IMPERIAL COLLEGE LONDON
Faculty of Natural Sciences

Centre for Environmental Policy

Assessing the sustainability of HGV biofuel options for the UK Retail Industry

by

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A report submitted in partial fulfilment of the requirements for the MSc and/or the DIC.

September 2012

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Assessing the sustainability of HGV biofuel options for the UK Retail Industry

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Abstract

There has been a growing recognition of the need to address sustainability issues in every sector of the economy. Measures have been taken internationally to address the converging issues of resource scarcity, energy security and environmental issues including biodiversity loss and climate change. The UK domestic transport sector (excluding international aviation) is the second largest cause of direct greenhouse gas emissions, behind the energy industry. This sector is therefore expected to play a major part in the UK's carbon reduction plan through emissions reductions.

The aim of this thesis was to assess the sustainability of alternative biofuels, suitable for Heavy Goods Vehicles in the UK. It also sought to determine which biofuels have the greatest potential to help the retail industry and the UK transport sector as a whole, achieve 2020 greenhouse gas emissions reduction targets.

To achieve these aims, the constraints and opportunities involved in achieving emissions reductions for this vehicle category were examined, including the potential role for biofuels. A model to assess the greenhouse gas emission savings potential of the various alternative fuels was developed as well as an appropriate sustainability benchmarking tool to evaluate which of the fuels and production pathways under consideration best meet the key sustainability criteria.

It was found that biomethane was the most likely biofuel to contribute to sustainable reduction in greenhouse gas emissions. However this would only be the case if an adequate supply of sustainable feedstock and adequate infrastructure could be assured.

Acknowledgements

I would like to thank my supervisor at Imperial, Jeremy Woods for his guidance and encouragement. I would also like to thank Ruth Gallagher and Justin Laney from John Lewis Partnership for being so generous with their time and advice. Special thanks to Moira Thomas and Simon Gray from John Lewis for providing key insight and data.

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Abbreviations

AD	Anaerobic Digestion
CEN	European Committee for Standardization
CHP	Combined Heat and Power process
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CSR	Corporate Social Responsibility
DDGS	Dried Distillers Grains with Solubles
DfT	Department for Transport
EPA	United States Environmental Protection Agency
EROI	Energy return on investment
FAO	Food and Agriculture Organization of the United Nations
FQD	Fuel Quality Directive
GHG	Greenhouse gas
GWP	Global warming potential
HGVs	Heavy Goods Vehicles
HVO	Hydrotreated vegetable oil
ILUC	Indirect Land Use Change
ISCC	International Sustainability & Carbon Certification
ISO	International Organization for Standardization
JLP	John Lewis Partnership
LCA	Life cycle analysis
LCFS	Low Carbon Fuel Strategy
LUC	Land use change
N_2O	Nitrous oxide
NOx	Nitrogen oxides
OSR	Oilseed rape
PPO	Pure plant oil
RED	Renewable Energy Directive
RINS	Renewable Information Numbers
RSB	Roundtable on Sustainable Biofuels
RTFCs	Renewable Transport Fuel Certificates
RTFO	Renewable Transport Fuel Obligation
RUE	Radiation use efficiency
UCO	Used cooking oil
UNEP	United Nations Environment Programme
WBCSD	World Business Council for Sustainable Development
WTT	Well to tank
WTW	Well to wheel
WWF	World Wide Fund For Nature

1. Introduction

This thesis assesses the sustainability of alternative biofuels, suitable for Heavy Goods Vehicles (HGVs) in the UK. It also seeks to determine which biofuels have the greatest potential to help the retail industry and the UK transport sector as a whole, achieve 2020 greenhouse gas (GHG) emissions reduction targets.

1.1. Background

There has been a growing recognition of the need to address sustainability issues in every sector of the economy. Measures have been taken internationally to address the converging issues of resource scarcity, energy security and environmental issues including biodiversity loss and climate change. The need to mitigate climate change in particular, has been recognised as a pressing issue and international treaties such as the Kyoto Protocol (UN, 1998), have been followed by further legislative measures at the EU and national level applying to all areas of the economy.

1.1.1. UK Transport emissions

In the UK, the Climate Change Act 2008 introduced legally binding targets for the national reduction of GHG emissions by at least 80% by 2050 (Crown, 2008). The Carbon Plan, introduced in 2011 by the UK Government, sets out a series of 'carbon budgets' (DECC, 2011a), five year plans with a cap on total emissions for the UK economy. Comprehensive analysis of emissions of carbon dioxide (CO_2) and other greenhouse gases has been carried out in order to evaluate the contribution and potential savings in emissions from each sector. In 2010, the UK domestic transport sector (excluding international aviation) was responsible for 21% of direct GHG emissions (DECC, 2012), making it the second largest cause of direct emissions, behind the energy industry. It is therefore expected to play a major part in the UK's carbon reduction plan through emissions reductions.

Road transport accounts for 90% of GHG emissions from the transport sector. This is due in part to heavy reliance on fossil fuel derived petroleum products which provide 96% of all road transport fuel (EC, 2011a).

Cars are the most significant emitters, accounting for over 55% of all road transport GHG emissions (DfT, 2011a). Figure 1 shows road transport emissions by transport mode in 2010.

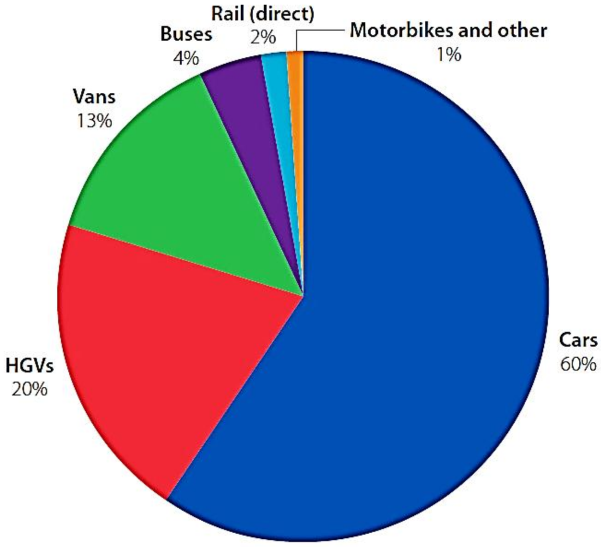

Figure 1: Breakdown of surface transport CO_2 emissions by mode (2010)
Source: (CCC, 2012)

Since 1999, HGVs have accounted for over 20% of road transport GHG emissions in the UK (DfT, 2012d). In 2009, this corresponded to approximately 4% of total domestic GHG emissions (*Ibid*). Since then, the proportion of emissions due to HGVs has increased along with an increase in goods carried, with 139 billion tonne kilometres of haulage carried out in 2010 by GB registered vehicles in the UK, a rise of over 10% from 2009 (DfT, 2011b).

The resultant increase in road freight diesel consumption, as a consequence of this surge, is a major source of concern for policy makers and fleet operators, such as John Lewis Partnership (JLP), whose fleet of approximately 500 freight trucks travel a total of over 40 million miles per annum. Rising diesel prices have increased the economic burden of running such a fleet of large vehicles. There are also environmental concerns for the direct human health implications of diesel exhaust emissions, now confirmed as carcinogenic (IARC, 2012). In addition, there are issues of achieving corporate operational carbon reduction targets as well as the foreseeable need to comply with carbon reduction regulations. The UK Government has recently announced plans to introduce regulation requiring reporting of GHG emissions by UK quoted companies from 2013 (Defra, 2012a).

Attempts have therefore been made by manufacturers, industry haulage industry members and by private firms, including JLP, to reduce diesel consumption through a range of efficiency measures. The haulage industry, represented by the Freight Transport Association, has set its members a target of 8% emissions reductions by 2015 from a 2010 baseline through participation in the Logistics Carbon Reduction Scheme (LCRS, 2010). This is in response to freight industry reporting figures that revealed that operational CO_2 emissions had almost doubled between 2005 and 2008, largely due to diesel powered road haulage (*Ibid.*, p.12).

It is possible to implement a range of technology and operational efficiency measures. However, the compression ignition engine, the most efficient internal combustion engine currently available for the larger HGVs, is limited in its ability to achieve a step change in emissions reductions without major modification. Hence the potential for biofuels to offer greatly reduced 'well to wheel' (WTW) emissions without major changes to the powertrain is an attractive alternative to reduction of consumption in an economy reliant on growth.

The role envisioned for biofuels has been reflected in several published strategies for GHG emissions reductions to 2030 and beyond, including a report by the World Business Council for Sustainable Development (WBCSD), which projects biofuels as the major component in limiting transport emissions as far ahead as 2050, despite all other applicable technologies being implemented (WBCSD, 2004).

This central role for biofuels in transport emissions reduction strategies, supported by government fiscal and regulatory support, has therefore resulted in a sharp increase in their global production, increasing over five times in volume between 2000 and 2011 to over 100 billion litres per annum (Figure 2). It is therefore essential that their use is making a positive contribution to the aims for which they were introduced.

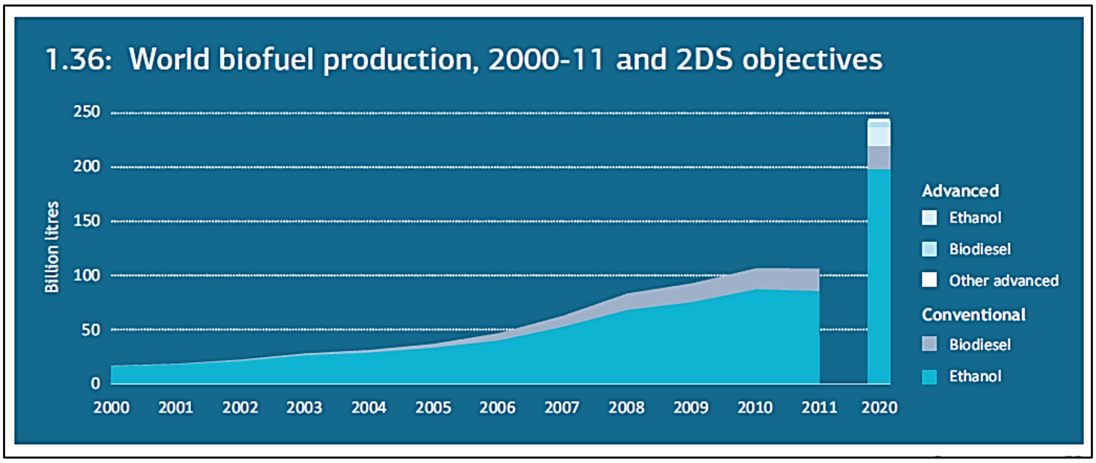

Figure 2: World Biofuel production 2000-2011

Source: (IEA, 2012)

1.1.2. Regulations

In the UK, the Renewable Transport Fuel Obligation (RTFO) is the main legislation for the regulation of biofuels used for transport in the UK (DfT, 2012a). The RTFO came into force in 2008 in an attempt to reduce transport emissions, and reliance on petroleum fuels through the use of biofuels and other forms of renewable energy, with particular emphasis on biofuels sustainability standards (DfT, 2012b).

The EU introduced the Renewable Energy Directive (RED) in 2009 (EC, 2009a), with many elements specifically geared to the transport sector, including minimum requirements for biofuels to qualify as ‘renewable’ in terms of GHG emissions, as well as other environmental and social sustainability criteria. The EU also adopted the Fuel Quality Directive (FQD) in 2009 (EC, 2009b), with the obligation to reduce carbon intensity of fuels by 6% by 2020. Since then, the RTFO has been amended to incorporate the same sustainability criteria as the RED. The UK as an EU member state is legally obliged to implement its mandate of 10% renewable energy in the transport sector by 2020.

