Greenhouse gas balances for ethanol production using different methodologies (Source: Whittaker et al. 2011)



6.3 The use of Emission Factors

Emission factors provide a useful shortcut for use in LCA, avoiding the need for detailed calculations of emissions by linking a typical quantity of GHGs released to the atmosphere to a particular activity or process step. For example, fertilizer emission factors link GHG emissions to application of a certain amount of fertilizer, but GHG emissions from fertilizers combine production emissions, soil emissions and emissions during transport. The "real" emissions vary widely depending on production technology and field application conditions, so it is best to use customized emission factors relevant to the particular plant and application, but this is rarely available and therefore reliance is placed on published emission factors for GHGs associated with the production of a range of fertilizers. The result is that the calculated GHG emission may not accurately reflect those actually incurred in applying a particular fertilizer to a particular crop.

7. What are the Implications of our Understanding of Bioenergy System Greenhouse Gas Balances for Policy Initiatives or "How can Policy Frameworks Incentivize "Real" Greenhouse Gas Reductions?"

This report does not aim to make policy recommendations for UK bioenergy development. However, it does deal with a number of issues that are relevant for policy development and the implications of some of these are summarized below:

Bioenergy systems are different and parameters that are significant for the GHG balance of one system may be unimportant for another

Significant effort is required to carry out LCA analyses. Table 1 identified the areas that are most significant for different feedstock types and it would make sense to focus effort in confirming the accuracy of the more significant emission sources, rather than trying to quantify all contributions.

The overall ***yield*** and any ***land-use change*** are very often crucial parameters which are therefore worth confirming to an appropriate level of accuracy if possible, but extensive efforts to quantify figures that are subject to external variations may not make sense e.g. emissions associated with indirect land-use change are likely to be driven by complex contextual interactions with food and other systems so that the accuracy may be limited.

Land-use change is important

Which land or land uses will be used to provide feedstock can have a profound impact on bioenergy greenhouse gas balances, especially for annual and perennial crops. However, understanding of the long term GHG consequences and indirect impacts is limited and many non-bioenergy uses have similar consequences. It may make sense to restrict the zones in which certain biomass feedstocks can be planted or encourage planting in preferred areas. However, in the longer term Improved understanding of global land-use patterns, drivers for and consequences of land-use changes are required.

There is an urgent need to improve understanding of future food, fuel and land-use demands

The interface between bioenergy and food production physically involves land, but also water and nutrients. The inter-relationships between these sectors is critical in terms of GHG emissions, but is relatively poorly understood. This results in very large variations in future GHG projections which are unhelpful in steering policy direction. There is an urgent need to improve understanding of future food, fuel and land-use demands and the relationship between bioenergy and the wider energy system, all of which affect the GHG balance of bioenergy systems.

Life cycle assessment is the most appropriate existing tool for bioenergy GHG assessment, but new approaches that address its inadequacies should be investigated

LCA is inadequate for bioenergy GHG assessment in two main respects: It cannot capture the 'top down' overview of macro-scale impacts in the way that input-output analysis does; it is a static tool that cannot represent dynamic changes, which are increasingly important given our limited carbon budgets. Consideration needs to be given to if and how LCA can be adapted to address these issues.

Where LCA is used, it must be used appropriately, so that the LCA system being studied and methodology adopted are truly appropriate to the system being implemented and question being asked. Counterfactuals must be based not on 'hypothetical options' but on 'economically feasible' options, considering for example, what alternative land use might reasonably be, given the need to generate revenue from that land. It is also important to ensure that the GHG impacts of the "status quo" or alternatives are calculated using the same supply chain methodology as for the bioenergy system. Such figures are difficult to access for the existing UK energy system. There is a danger that LCA can be used to validate or justify policy and strategies without being truly representative of the system (e.g. using published figures rather than collecting them for specific sites or taking published LCAs as representative of all bioenergy).

There is a need to improve understanding of carbon dynamics, particularly for forestry systems

LCA is a static tool that takes no account of the timing of emissions and this is a serious limitation in its adequacy for assessing bioenergy systems. There is a need to develop methods of assessing carbon dynamics, particularly for forestry systems.

Sustainable forest management should incorporate sustainable management of the forest carbon stock

Existing sustainable forest certification schemes do not take account of forest carbon stocks, but this is currently under review by the Forestry Stewardship Council (FSC). Implementing a modified scheme which took this into account would have huge benefits in terms of increasing confidence in the GHG benefits from forestry systems. Table 1 showed this was one of the most significant factors for those systems and it might ultimately be possible to be confident about GHG reductions simply by having an FSC certification regardless of supply pathway.

Importing goods and materials to the UK effectively exports our emissions obligations

UK GHG emissions are decreasing at the expense of increases overseas, but this is an issue not just for bioenergy, but many other aspects of the UK economy where we import products in a manner that is equivalent to exporting our carbon emissions.

Sustainability is about more than greenhouse gases

It is important to remember that GHGs are important, but are only part of the wider sustainability framework, which also needs to incorporate consideration of nutrient balances, water availability, biodiversity, eutrophication, toxicity etc.

Achieving real greenhouse gas reductions is an important objective, but difficult to "prove" and elusive to manage.

The UK's bioenergy strategy is framed around a desire to achieve "GHG reductions" and this can be difficult to assess for many bioenergy systems for a variety of reasons, detailed above. Additionally some of the key parameters are often not within the direct control of the bioenergy producer. Sustainability certification may help with some elements, but it may make more sense to focus on limiting (or allocating a GHG budget for) the supply chain emissions (which are identifiable and manageable) rather than consider the net GHG balance, which is influenced by many parameters beyond the control of the bioenergy producer e.g. land-use changes during production and the carbon intensity of displaced fuel.

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