Although the renewable energy referred to in the RED, can encompass use of technologies such as hybridisation and electrification, in reality, these technologies are not yet widely commercially available for road transport. In particular, for HGVs, the costs and energy density would make electrification prohibitively expensive and impractical. (Hazeldine, et al., 2009)

Although the implementation of various other technologies and efficiency measures can reduce the carbon emissions of the road transport sector significantly, it is the use of lower carbon intensity alternative fuels to diesel that is seen as a key approach to emissions reduction.

The use of biofuels is therefore considered the main method to achieve compliance with the mandates. This has led to a large increase in biofuel consumption and production, particularly in the EU and the US, where mandates with specific biofuel targets have been introduced. Biofuels have been incrementally mixed into conventional diesel in an attempt to achieve these targets. In the EU, the FQD mandates that the overall CO_2 intensity of transport fuel should be reduced by at least 6% by 2020. In the US, there has been a mandate for the production and use of biofuels, with a target of 136 billion litres per year produced by 2022, with over 75 billion litres of this from corn ethanol and the rest from next generation biofuels yet to be commercialised (Bracmort, 2011)

However, there is now great uncertainty with EU and US policy on renewable energy and biofuels. While the EU and US mandates still remain in place, key recent official reports have shown that the majority of the crop derived biofuels have a negative impact. The specific areas highlighted in the reports are a net increase in GHG emissions, once indirect land use change effects are considered (Laborde, 2011), (CCC, 2012)) and the impact on global food prices (FAO, OECD, 2011a). In addition, the EU has missed its own deadline as set out in the RED for determining a policy to address the indirect effects of biofuels, leading to great uncertainty about the future of the industry and government policy direction (Pelkmans, et al., 2012).

Meanwhile, California, the only US state that has introduced a non-fuel specific standard mandate similar to the FQD, known as the Low Carbon Fuel Standard, has been challenged in a federal court. The standard was initially declared unconstitutional in late 2011, but the ruling is currently under appeal (Gullo & Doan, 2012).

In addition, the extreme drought in the US, which has greatly diminished corn and soy yields, has reduced the availability of these crops for animal feed, food and biofuel production. This is anticipated to greatly reduce the availability of exports next year from the US, the largest grain exporter in the world. Concerns over the knock-on effects from this drought have already led to some countries stockpiling grain, increasing the likelihood of a hike in food prices around the world next year. Such matters will only strengthen calls for the mandates to be adjusted downwards or suspended at least temporarily (The Wall Street Journal, 2012).

However, while these mandates remain in place, biofuels will continue to play a significant role in the road transport sector.

1.1.3. Other industry concerns

The sharply increasing price of diesel has been a major economic incentive for hauliers to seek viable alternatives. The operational costs of running an HGV truck have risen substantially due to the increased cost of diesel, with fuel now accounting for 40% of operational costs as compared to 30% in 2011. (Freight Transport Association, 2012).

In addition, many corporations now include carbon reduction strategies as part of their CSR policy and from 2013; carbon reporting will become compulsory for large listed companies (Defra, 2012a). JLP has a stated corporate goal of delivering a 15% absolute reduction in operational carbon dioxide equivalent (CO_2e) emissions (2010/11 baseline) by 2020/21 (John Lewis, 2011).

However, despite companies already implementing a range of efficiency measures to reduce diesel consumption, these measures are unlikely to reduce emissions to a large enough extent while still relying on diesel as fuel for the conventional compression ignition engine.

JLP, as well as other major retailers have therefore begun investigating and trialling alternative fuels. Sainsbury's currently use several trucks running on biomethane that originated from landfill. McDonalds are using hauliers that use biodiesel derived from their own used vegetable oil, and elsewhere in the EU, a major Swedish haulage firm is running trucks on ED95 ethanol produced from industrial waste by-products. All of these fuels could lay claim to being highly sustainable, negating the need for purpose grown crops, thereby avoiding competing with food for land and reducing the risk of undesirable land use change.

However, the sustainability of these, as well as other existing and emerging HGV biofuels will depend on many factors, including the aggregate level of demand for feedstocks, extraction or cultivation impacts, management and handling of materials along the supply chain as well as the use of energy in production and efficiency in final use of each fuel.

Eventually, new and emerging second and third generation biofuels with improved engine design and technologies, such as full hybridisation, may enable great efficiency savings ensuring sustainable and affordable road freight transportation.

However, the market is confined to a limited set of currently available fuels and powertrains, some of which offer far more potential than others for sustainable efficiency and emissions savings. Therefore, choices will have to be made in a context of uncertainty in policy and the availability of most options.

1.1.4. Alternative biofuel options

Biofuels as defined in this project are liquid or gaseous products derived from biomass, which are able to provide energy for transport by combustion. Certain second generation or advanced biofuels such as those made from lignocellulosic feedstocks or by biomass to liquid techniques, such as Fischer Tropsch diesel are not as yet commercially viable and are not in use by HGVs. Therefore the focus of this research will be on first generation biofuels, produced from energy crops, as well as liquid and gaseous biofuels produced from waste that are currently available either in the UK or elsewhere in the EU. The biofuels included are.

An overview and basic technical comparison of the biofuels that are considered appropriate for use in HGVs are described in Appendix 1.

1.2. Aims

This thesis aims to assess the extent to which HGV truck fleet operators can contribute to 2020 GHG emission reduction targets for the retail sector and for the UK as a whole. It also aims to assist retailers and the road haulage industry in making the most sustainable fuel choices by determining which existing and emerging biofuels best meet environmental, social and economic sustainability criteria.

1.3. Objectives

To meet these aims, this thesis will:

- Identify the motivation behind current moves to reduce GHG emissions from UK HGV fleets, including key legislative and economic factors.
- Examine the constraints and opportunities involved in achieving emissions reductions for this vehicle category, including the potential role for biofuels.
- Develop a model to assess the GHG emission savings potential of the various alternative fuels and value chains being considered.
- Develop an appropriate sustainability benchmarking tool to evaluate which of the fuels and production pathways under consideration best meet the key sustainability criteria.

1.4. Methodology

A deductive methodology with a mixed methods approach was utilised in this thesis, incorporating both quantitative and qualitative elements of data.

A detailed literature review was conducted to determine the areas of consensus and controversy relating to biofuels and to understand the latest developments in relation to emissions reductions strategy for the road haulage industry. In particular, it was important to determine the context in which the use of biofuels was taking place. A provisional assessment of the suitability and potential availability of the various fuel options for use by HGVs was also carried out.

In order to determine the potential for greenhouse gas reductions from the various fuels, a desk-based comparison of ‘well to wheel’ (WTW) analyses was carried out to determine which approach would be suitable for use in obtaining quantitative evaluations of the alternative biofuels in terms of carbon emissions. Various approaches to estimating emissions were considered, and an appropriate GHG calculation tool was chosen. Default values were initially used to determine which fuels seemed most promising in terms of GHG emissions reduction. Adaptions were made to incorporate important regional variations and other key factors, then a model was developed to assess the carbon intensity and emissions of each fuel, using a quantitative LCA approach. Fuels were then compared on the basis of WTW GHG emissions. This is discussed in chapter 2.

In order to assess elements of sustainability other than climate change causation, a review of current world developments as well as a review of academic literature was conducted in relation to the three main areas of sustainability. Previous benchmarking studies of the various voluntary schemes against mandatory criteria in the RTFO and RED were also analysed. Experts from the waste treatment and transport industries as well as the JLP CSR team were contacted for their input with respect to additional relevant criteria. The key sustainability criteria are discussed in chapter 3.

A sustainability assessment matrix was then developed to benchmark the various biofuels. This qualitative approach was then combined with a quantitative element, by utilising a risk based scoring system to compare the fuels. Details of the methods used in this matrix development can be found in chapter 4. The results of this assessment were then presented in a simplified scorecard.

The overall best performing fuel in both CO_2 and overall sustainability was discussed for its potential in the near and medium term as a prospect for John Lewis and the haulage industry in order to sustainably reduce GHG emissions. Quantitative fleet data from JLP was incorporated to assess potential GHG savings. These findings are discussed in chapter 5 and specific recommendations made, based on the findings.

Overall conclusions are then presented in chapter 6.

2. Greenhouse Gas Emissions Modelling

2.1. Scope of emissions calculations

There are many different approaches to calculating and accounting for GHG emissions from biofuels. Emissions factors used for the purposes of Scope 1 (direct operational) UK company reporting requirements, currently regard biofuels as having zero CO_2 emissions (Defra, 2012b). This is based on the assumption that carbon sequestered in the growth of the crop used for the biofuel feedstock cancels out exhaust CO_2 emissions arising from the combustion of the fuel.

However, such an assessment of biofuels fails to encompass the real impacts and benefits attributable to the various biofuels. For it is during the 'well to tank' (WTT) stage of the biofuel production chain, that more significant climate change impacts are likely to occur. Therefore, WTT emissions, arising from the supply chain of the fuel, referred to as 'indirect emissions' in Defra company reporting guidelines (Defra, 2012a) must also be considered. Such WTT emissions were incorporated into the reporting requirements for the RED and RTFO (Bauen, et al., 2008), which, following the amendments to the RTFO in 2011, now have a convergent 'Well to Wheel' methodology, taking into account the following stages:

- Land Use Change (if applicable[1])
- Cultivation Emissions (including emissions arising from production and use of fertilisers and pesticides as well as fossil fuel used in farm machinery)
- Processing plant emissions
- Transport and Distribution
- Emissions arising from the end use of the fuel.

This is the scope of the initial quantitative comparison of the biofuels carried out in this assessment.

For the purposes of RED methodology and for the following calculations, end of exhaust emissions are still counted as zero for all biofuels, regardless of actual end of pipe CO_2 emitted. A similar zero operational emissions factor is given for those biofuels derived from waste. The RED methodology by its wider scope, seeks to account for total LCA GHG emissions due to biofuel use, by considering supply chain emissions and those due to land use change. This therefore equates to

[1] Land use change is only considered relevant if it took place since January 2008.

measuring WTT emissions for the various biofuel pathways.

Within the RED system boundaries, co-products[2] are also considered, using an energy allocation approach, whereby the supply chain GHG emissions arising from cultivation, processing and transport of feedstock for biofuel are partially allocated to the co-products. The proportion of GHG emissions allocated to the co-products is dependent on their energy content relative to the main product. This proportion of total WTT GHG emissions is then deducted from the WTT total for the biofuel (main product).

For the purpose of applying this methodology to such WTT calculations, the 'Biograce' tool (Biograce, 2012), which follows the RED methodology and whose approach has been adopted by the Department for Transport and other governments in the EU was utilised where applicable[3]. The Biograce project which led to the creation of the calculator tool used is an EU initiative whose aim is to harmonise the calculation approach taken by the 27 EU Governments. It is based on values and factors derived from the JEC Well to Wheel analysis v2c (JEC, 2007) and the IPCC guidance 2006 (IPCC, 2006). As the RED default values are generalised to be representative of the whole of the EU, this does not take into account regional variations. Therefore, with the use of a recent report by AEA (Webb, et al., 2010), commissioned by the Department for Transport (DfT) showing cultivation emissions data specific to sub-regions within the UK, using the RED methodology, such regional variation will also be considered. An alternative approach, the UK-DNDC methodology will also be considered for assessing cultivation emissions.

Sources of supply chain emissions not included in the RED analysis will then be factored in where relevant. Finally, a comparative risk based assessment of WTW impacts will be made, taking into account likely consequential impacts of the various biofuel pathways and co-products, with regard to indirect land use change and other significant indirectly attributable emissions.

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[2] A co-product is a valuable ancillary output generated as a result of a production process designed primarily to produce another primary product. Examples of co-products in the biofuel process are DDGS from ethanol production and organic fertiliser from anaerobic digestion.

[3] Certain pathways relating to biomethane are not covered in the RED and relevant values have had to be derived from other sources including the updated JEC WTT report from 2011. (JEC, 2011a)

2.2. Cultivation emissions

The level of GHGs released during the cultivation stage of biofuel production is particularly significant, as nitrous oxide (N_2O) which has a global warming potential[4] (GWP) of 310 (EA, 2011) remains in the atmosphere for more than 100 years. This potent GHG is released as a by-product of fertiliser manufacture, an energy intensive process responsible for an estimated 1% of total global anthropogenic GHG emissions (IFA, 2009).

Direct emissions from cultivated land following fertilizer application and indirect emissions via N_2O volatilisation and leaching to water, are also significant sources of N_2O emissions. Quantification of these emissions is thought to be one of the largest sources of uncertainty in estimating biofuel supply chain emissions.

Several approaches have been used to calculate N_2O emissions from agricultural land, varying in complexity and specific to each region. The IPCC Tier 1 methodology was chosen for calculating the RED default values for cultivation emissions having been employed by the JEC research project on which they are based (JEC, 2007).

The IPCC Tier 1 approach involves an assumption that direct N_2O emissions are directly proportional to the quantity of nitrogen fertiliser applied to the land. This default factor assumes that 1% of applied nitrogen is subsequently released to the atmosphere. A fixed emission factor is also used to calculate indirect N_2O emissions resulting from the leaching and volatilisation of ammonia and nitrogen oxides (NOx). Such rates are known to vary between regions and even to the scale of an individual field. The level of uncertainty indicated by the IPCC -90% to +300% is an indication of the level to which this approach is a generalisation.

For the purpose of discerning which regions would be most suitable for a particular crop, so as to minimise such emissions, EU member states have been requested to carry out a study to determine the average emissions from each of its various regions, at the NUTS2[5] level of detail. A recent AEA study commissioned by the

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[4] The global warming potential is the cumulative radiative forcing between the present and a future time "horizon" caused by a unit release relative to CO2 (usually 100 years). (EA, 2011)

[5] NUTS2 is the second tier of the Nomenclature Units of Territorial Statistics (NUTS), which divides the countries of Europe into sub-regions for analysis purposes. The UK has 37 such regions. (UK National Statistics, 2012)

DfT (Webb, et al., 2010) evaluated the average cultivation emissions arising from each of the NUTS2 regions of the UK for a range of crops using the IPCC methodology. This then showed which regions were 'RED compliant' i.e. resulting in average emissions equal to or below the EU RED default cultivation value for a region, for a particular crop. Using these results, a calculation was then made of total WTT emissions for the fuels as shown in Tables 1, 2 and 3 below.

The results of the AEA study (*Ibid*) showed that feed wheat was the only UK grown crop which emerged with a generally favourable regional emission value relative to the RED default value. This was in part due to the lack of a default value for some of the other crops studied, including winter and spring barley.

The other two crops analysed in the study, for which an EU default value is given, were sugar beet and oilseed rape. In the case of oilseed rape, only three regions had lower estimated cultivation emission values than the RED default. For sugar beet, there were no regions with a compliant NUTS2 cultivation value in the UK.

The cultivation emission values derived from the AEA UK study were then incorporated into the Biograce calculation tool (Biograce, 2012), keeping the EU RED default values for all other stages of the supply chains. The resulting impact on total WTT emissions of including UK specific cultivation data is shown in Table 1 and Table 2.

Table 1: WTT emissions savings (IPCC Tier 1) by UK region for oilseed rape based biofuels

	Biodiesel			HVO			PPO		
Feedstock/ NUTS2 region	**Cultivation emissions (CO_2 eq per MJ)**	**WTT emissions (CO_2 eq per MJ)**	**WTT GHG savings (%)**	**Cultivation emissions (CO_2 eq per MJ)**	**WTT emissions (CO_2 eq per MJ)**	**WTT GHG savings (%)**	**Cultivation emissions (CO_2 eq per MJ)**	**WTT emissions (CO_2 eq per MJ)**	**WTT GHG savings (%)**
Highest: Wales UKL1	39.91	63	24	39.91	54.9	34	39.91	46.3	45
Typical:[a] E Midlands UKF1	31.77	55.2	34	31.77	46.8	44	31.77	38.2	54
Lowest: Scotland UKM2	27.07	50.5	40	27.07	42.1	50	27.07	33.5	60
EU RED Default value	29.00	52.0	38	29.00	44.0	47	29.00	36.0	57

[a]'Typical' Values are for the region with soil properties and yields closest to UK average (Webb, et al., 2010)

Table 1 illustrates the following GHG savings outcomes for biodiesel, hydrotreated vegetable oil (HVO) and pure plant oil (PPO) depending on region.

Inclusion of the UK NUTS2 values meant biodiesel from oilseed rape (OSR) was pushed below the 35% threshold, meaning it would not be classed as renewable under the RTFO on this basis. As shown in Table 1, in no NUTS2 region of the UK was OSR biodiesel able to reach a 50% savings level on a WTT basis (the level required for RED compliance from 2017 and by the RSB[6] certification scheme). Further examination of OSR data, showed that for biodiesel, 21 out of 35 regions in the UK results in WTT emissions savings of less than 35% using the Biograce model (Webb, et al., 2010; Biograce, 2012).

Using oilseed rape for production of HVO resulted in the 35% level being achieved in all regions except the two NUTS2 regions comprising Wales. However, as shown in the table, only one region of OSR cultivation, the UKM2 NUTS2 region in Scotland, would lead to OSR HVO achieving a 50% GHG savings threshold (*Ibid*).

OSR used in PPO production was able to achieve the 35% threshold in all regions and was able to achieve the 50% level of GHG savings in 32 out of 35 NUTS2 regions.

[6] The RSB RED certification scheme is one of the eight schemes currently accepted by the EU and in the UK as proof of compliance with sustainability criteria for biofuels, including GHG emissions.

Table 2: WTT Emissions savings by UK region for bioethanol (ED95) feedstocks

NUTS2 Region	BIOETHANOL FEEDSTOCK: Feed wheat (FW) Cultivation emissions (CO_2 eq per MJ)	Feed wheat (FW) WTT emissions (CO_2 eq per MJ)	Feed wheat (FW) WTT GHG savings % [a]	Feed wheat (FW) WTT savings% 4% ignition improver cost [b]	Sugar beet (SB) Cultivation emissions (CO_2 eq per MJ)	Sugar beet (SB) WTT emissions (CO_2 eq per MJ)	Sugar beet (SB) WTT GHG savings % [a]	Sugar beet (SB) WTT savings% 4% ignition improver cost [b]
UK Lowest FW - UKF1 SB -UKH3	20.09	40.9	51%	47%	13.47	42.1	50%	46%
UK Typical[c] FW - UKH1 SB - UKH1	20.78	41.76	50%	46%	13.47	42.1	50%	46%
UK Highest FW - UKD1 SB - UKE1	31.52	52.3	38%	34%	15.8	44.4	47%	43%
ENSUS plant - UKC1	20.92	41.7	50%	46%	N/A	N/A	N/A	N/A
Vivergo plant - UKE1	20.69	41.5	50%	46%	N/A	N/A	N/A	N/A
British Sugar plant, UKH1 (Norfolk)	N/A	N/A	N/A	N/A	14.44	43	49%	45%
RED Default value	23.31	44.1	47%	43%	11.46	40.1	52%	48%

[a] compared to fossil fuel baseline

[b] When ethanol is used in HGVs, the necessary ED95 additive (ignition improver) increases GHG load by about 4% when compared to fossil fuel diesel (Börjesson, et al., 2010)

[c] 'Typical' Values are for the NUTS2 region with soil properties and yields close to UK average (Webb, et al., 2010)

Table 2 illustrates the following GHG savings outcomes for bioethanol (ED95) derived from feed wheat and sugar beet feedstocks depending on region.

Neither of these UK feedstocks considered for bioethanol production meet the 50% savings threshold when the 4% (Börjesson, et al., 2010) increase in emissions due to necessary ignition improver is taken into account.

Thirty of the thirty-five NUTS2 regions of the UK result in savings above the 35% RED requirement. However, the North West region, encompassing the NUTS 2 regions UKD1 to UKD5, fails to meet the RED requirements when ignition improver is taken into account. Without ignition improver, however, a 38% saving is achieved in this region.

This shows that all of the bioethanol plants are placed in suitable locations to obtain locally sourced feed wheat and meet the 35% minimum RED requirement with a safe margin of 10%, when applying the RED methodology and IPCC Tier 1 approach. The higher level 50% threshold is not able to be reached by any of the pathways considered, when ignition improver is taken into consideration.

However, there is a great deal of uncertainty with this approach, which relies predominantly on a fixed proportional relationship between the quantity of nitrogen fertiliser applied and the nitrous oxide emitted from the land. For it ignores the complex mechanistic nature of N_2O release, involving the action of microbes in the soil and dependence on climatic variation, precipitation patterns and other biogeochemical processes as well as farming practices (Brown, et al., 2002). A methodology has therefore been developed to take such factors into account. It is known as the Denitrification, Decomposition (DNDC) methodology (Giltrap, et al., 2010).

This DNDC method, by incorporating many more variables allows for greater accuracy. However, such an approach is dependent on more in depth and robust data collection and monitoring. This approach has been adapted for use in the UK in several studies, including a recent, supplementary study to the AEA report for UK emissions analysis (Webb, et al., 2011). This approach in the AEA supplementary study greatly affected the GHG savings outcomes for the three biofuel feedstocks in question, adversely affecting sugar beet and OSR but benefiting feed wheat.

Table 3 shows the outcome when the cultivation emissions data from this UK-DNDC based study was incorporated into the Biograce calculation tool.

As shown below, all three oilseed rape derived fuels failed to reach the minimum 35% target, let alone the 50% threshold, when the cultivation emissions data from this UK-DNDC based study were incorporated.

Table 3: UK_DNDC Cultivation emissions effect on overall GHG savings for biofuels

	UK IPCC Method (AEA Report)			UK-DNDC METHOD (AEA Report)		
Biofuel type	**Typical UK Cultivation emissions (CO_2 eq per MJ)**	**WTT emissions (CO_2 eq per MJ)**	**WTT GHG savings (%)**	**Typical UK Cultivation emissions (CO_2 eq per MJ)**	**WTT emissions (CO_2 eq per MJ)**	**WTT GHG savings (%)**
ED95 from sugarbeet. Pulp co-product	13.47	42.1	46%	20.51	49.1	37%
ED95 from feed wheat, DDGS as animal feed Average	20.80	41.6	46%	12.86	33.7	56%
Biodiesel from OSR. Rapeseed cake co-product	31.77	55.2	34%	58.94	82.4	2%
HVO from OSR. Rapeseed cake co-product	31.77	46.8	44%	58.94	74.0	12%
PPO from OSR. Rapeseed cake co-product	31.77	38.2	54%	58.94	65.4	22%
CBG from corn[a] and barley, double cropped	20.95	27.0	68%	21.60	27.7	67%

[a]Compressed biogas pathways were derived from the recently updated JEC analysis (JEC, 2011a). Corn value for UK was not given in the AEA study, so the EU Red 'Typical' and default value of 20.17g CO_2 eq/MJ was used, derived from the EU RED pathway for corn bioethanol. It was assumed a 50% mix with winter barley, for which values were given in the AEA DfT reports. Therefore, the emissions value for the combined feedstock was the average of the sum of the applicable UK typical value for barley and the default EU corn cultivations emission value.

Sugar beet, although reduced in net GHG benefit by the application of the DNDC methodology, is not impacted as badly as OSR and is still able to reach the 35% requirement, though failing to reach the 50% threshold. Feed wheat, on the other hand, is pushed above the 50% savings threshold by a clear margin.

The wide variety of impacts shown in the UK-DNDC analysis is due to the wide variety of direct soil emission factors calculated for each crop. In the AEA study (Webb, et al., 2011), these factors varied from an extremely low 0.5% for feed wheat, to the much higher 2.8% for OSR and 10% for sugarbeet. This is partially attributed to residues being returned to the land in greater quantities in the case of OSR and sugar beet, as opposed to cereal grain crops such as feed wheat.

However, all cereals other than wheat were found to result in soil emission factors well above 1% (see Table 4), which cannot be explained by residue return. Although not as thorough as some previous studies using the DNDC method (Giltrap, et al., 2010), the UK-DNDC results from AEA are further evidence that the 1% direct emission factor used in the IPCC Tier One methodology (and for the RED default values) may result in a significant underestimation for the majority of crop cultivation (Crutzen, et al., 2008).

Table 4: Direct soil emission factors from AEA UK-DNDC Study

Crop Type	Direct Soil Emission Factor
winter wheat	0.50%
sugar beet	10.00%
OSR	2.80%
winter barley	3.50%
spring barley	4.90%
oats	3.30%
triticale	4.10%
Mean Average	**4.16%**

Further evidence for this emerges from the 'top-down' approach as employed by Crutzen (Crutzen, et al., 2008), using changes in atmospheric N_2O levels as a starting point. Crutzen calculated that a fixed emission factor equal to 4% of applied nitrogen fertiliser should be employed to calculate direct land emissions arising from crop cultivation, as opposed to the 1% emissions factor used in the IPCC Tier 1 approach. This was shown to better match the overall global rise in atmospheric N_2O levels attributable to the development and application of synthetic fertilisers (Crutzen, et al., 2008). However, this top down approach has been seen as inappropriate for LCAs of biofuels (Renewable Fuels Agency, 2008).

Nevertheless, actual 'bottom up' field measurements have concurred with this higher level of N_2O emissions in several studies (Crutzen, et al., 2008). The mean average of 4.16% from the AEA UK-DNDC study results (shown in Table 4), demonstrates a close fit to this higher emissions factor. A more detailed study of field measurements, taken across Europe and Canada and in farms across Sweden (Klemedtsson & Smith, 2011) also shows a similar result. In both reports, the individual results show a wide range, varying between regions but averaging around 4%.

If the 4% emission factor was utilised in the LCA models used to calculate biofuel emissions, the impact on their GHG savings would be extremely significant, meaning most would fail to reach the minimum requirement of 35%. Such a level of N_2O emissions would negate any gains otherwise attributed for most crop derived fuels.

It has been argued that livestock production has contributed to a proportion of these N_2O emissions through organic manure and organic fertiliser (Davidson, 2009). However, this is still largely a continuation of the nitrogen cycling of anthropogenically fixed nitrogen due to the feeding of cattle with crops such as soy and by Dried Distillers Grains with Solubles (DDGS) co-products produced on fertilised land (Klemedtsson & Smith, 2011). Even if a 2.5% emissions factor were used, which takes the livestock related N_2O emissions into account (Davidson, 2009), this would still have a significant effect on the number of fuels considered 'renewable' (Olesen, et al., 2006).

N_2O emissions are also shown to be sensitive to rises in temperature and precipitation. Brown (Brown, et al., 2002) found that just a 1^oC rise in average annual temperatures could lead to an increase in N_2O emissions of around 18%. This has serious implications for climate change, when world temperatures are shown to be rising (U.S. Global Change Research Program, 2012) and is further reason for the IPCC 1% direct land emissions factor to be revised upward or a new approach introduced for calculating cultivation emissions.

2.3. Processing emissions

Processing emissions are within the scope of the RED methodology and are included in the calculations for the RED default values as well as being incorporated into WTT GHG calculation tools including Biograce. However, the CO_2 and methane emitted during this stage are not all considered by such an approach. For biomethane, it is usually the upgrade process from biogas where the most significant emissions occur. The leakage may also occur during the anaerobic digestion stage. The methane leakage at this point in the supply chain will determine whether climate benefits can be derived from use of biomethane as opposed to diesel in HGVs. With a modern system and good management, the leakage is usually about 0.5% of upgraded biogas. However, this may be much higher with older systems (Börjesson, et al., 2010, p. 40).

Bioethanol and biobutanol give rise to significant GHG emissions as a result of the fermentation stage of their production. With almost a tonne of CO_2 formed with every tonne of ethanol produced, this equates to a 35.6g / MJ increase in direct WTW emissions. Ensus consider this quantity of CO_2, equating to approximately

300,000 tonnes per year, to be significant enough to capture it for sale to the food and beverage industry for use in soft drinks and other products (Ensus Group, 2012b).

Pritchard (Pritchard, 2009) calculates an additional 35.6g per MJ should be added to the CO_2 emitted on combustion of the bioethanol to account for these fermentation emissions. Biobutanol, formed by the ABE process, gives off even greater CO_2 emissions per unit energy of fuel produced, with 4 moles of CO_2 produced for every one mole of n-butanol. This equals the CO_2 emitted on combustion, bringing the total direct CO_2 emissions per MJ of butanol used to an estimated 140g per MJ (*Ibid*). Although such emissions may be disregarded on the basis of their being cancelled out by sequestration involved in photosynthesis, this is not necessarily the most logical approach as discussed in section 0. Other processing emissions will not be considered unless already included in the scope of RED methodology.

2.4. Alternative end use of co-products

Utilising DDGS, the main co-product of bioethanol production, as a fuel to provide energy for the ethanol production process, as opposed to partially displacing soy (Hazzledine, et al., 2011) as livestock feed, has been shown by the recent JEC report (JEC, 2011a) to result in significantly lower WTT GHG emissions. This is due to displacing of fossil natural gas or coal in the Combined Heat and Power (CHP) process with the DDGS, with resultant CO_2 emissions from the combustion counted as zero.

Such alternative uses for the co-product have also been shown to reduce emissions in the case of HVO production, where rapeseed cake may also alternatively be used as a livestock feed or as a fuel. Similarly where the bagasse left over from sugar cane ethanol production processes provides a 45% increase in GHG savings when credited for renewable electricity production. The biggest saving by alternative use of a co-product is through the co-production of biogas and heat from sugar beet pulp and slops left over from ethanol production, offering a further 63% reduction in GHG emissions as compared to using the pulp as animal feed.

Table 5: Alternative uses of co-products

Feedstock and pathway	WTT GHG emissions (CO_2 eq /MJf)	Variation in WTT GHG emissions from alternative use for co-product %
Ethanol from wheat		
1:NG, CHP, DDGS as feed	45.8	0 (base value)
2: NG, CHP, DDGS as fuel	38.4	-16.2%
3: NG, CHP, DDGS as biogas	28.7	-37.3%
Ethanol from sugar beet		
1: Pulp to animal feed, slops unused	37.6	0 (base value)
2: Pulp to heat/ slops to **biogas**	13.9	-63%
Biodiesel - oilseed rape		
1: meal as animal feed, glycerine as chemical	42.1	0 (base value)
2: Cake and glycerine to **biogas**	28.2	-33.0%
HVO - oilseed rape		
1: Cake as animal feed.	43.5	0 (base value)
2: Cake to biogas	26.6	-39%
HVO - palm oil		
1: Palm oil, CH4 from waste	49.6	0 (base value)
2: Palm oil, no CH4 from waste captured	25.2	-49.1%
Ethanol from sugarcane		
1: No credit for excess bagasse	24.6	0 (base value)
2: HFO Credit for excess bagasse	13.6	-44.7%

Source: All WTT emission values derived from (JEC, 2011a)

2.5. Fuels derived from waste

Biogas pathways derived from farm, municipal or catering industry food waste and biodiesel pathways derived from used cooking oil (UCO) are generally recognised as more sustainable than the first generation biofuels derived directly from edible grain and oilseed crops. Such waste derived fuels are therefore awarded double Renewable Transport Fuel Certificates (RTFCs) per unit of fuel under the RTFO. Aside from avoiding competition with other potential uses of arable land, including food production, their WTW greenhouse gas emissions are also considerably lower, as the use of fertilizers and associated N_2O emissions are avoided, as shown in

Table 6.

As shown in the table, the greatest reduction in emissions is for biogas made from liquid manure with total GHG savings of 202%. The reason the reduction is so high is that left untreated the liquid manure will give rise to substantial emissions of methane, which is 23 times more potent than CO2 as a greenhouse gas. So by processing this manure into biogas for use in vehicles you are not only replacing fossil fuel emissions, but also removing a source of methane emissions and so a double benefit is obtained. However, this assumes efficient processing with minimal methane leakage.

Table 6: WTW emission savings for waste derived biofuels

	Cultivation emissions/ CO_2 eq. per MJ fuel	Processing emissions/ CO_2 eq. per MJ fuel	Supply chain Transport emissions/ CO_2 eq. per MJ fuel	Total WTW emissions with combustion credit/ CO_2 eq. per MJ fuel	WTW GHG savings with combustion credit / %
CBG from municipal waste	0	18.5	2.8	21.4	**-74%**
CBG from liquid manure + credit for avoided methane from manure[a]	0	9.3	-94.7	-85.4	**-202%**
CBG from dry manure	0	9.3	3.5	12.9	**-85%**
FAME Biodiesel from UCO	0	20.0	1.3	21.3	**-75%**
HVO from UCO	0	10.4	1.3	11.7	**-86%**

[a]The credit value of 94.7g CO_2 eq/MJ for avoided methane and N2O emissions from alternative storage and use of liquid manure is derived from the JEC report 2011 (JEC, 2011a) All other values from RED default values.

2.6. Limitations to RED methodology

Guidance is given by the Department for Transport on the necessary method and elements to include in the GHG emissions calculations for compliance with the RTFO and FQD reporting requirements for the different stages of production.

Since November 2011, in order to implement the RED, the amended RTFO has incorporated the reporting criteria laid out in the RED. As a result, the reporting of ‘unknowns’ is no longer permitted for key stages of the production chain, such as biofuel feedstock type or previous land use. Instead, actual quantified values have to be submitted.

Despite this increased transparency of reporting requirements, there still remains a great deal of uncertainty in the methodology used to calculate the emissions values used in certain disaggregated stages of the supply chain by reporting suppliers.

Therefore, the following sections explore key limitations to the methodology including energy allocation, land use change (direct and indirect) and exhaust emissions.

2.6.1. Allocation on an Energy Basis

There are several ways of accounting for co-products in an LCA. ISO 14041 (ISO, 1998) recommends the expansion of the system boundaries to take into account the knock on effects of co-products to reflect their wider impacts. This would entail taking into account the economic values of the main and co-products as well as the value and impacts of the product which the co-product may replace. In the case of high protein co-products, such as oilseed cake or DDGS, this would involve analysis of their interaction with the market for soy meal, the main such alternative product for which they may be used as a substitute. Such a system expansion approach was adopted for the JEC WTW reports (JEC, 2011a; JEC, 2007).

However, such market interactions are prone to frequent fluctuations, with demand for each co-product dependent on price and relative pricing of similar products. This will in turn depend on factors such as grain and feed availability, world agro-economic markets as well as fossil fuel pricing.

Therefore, for the purposes of GHG reporting, under the RTFO and the RED legislation, the simpler, energy allocation approach has been adapted.

However, despite having the merit of more consistency, allocation of GHG burden on the basis of energy content does not accurately reflect the GHG mitigation potential of DDGS and OSR cake as a feed product (JEC, 2011a). For the economic and nutritional value of DDGS and oilseed cake as a livestock feed is based on protein, not energy content (Hazzledine, et al., 2011). Also, as a high protein feed for livestock, it only displaces about 30% of the soy meal used (*Ibid.,* p.9). This is due to factors such as its low pH tending to increase the risk of the health condition acidosis in cattle if used in higher quantities (Krause, 2008). Therefore, crediting the bioethanol produced from wheat with a 40% emissions reduction, or 45% from corn bioethanol, as a result of allocation to DDGS on an energy basis, could be a large overestimation of the true effect such co-products have on LCA emissions of biofuel in comparison to the main product.

However, in circumstances where DDGS, or oilseed meal is used as a fuel, as previously discussed, the energy allocation methodology would be the most appropriate method.

2.6.2. Land Use Change

The release of carbon stocks from the ground and vegetation when deforestation occurs, or from newly converted grassland or wetland, can result in such a large short term carbon emission from the land that would cause the carbon payback time[7] to extend to a number of decades or even centuries.

The use of high yielding perennial crops, such as some of the energy grasses (e.g. Miscanthus) may lessen this payback time through additional carbon sequestration as they do not require intensive use of fertilisers nor annual ploughing, which releases large amounts of soil carbon to the atmosphere. Oil palm crops may also have a positive sequestration effect gradually compensating for LUC emissions.

However, short term emissions from land use change are particularly high in areas where peaty soils and tropical rainforest areas in regions of Brazil, Argentina, Malaysia and Indonesia are converted for other uses. For example, when oil palm is grown on newly converted peaty soils or drained wetlands in tropical areas, as is the case for the 2.15 Million Hectares of peatland in Southeast Asia converted to oil palm plantations since 1990, (Miettinen, et al., 2012) the carbon emissions initially caused amount to approximately 106 tonnes CO_2 equivalent per hectare (*Ibid).* This magnitude of GHG emissions would offset any sequestration accrued during cultivation for a number of centuries (Gibbs, et al., 2008). Even the conversion of grasslands for cultivation in temperate regions may result in a payback time of several decades. (Vellinga & Hoving, 2011)

Therefore, EU RED has reporting criteria whereby crops grown on previously biodiverse or high carbon content lands converted since January 2008 (EC, 2009a) are not admissible feedstocks for biofuels. Most biofuel feedstock in Europe are therefore not grown on such land, often due to lack of necessity, because of the availability of previously converted arable land for food and feed crops or of unproductive 'marginal' or set aside arable land. However, outside of the EU, much land use change does still occur on such high carbon stock land.

The lack of verifiable information on the origin of certain imported feedstocks and the extent to which it is derived from land with high carbon stocks (EC, 2009a)was noted as an issue of concern and uncertainty in last year's Overarching Impact Assessment (DfT, 2011c) carried out by the UK DfT relating to biofuel policy. This

[7] The carbon payback time of an ecosystem equals the years of carbon sequestration that are needed before the emissions caused by land use change are compensated. (Vellinga & Hoving, 2011)

area of uncertainty is of particular concern where the feedstock is sourced from regions where widespread tropical deforestation has been occurring as is the case with soy, sugarcane and oil palm.

Much of the tropical deforestation and conversion of high carbon stock land in the soy, sugarcane and oil palm growing regions of South America and Southeast Asia is, however, indirectly rather than directly attributable to biofuel production. This is due to the displacement of other arable activity from arable land to newly converted land. This is now recognised as a large and extremely serious 'side effect' of increasing demand for biofuels that should be thoroughly understood and addressed (Renewable Fuels Agency, 2008) (Laborde, 2011) (Fargione, et al., 2010).

2.6.3. Indirect Land Use Change

Indirect land use change (ILUC) linked to biofuel production has serious effects on GHG emissions. Some argue that this is too complex and uncertain an area to quantify and attribute to biofuel production. Some also argue that it is unjust to only require such standards from biofuels when the demand for such feedstocks comes from many other sectors, including the chemical and cosmetics industries as well as the livestock industry, which are not currently held accountable for GHG emissions arising from their supply chain. However, biofuels were devised and promoted with the primary purpose of GHG emissions reduction to prevent catastrophic climate change. (EC, 2009a). It therefore seems imperative that they should first and foremost achieve a significant net benefit in terms of GHG emissions. It is therefore incumbent on legislators to encourage production and feedstock choices that minimise not only well to wheel but also consequential GHG emissions due to their production and use.

Increasing yields would in theory lessen the extra demand for new land posed by displacing arable food crops for biofuel feedstocks. However in recent years, yields around the world have not been keeping up with increased demand, thus requiring more land to be utilised for agriculture. This pattern of increasing land use is apparent for many varieties of arable crop, including oilseed rape. In the UK for example, oilseed rape yields remained relatively static in the decade between 2000 and 2010 (Figure 3). However, during the same period, UK land area used for OSR cultivation increased by 60% to nearly 7000 km^2 as shown in Figure 4.

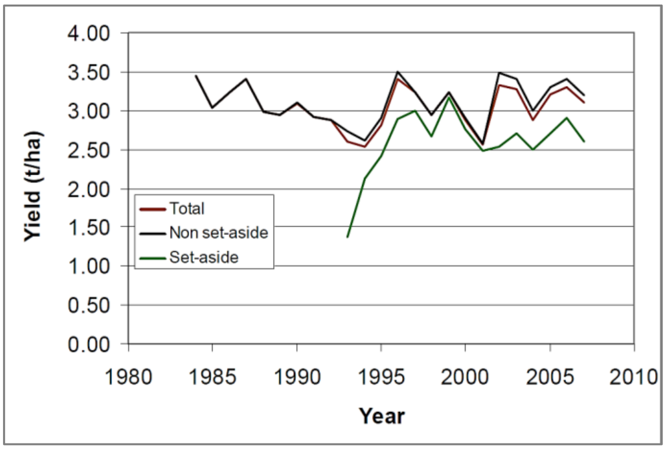

Figure 3: Oilseed rape yields (t/ha @91%dm)
Source: Defra production statistics

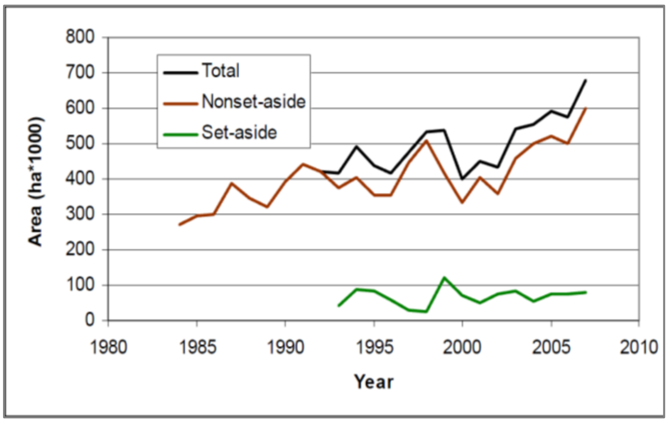

Figure 4: UK Oilseed rape area (ha), 1984-2007
Source: Defra June census data

Even where yield increases occur, this is often not enough to compensate for new land conversion to accommodate growing global demand for major agricultural commodities. This can be illustrated by the case of the large yield increases in Brazil that occurred in the 20 year period between 1984 and 2004 which did not prevent the land area used to cultivate the soybeans increasing by a factor of three during the same timescale.

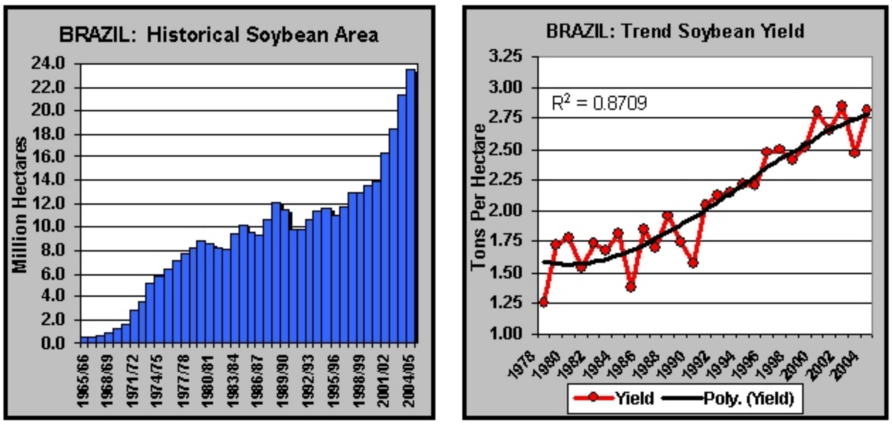

Figure 5: Brazil Soybean Area and Yield trends
Source: (USDA FAS, 2004)

Argentina and the US also rapidly expanded soy production over this period, resulting in a combined area of almost 63 million hectares being dedicated to soy cultivation. Soy production has continued to expand since 2004 in all three countries with a total of 73 million hectares being harvested in 2010 (USDA, 2012a). Brazil and Argentina are currently the largest exporters of soy beans in the world; however, Argentina is also by far the largest exporter of soybean oil, a major feedstock for world biodiesel supplies. The high carbon footprint of this particular feedstock, reflected in a default value below minimum RED requirements is due to the combination of leguminous nitrous oxide related emissions and the need for large amounts of herbicides and pesticides as well as the energy intensive process required to separate the oil and soy meal from the raw bean (Steinfeld, et al., 2006).

There is a great deal of variety between yields of feedstocks, depending on where and how they are grown. In the case of bioethanol Brazilian sugarcane, for instance, has an ethanol yield over eight times that of US corn (Fargione, et al., 2010). This results in a much more efficient use of land, particularly as sugar cane is a perennial crop which only requires ploughing every six years and is largely rain fed, requiring no irrigation.

Oilseed crops also vary greatly with Southeast Asian oil palm plantations yielding at least 5 times more oil per hectare than European rapeseed, and perhaps as much as 13 times the yield of Argentinian soy, resulting in a much lower marginal land area required to accommodate increased demand for oil from palm than from rapeseed and soy (Fargione, et al., 2010).

Such variations in yield are shown in Table 7 below.

Table 7: Current yields and growth trends for current biofuel crops

Feedstock	Location	Current yield (3 years avg Mg ha^{-1})	Trend[a] (Mg ha^{-1} $year^{-1}$)
Corn[b]	United States	9.8	0.15
Sugarcane[c]	Brazil	87.1	0.87
Soy[b]	United States	2.8	0.02
Palm FFB[d]	Indonesia	17.9	0.09
Palm FFB[d]	Malaysia	21.3	0.20
Palm FFB[d]	Rest of World	6.5	0.08
Rapeseed[d]	Europe	2.7	0.02

Abbreviation: FFB, fresh fruit bunches.
[a] Based on yields since 1990.
[b] Data from ERS-USDA 2010.
[c] Data from Macedo et al. 2008 and FAO 2010.
[d] Data from FAO 2010.

Source: (Fargione, et al., 2010)

The increased volumes of edible oil consumed as fuel by the EU and UK transport industry has, however tended to increase aggregate demand for Southeast Asian palm oil which provides a high yielding, lower priced replacement for oil use in the food industry and other sectors.

This in turn leads to land use change in order to accommodate the increased demand for palm oil. However, this may have serious climate change and biodiversity implications. Malaysia and Indonesia, which provide the majority of global palm oil production, lack low carbon stock, low biodiversity land on which to base this expansion. Therefore, with no economic or regulatory incentives in place to avoid cultivation of such areas, an increasing percentage of recent land conversion for palm plantations has been on tropical peatland areas. The area of peatland converted to such industrial use is expected to rise from the current 2.15 million hectares to as much as 4 million hectares by 2020. These peatland areas are particularly significant in terms of climate change mitigation, for the emissions arising as a result of draining such land, has now been estimated to be as high as 106 tonnes per hectare (Page, et al., 2011).

However, the main market for palm oil is for use as the world's most popular vegetable oil. It is also used in large quantities by the cosmetics industry, as a major ingredient in soap, as well as makeup and many other products (Environment Agency, 2010). Its use for biodiesel and more recently HVO production, has increased greatly in recent years, contributing to further land use change to meet this additional source of demand for palm oil production. However, the proportion of Southeast Asian land use change on peat soils attributable to biofuels is extremely hard to quantify (DfT, 2011c). Argentinian soy has provided more biodiesel to the UK market than either EU grown rapeseed or the much higher yielding oil palm, until the surge in utilisation and imports of UCO as a result of the 20p duty differential introduced in 2010. (DECC, 2011b). This was despite the default GHG savings value for soy falling below the minimum 35% necessary to be accepted as renewable under the RTFO.

Although complex agro-economic models have been devised to estimate the impact biofuels have on such scenarios, this has still been a source of a great deal of uncertainty (Bowyer, 2010). Nevertheless, several studies have tended to concur in terms of which feedstocks tend to have more impact than others in terms of such ILUC effects, with the oilseed crops having more of a detrimental effect than the grain crops used in ethanol production. However, annually harvested crops currently used for feedstock, have been shown by most research studies to contribute to indirect land use change, despite a wide range of results and uncertainty as shown in Figure 6.

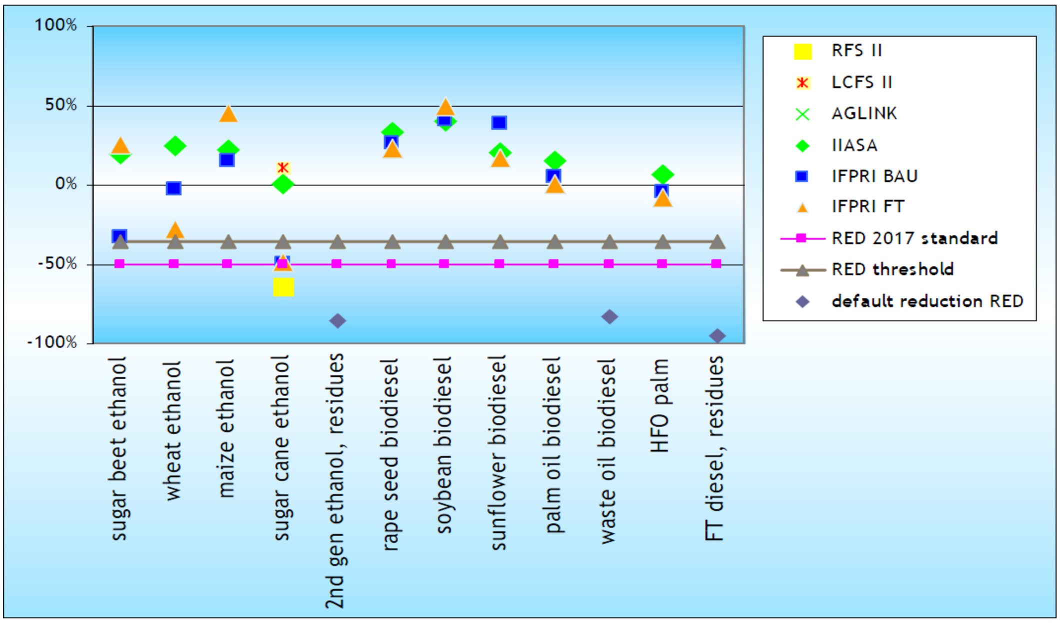

Figure 6: Net Greenhouse gas reductions of various biofuels, taking ILUC emissions into account

Source: (Croezen, et al., 2010)

This demonstrates the necessity to acknowledge the ILUC emissions in calculations used in legislation. On this basis the state of California has incorporated crop specific indirect land use change factors into the legislative GHG saving requirements for the Low Carbon Fuel Standard (LCFS) (California Environmental Protection Agency, 2012). It is not thought to be a robust scientific calculation, but is used as a legislative signal to suppliers and investors to lower supply of those fuels likely to contribute the most to ILUC. This need to incorporate ILUC is embedded in the IPCC guidelines on which the RED criteria were founded and is also incorporated into the RED itself. Article 19 par. 6 of the RED (EC, 2009a) calls for the EC to publish a report containing a 'concrete methodology' to address ILUC by December 2010. However, this has not yet been acted on, though several approaches have been proposed. One of the policies being considered by the EC is the inclusion of a feedstock specific ILUC factor (EC, 2011b), as has been incorporated into US legislation.

A less expansive, but nevertheless valid approach to addressing ILUC, would be to incorporate tank to wheel (TTW) CO_2 emissions for all fuels derived from crops cultivated on good quality land fit for yielding food crops. Those biofuels derived from crops grown on degraded or contaminated land would then gain a comparative advantage over the other fuels by being the only crop based biofuels to have their tank to wheel emissions omitted from the WTW GHG calculation. This method of differentiation would be in lieu of the 29g CO_2eq/MJ credit envisioned in the RED (EC, 2009a). This approach is explained in the following section on exhaust emissions.

2.6.4. Exhaust Emissions

Many biofuels result in exhaust GHG emissions approaching the level of those emitted by fossil fuels and in the case of biodiesel and pure plant oil; these direct emissions are even higher than those from mineral diesel (see Table 8).

However, such direct emissions are not accounted for in the LCA approach adopted by the EU. The basis, on which these emissions are disregarded for the purposes of evaluating biofuel GHG emissions, is that they are balanced out by the carbon sequestered in the growing of the feedstock crop.

The validity of this argument has however been challenged, in relation to biofuels derived from energy crops grown on land that would otherwise be used for food crop production. In this scenario, the cultivation of crops for biofuel would sequester as much carbon as would have occurred if used for human consumption. The pathway for CO_2 release would however vary, with release from combustion of biofuel in a vehicle engine, displacing the human respiration releasing the equivalent carbon back into the atmosphere. This results in the net neutral emissions assumption used as a basis for the RED methodology.

However, this implies a credit for a carbon emissions reduction on the basis of having prevented human respiration due to consumption of the food crops (EEA Scientific Committee, 2011) However, in reality, due to the generally inelastic demand for food and the need to feed a growing human population, this tends to instead result in the displaced food crops being grown elsewhere. This in turn leads to GHG emissions from the new land conversion and new cultivation to replenish supplies of the food crops, in addition to the cultivation and combustion emissions due to the new biofuel crop as well as the same level of human respiration as before. Therefore, it is argued that to neither quantify the exhaust emissions, nor the emissions due to such land use change effects is equivalent to an accounting error (*Ibid*).

As most biofuels emit almost as much carbon as fossil fuels on combustion, using this argument, the only way energy crops would genuinely result in a net reduction in carbon emissions would be if additional sequestration resulted from their cultivation, by additional biomass as opposed to the displacement of other biomass.

This would be the case with some perennial energy crops when planted on unproductive land, for example, in the large, previously cleared forest areas of Indonesia, where the clearance was for logging and pulp industry (Smith & Searchinger, 2012), or on badly eroded agricultural land. This would of course also be applicable where biofuel crops are cultivated on the 'severely degraded or contaminated land' as defined in RED section 17 (EC, 2009a) or where the biofuel is derived from waste products.

Therefore, a proposed alternative to attempting a quantification of ILUC, which would also have the effect of helping to weed out all 'unsustainable' biofuel feedstocks in terms of GHG emissions, but based on simpler, quantifiable data, without system expansion, would be to incorporate the exhaust emissions for all biofuels derived from crops grown on land which would otherwise be suitable for food crop cultivation. This approach is regarded as justifiable by the European Environment Agency (EEA Scientific Committee, 2011)and by the authors of another recent research paper (Smith & Searchinger, 2012). If this methodology were adopted, those crops grown on degraded or contaminated land (EC, 2009a) which would not otherwise be used to harvest food crops, would gain an absolute advantage over other crop based fuels by being the only such biofuels able to achieve emissions reductions requirements. This would be achieved by omitting exhaust CO_2 emissions from GHG calculations for fuels derived from such feedstocks, while including the exhaust emissions from those derived from good quality arable land.

2.7. Model details and outcomes

This GHG calculation model accounts for all direct supply chain emissions for those biofuels derived from crops grown on good quality arable land in lieu of any indirect negative effects. The model assumes current consumption patterns continue in relation to demand for animal derived products meaning perfectly inelastic demand for livestock feed cultivation. Perfectly inelastic demand is also assumed for crops destined directly for human food.

One unit of arable land displaced by biofuel crop cultivation is assumed to be replaced by one unit of land elsewhere with similar soil qualities, yields and agro-chemical inputs. Cultivation emissions are estimated according to the RED methodology. Fuels derived from waste are not included in the following table as their values will be as quantified in Table 6. This is because they are assumed to have no ILUC effects.

Table 8: Full WTW Emissions for crops displacing food/feed crops

Feedstock and pathway	WTT GHG emissions/ (g CO_2 eq /MJf)	Direct Combustion emissions/ (g CO_2 eq /MJf)	Fermentation emissions (g CO_2 eq /MJf)	TOTAL WTW Emissions(g CO_2 eq /MJf)	WTW GHG Increase %
Diesel baseline	**17.4**	**72.6**	**N/A**	**90.0**	**0**
Ethanol from wheat					
1:NG, CHP, DDGS as feed	45.8	71.6	35.6	153.0	70%
2: NG, CHP, DDGS as fuel	38.4	71.6	35.6	145.6	62%
3: NG, CHP, DDGS as biogas	28.7	71.6	35.6	135.9	51%
Ethanol from sugar beet					
1: Pulp to animal feed, slops unused	37.6	71.6	35.6	144.8	61%
2: Pulp to heat/ slops to **biogas**	13.9	71.6	35.6	121.1	35%
Ethanol from sugarcane					
1: No credit for excess bagasse	24.6	71.6	35.6	131.8	46%
2: HFO Credit for excess bagasse	13.6	71.6	35.6	120.8	34%
Biodiesel - oilseed rape					
1: meal as animal feed, glycerine as chemical	42.1	75.3	N/A	117.4	30%
2: Cake and glycerine to **biogas**	28.2	75.3	N/A	103.5	15%
HVO - oilseed rape					
1: Cake as animal feed.	43.5	69.0	N/A	112.5	25%
2: Cake to biogas	26.6	69.0	N/A	95.6	6%
HVO - palm oil					
1: Palm oil, CH4 from waste	49.6	69.0	N/A	118.6	32%
2: Palm oil, no CH4 from waste captured	25.2	69.0	N/A	94.1	5%
PPO from rapeseed	37.9	73.8	N/A	111.6	24%
Biomethane from maize + ley crops	34.0	55.4	N/A	89.4	-1%
Biomethane from wheat (whole plant)	20.2	55.4	N/A	75.6	-10%

All WTT values in Table 8 derived from: Well-to-wheels Analysis of Future Automotive Fuels and Powertrains in the European Context (WTT Appendix 2), JEC,2011, except for 'Biomethane from maize and ley crops' value derived from: Börjesson, P.; Tufvesson, L., Lantz, M. , 2010, Life Cycle Assessment of Biofuels in Sweden, Lund, Sweden.

Values for fermentation derived from: Pritchard, H., 2009, The volume of Carbon dioxide versus energy balances for transportation fuels, Energy Environment Science, p815 -817

Values for direct combustion emissions for diesel, bioethanol, biodiesel and biomethane derived from: 2012 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting, Annex 9, p41 (table 9b), Defra, 2012)

Direct combustion emissions for PPO derived from (Nordic Folkecenter for Renewable Energy, 2012) accessed at http://www.folkecenter.net/gb/rd/transport/fuels-and-supply/plant_oil/9194/, August 23, 2012

Direct combustion from HVO derived from: Nylund, N.-O., Erkkilä, K., Ahtiainen, M. & Murtonen, T., 2011. Optimized usage of NExBTL renewable diesel fuel, VTT, Finland: Optibio

Table 8 shows all well to wheel emissions including combustion emissions, which results in a net gain in GHG emissions in comparison to diesel for all biofuels shown except for biomethane purpose grown crops pathways. Even these fall well short of the RED minimum threshold of 35% savings. The highest GHG emitter on a WTW basis examined in Table 8 is shown to be ethanol from wheat when DDGS is used as feed.

Biomethane, biodiesel and HVO derived from purpose grown crops (PGCs) are able to be mixed with their waste derived equivalents. The proportion of waste derived to PGC derived biofuel will determine the overall GHG savings benefit. In the case of biomethane, the greatest savings are derived from use of wet manure and the least are derived from PGCs. However, when the process of co-digestion involves a mixture of feedstock sources a favourable average GHG saving can be obtained. This is shown in Table 9 by the three alternative feedstocks mixed in equal proportions resulting in total average GHG savings of 69.7%.

Table 9: Co- digestion of municipal waste and farm derived feedstocks for biomethane

Feedstock	Biomethane from municipal waste	Biomethane liquid manure	Biomethane maize and ley crops	Mean average GHG emissions of mix	Mean average emissions variation from diesel baseline
WTW GHG emissions	21.4 g CO2 / MJ	-85.4 gCO2 /MJ	89.4 g CO2 /MJ	**25.4g CO2 / MJ fuel**	**-69.7%**

RED default values (derived from (Biograce, 2012)) used for municipal waste and liquid manure. Maize and ley crops derived from (Börjesson, et al., 2010)

There are many variables not accounted for however, including the extent of methane leakage during the processing. These GHG calculation results do however show the differentiation between waste derived biofuels and the others as well as the advantage of biomethane over the other PGC derived fuels.

3. Sustainability Criteria

3.1. Key Criteria

This section will make a comparison between the various biofuels and feedstocks under consideration in terms of sustainability factors other than GHG emissions. Particular focus will be drawn to those areas of sustainability most relevant to retailers such as JLP in making fuel choices for their HGVs, taking into account their well-established standards in such areas.

3.1.1. Social

One of the key impacts of biofuels is on food availability and affordability and is explored fully below.

3.1.1.1. Food vs. Fuel

The need to address the issue of the potential impact of biofuel production on world food availability and pricing is critical; as such effects generally have the greatest impact on the world's poorest nations and people. This issue has been highlighted in several recent reports (FAO, OECD, 2011; Action Aid, 2012; Kretschmer, et al., 2012), and is especially significant for a food retailer such as Waitrose.

The 'Food versus Fuel' debate has arisen because of the perceived adverse effect of biofuel feedstock cultivation on world food availability and affordability. Aside from indirect land use change impacts on GHG emissions and biodiversity, this is perhaps the most serious and far reaching consequence of current biofuel policy and production.

This debate particularly came to the fore after the food spikes of 2008 (Wiggins, et al., 2010) which resulted in worsening malnutrition in developing countries and widespread social and political unrest, most notably in the Middle East, where it was a contributory factor in 2011'Arab Spring' uprisings (Lagi, et al., 2012). Although other major factors, including rising oil prices have played a part in food price spikes and volatility, biofuels were thought to be a significant contributory factor (FAO, OECD, 2011a; Action Aid, 2012). Last year, concerns over the effect of biofuels on food prices, led to a key report being drafted by a consortium of international organisations including the UN FAO, the World Bank and the OECD (FAO, OECD, 2011a), that called for suspension of biofuel mandates in the US and the EU. In the wake of the low yields of grain and other crops affected by extreme drought and erratic precipitation patterns this year, in many key crop production areas of the world, the need to address such an issue is now seen as more urgent than ever.

Perhaps the most significant of this year's climatic phenomena in terms of resulting decreases in agricultural output is the occurrence of the worst drought in the US for over fifty years (BBC, 2012a) which has severely affected the predominantly agricultural Mid-West region. See Figure 7 below.

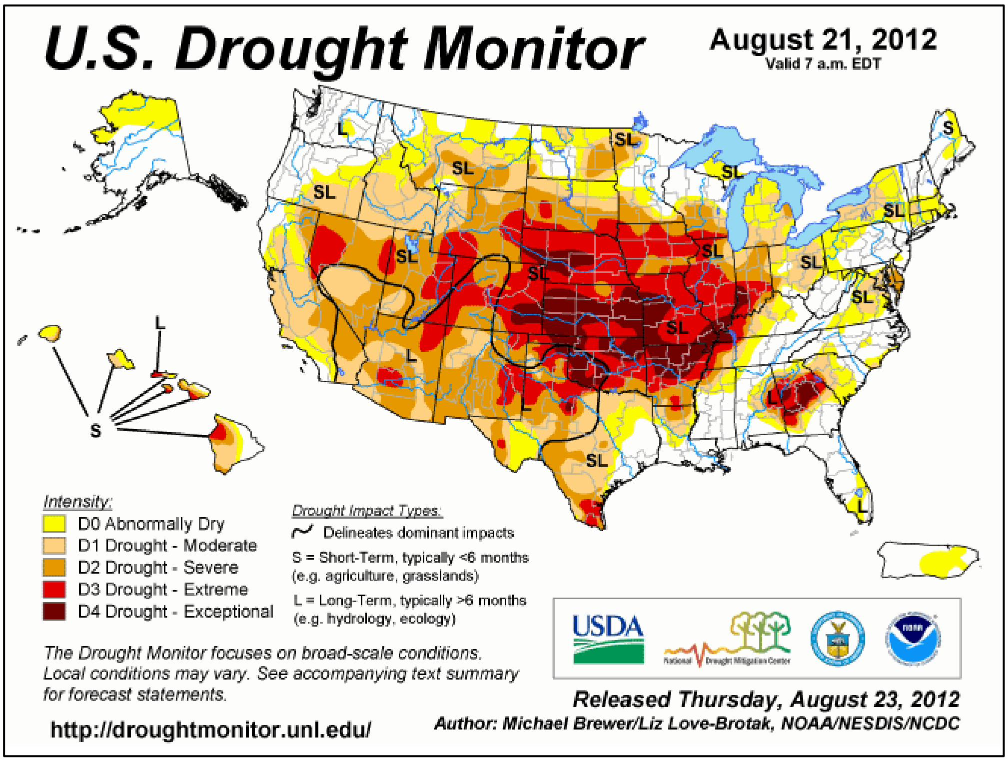

Figure 7: US Drought Monitor

Source: (National Drought Mitigation Center, 2012)

The US is the world's largest exporter of corn, other coarse grains, wheat and soy. Their use as biofuel feedstocks and the potential effect on food availability and affordability are discussed in the following two sections.

3.1.1.1.1. Use of corn and wheat

As a result of the US drought, the drop in production of the US corn crop is anticipated to reduce world corn supplies by 56.5 million tonnes (USDA, 2012b). This has led to further calls from the UN FAO for the US Government to suspend its biofuel mandates (BBC, 2012b), in order to help prevent a recurrence of the 2008 food spikes next year, as large grain price increases are expected to feed through to a wide range of food commodity prices, including meat[8]

Despite the continuation of the drought, the US Environmental Protection Agency (EPA) mandate which required 40% of the US corn crop to be used as feedstock for bioethanol in 2011 (Wisner, 2012a) remains in place, and is therefore set to increase to an even higher percentage of a diminished corn harvest, raising to 4950 million bushels (over 126 million tonnes) by next year (*Ibid*). This inelastic demand will put an extra burden on world coarse grain supplies. This could be somewhat mitigated by the accounting system of Renewable Information Numbers[9] (RINS) issued by the EPA. As ethanol production has exceeded the mandate level for several years, excess RINs issued previously could be used next year by suppliers in lieu of the full ethanol blending mandate. However, it is unclear how many RINs are in circulation and to what extent they will ease the pressure on US corn supplies (Wisner, 2012b).

There have already been noticeable knock-on effects in the US and internationally affecting other commodities. As a result of the combined demand for corn for biofuels and livestock feed, corn prices rose over 60% in two months between June and August 2012 (White, 2012). The rise in world corn prices due to the US drought is also expected to result in a number of countries, at least partially switching from corn to wheat as a source of feedstock for livestock and poultry, increasing wheat consumption for this purpose by an estimated 3.2 million tonnes (USDA, 2012b).

Adverse weather this year has also negatively impacted world wheat crops. In Russia, the world's third largest wheat exporter, yields have been reduced by over 25% as a result of drought conditions. There is currently speculation that this may reduce Russia's wheat exports by as much as 60% (Devitt, 2012) as compared to last year's exports of 21 million tonnes (USDA, 2012b), reducing world wheat supplies by a further 11 million tonnes.

Further pressure on world wheat availability is also resulting from the stockpiling of wheat to bolster reserves in Egypt and elsewhere in the Middle East. Egypt is the largest producer of wheat in the Middle East, however, because its arable land and

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[8] 38% of US corn production is used for livestock feed this year. (USDA, 2012b), therefore the cost of animal feed will rise, leading to higher meat prices.

[9] RINS are identification numbers allocated to each gallon of biofuel produced in the USA in a system operated by the US EPA.

fresh water availability are already utilised at full capacity, (Rasmussen, 2012) it has in recent years also become the world's largest importer of wheat, with imports of around 11.6 million tonnes in 2011 and 9 million tonnes so far in 2012 (Index Mundi, 2012). This increase in imports is also an attempt to stockpile wheat reserves, in order to stabilise domestic prices and prevent a repeat of the civil unrest that resulted from previous wheat price spikes. For Egypt, as well as many other developing countries, wheat, in the form of bread, is a key constituent of the population's diet (Crilly, 2012). Such stockpiling however will also tend to further push up world wheat prices further.

Such rises in world grain prices will tend to have an inflationary effect on food prices in the UK in 2013 leading to a further downturn in the overall economic situation in the UK (British Chambers of Commerce, 2012) with a resultant increase in the number of those living in a state of poverty, already estimated to be over 13% of the population (Cribb, et al., 2012).

In such circumstances, the use of almost 85% of UK's surplus wheat production capacity as bioethanol feedstocks (NNFCC, 2012) as opposed to being used for food production, could lead to increased poverty levels by significant reduction of the world's wheat supply, especially as world grain reserves have already dropped by 7.6% in the last two years (USDA, 2012b).

For 2.2 million tonnes of wheat, (*Ibid*) the equivalent earmarked by the two major UK wheat ethanol plants, (Cooper, 2012; Ensus Group, 2012a; Vivergo Fuels, 2012) could, if used directly for human food, meet the wheat consumption requirements of over 32 million people, based on current global per capita direct wheat consumption (FAO, 2012) , or over 40 million people in Low Income Food Deficit Countries (Ibid). Instead its use a bioethanol feedstock will reduce the UK exportable surplus stock of wheat, from well over 2.5 million tonnes (NNFCC, 2012) to only 400,000 tonnes. This would tend to push up world food prices further.

However, the rise in commodity prices due to the US drought and reduction in world wheat stocks is viewed as a positive development by the head of agriculture trading of Glencore, the multi-national commodity trading company that has an exclusive deal to sell the DDGS co-product from the Ensus bioethanol plant to the livestock industry. (Cusick, 2012). The rise in wheat price may also benefit UK farmers financially in the short term, with Vivergo offering financial incentives for farmers who provide at least 120 tonnes of wheat to their bioethanol plant and extra financial incentives for high starch varieties to be cultivated, thereby maximising ethanol yield, but decreasing DDGS output (Horne, 2010).

3.1.1.1.2. Use of soy

World production of soybeans, a major feedstock for biodiesel, has also been greatly reduced by the US drought. As a result, US soy exports are expected to be reduced by 19% in 2012/13 from the 2011/12 level. (USDA, 2012b). Internationally, this has led to increasing demand for Brazilian soy exports, which has subsequently depleted Brazil's surplus stocks. Globally, total soybean stocks have now been depleted by 20% between 2010 and 2012 (USDA, 2012b). Soy prices have consequently reached record high levels on international markets (Hunt & Thukral, 2012). Such elevated soy prices are also likely to increase demand for alternative biodiesel and HVO feedstocks, including palm and rapeseed, whose market price is also likely to increase as a result. However, perhaps the most tangible short term impact of the soy price increase will be further increases in the cost of meat production, as more than 80% of the world's soybeans are used for high protein livestock feed (Koneswaran & Nierenberg, 2008). As 62% of global traded soy meal is imported by the EU (USDA, 2012b) for use in livestock production, the rises in soy price will further impact on the EU livestock industry as well as the price of chicken, pork, beef and dairy products in the UK.

The large increase in meat and dairy consumption in China in recent years, linked to its increasing urbanisation and fast growing economy, has led to another significant source of demand for soy, particularly for use as livestock feed. Despite being a large agricultural producer, China has become a net importer of soy and other oilseeds, due to the large scale of domestic demand. Consequently China has now reached an annual total oilseed import level in excess of 62 million tonnes, an increase of over 41% since 2008 (USDA, 2012c). China's large increase in meat and dairy consumption is expected to continue, despite the current price rises, with resultant soy imports projected to increase by 3.5% to 59.5 million tonnes in the coming year (*Ibid*).

3.1.1.1.3. Biodiesel versus livestock

The use of crops for biofuel production has negative impacts on the livestock industry by competing for grain, land and water resources. However, it is the reliance on livestock for a large proportion of human food production that is a more significant burden on overall food availability than that caused by biofuel production.

Globally, with its use of 35% of all crop production and 75% of the world's agricultural land area, (Foley, et al., 2011) the livestock industry is 'a net drain on the worlds potential food supply' (*Ibid*) far in excess of that attributable to biofuel production.

The FAO calculated that livestock is the greatest user of the world's land resources (FAO, 2009). However, it is the intensive rearing methods that rely heavily on arable land for livestock feed production, requiring over one third of global crop production, rather than the grazing of cattle in pastures unsuitable for other food production (Foley, et al., 2011) that has the greatest negative impact on global food production potential.

Due to the prioritisation of high protein livestock feed production in South America, soybean has become the predominant crop cultivated on the majority of cultivated land and associated with most of the expansion of arable land in South America. This expansion has happened concurrently with the diminishment of the land area dedicated to crops predominantly used for direct human consumption such as rice, wheat and beans, (Pacheco, 2012). See Figure 8 below.

	Harvested areas (million ha)		Production (million TM)		Annual growth (in %)	
	1990	2010	1990	2010	Area	Production
Beans	5.4	4.2	2.9	4.0	(1.3)	1.7
Cassava	2.5	2.4	31.2	31.6	(0.3)	0.1
Maize	15.6	19.2	31.8	92.2	1.0	5.3
Oil palm	0.2	0.4	2.9	7.2	3.8	4.6
Rice	5.5	5.1	13.4	23.4	(0.4)	2.8
Soybeans	17.7	46.2	33.1	132.3	4.8	6.9
Sugarcane	5.3	10.2	335.0	811.7	3.3	4.4
Wheat	9.7	8.2	16.8	25.7	(0.9)	2.1

Source: Adapted from FAOSTAT (2011)

Figure 8: Harvested area of selected crops in South America

Source: (Pacheco, *op. cit.*, p.4)

If demand for oil for biofuel use or direct human food use was a priority in arable land use, the area dedicated to oil palm would likely be far greater than its present land coverage, as oil palm yields much greater oil quantity per hectare than soybean. However as shown in Figure 8, the area dedicated to soy is 155 times greater than that used to cultivate oil palm.

Globally, prioritisation of livestock feed production means the area dedicated to animal feed crops is an estimated 0.5 billion hectares (Steinfeld, et al., 2006), more than twelve times the area that was dedicated to biofuel crops, 36 million hectares in 2008 (United Nations Environment Programme, 2009).

Based on these figures, and allowing for uncertainty in the extent to which land use has increased for both biofuels and animal feed crops, the area dedicated to livestock feed is still likely to currently be at least ten times greater than that utilised for biofuel crops. Based on this assumption, if worldwide diet was changed so that half the cropland currently used for livestock feed production was released for other purposes, including direct human food production this would be likely to substantially reduce any ILUC or food versus fuel impacts of biofuels, by enabling far greater total food production potential. See Figure 9 which illustrates the effect of dietary change.

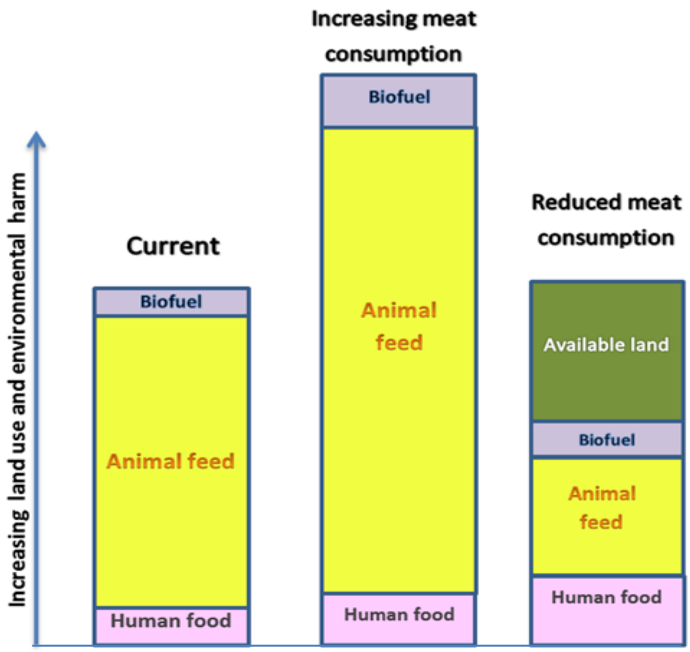

Figure 9: Effect of reduced animal product consumption on resource availability

Without such a change, it is unlikely that any other measures will achieve sustainable use of resources. As stated by the United Nations Environment Programme (UNEP) Energy and Agriculture panel in 2010, “a substantial reduction of impacts would only be possible with a substantial worldwide diet change, away from animal products.” (United Nations Environment Programme, 2010).

This is due to the inefficiency with which livestock convert vegetable protein to animal protein meaning that an average of ten times more land (Reijnders & Soret, 2003), is required to produce equivalent levels of nutrient and calories for humans in the form of animal protein as opposed to deriving them directly from vegetarian sources.

However, only 2% of the world’s soy is currently consumed by humans (Goldsmith, 2008). If direct human consumption of soy was increased fivefold to 10% of the current total world soy production, this would provide the equivalent protein to all the current animal protein derived from soy feed and make the other 90% of current soy cultivation cropland available for other purposes, an area of 92 million hectares. If half this land area were still devoted to animal feed crops, this would still free up 46 million hectares, thereby negating the need for destructive land use change including deforestation in order to meet increasing demand for dietary protein.

Similarly, 42% of the world’s total grain production[10] (FAO, 2011b) is used as livestock feed, a total of 768 million tonnes. If by decreasing intake of animal products to the extent that 50% of current grain use for animal feed was instead diverted to direct human use, it would be sufficient to supply the average global per capita grain consumption requirements for almost 4 billion people.[11] Even when allowing for increasing per capita grain consumption this would be more than enough to provide for the grain requirements of the expected growth in human population in the next 40 years.

However, with current trends, where world meat and dairy consumption has been

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[10] Wheat figures derived from (FAO, 2011b) Table 1 p.12 .Coarse grain figures from Table 4 p.17

(Wheat feed + coarse grain feed) / (total wheat production + total coarse grain production)

=(130.9 + 636.6)/(691+1151.8) = 767.5 / 1842.8 = 42%.

[11] World Food Outlook (FAO, 2011b) Tables 1 and 4. Per capita coarse grain = 28.8, wheat = 67.7. Total = 96.5kg/person/ annum = 0.0965 tonnes per person/ annum. Total coarse grain + wheat for feed = 767.7 million tonnes

767.7/ 2 = 383.85MT grain. 383.85/ 0.0965= 3976.7 million people.

increasing for decades, notably in China where average meat consumption has risen by a factor of four in 25 years, the likelihood of achieving such a reduction in meat and dairy consumption for the foreseeable future appears low. Without such dietary change however, deforestation and other major environmental impacts will tend to worsen, as the world struggles to meet demand for an increasingly livestock derived diet, thereby exacerbating the effects of impacts due to the simultaneous increase in crop use for biofuels.

3.1.1.2. Other impacts

Social impacts regarding land rights and fair treatment of labourers will vary depending on localised governance and management and may vary between individual operations even at a farm scale. These will be dealt with in the discussion of voluntary sustainability certification schemes in Section 3.2.

3.1.2. Environmental

Unlike atmospheric pollution due to greenhouse gas emissions and global interactions relating to food prices and availability, other environmental sustainability issues concerning biofuels tend to occur at a regional level. However, these issues can, in some cases, become highly significant and result in impacts on a global level.

This section will focus on the most significant impacts of specific feedstocks with respect to particular regions or biomes.

The following environmental sustainability issues relate to biofuels derived from purpose grown crops. Therefore, as with the food versus fuel issues, those derived from waste will not cause such impacts. However, in the case of biomethane, which can be derived from a mixture of sources, including purpose grown crops, the following discussion is relevant for deciding which combination of crops are the most sustainable to be used in anaerobic digestion.

3.1.2.1. Soil and biodiversity

Biodiversity is a key component of the earth's ecosystems and the 'ecosystem services' (Millennium Ecosystem Assessment, 2005) on which human society and all life on earth ultimately depend. However, human activity has had a large impact on the earth's diversity of life, leading to what has now become acknowledged as a mass extinction (Myers, 1989).

In the last 50 years, the greatest conversion of the earth's biomes[12] for human use has been grassland and forest (Millennium Ecosystem Assessment, 2005). The fastest rate of conversion in recent years has been in the tropics, where 80% of agricultural expansion has been on newly deforested land (Foley, et al., 2011). This has had a great impact on biodiversity, notably in the case of Southeast Asian oil palm and South American soy bean crops. This aspect of indirect land use change from biofuel demand for feedstocks has been documented in many reports by NGOs such as WWF and Friends of the Earth.

However, farmland biodiversity is an area that has generally received less attention but is just as significant as large areas of the world are now cultivated, including 77% of the land area of the UK (Angusa, et al., 2009).

Across Europe, farmland bird populations have dropped by 300 million, halving the population in 30 years (McKie, 2012). This is thought to be due to farmland management practices that have led to a lack of suitable habitat, such as set-aside land as well as practices that have led to a lack of insects and worms and hence lack of food for birds.

The loss of biodiversity in agricultural soil itself, through degradation, as well as being a major factor in the decline of Europe's farmland birds, is also acknowledged as a threat to the ability of soil to nurture plant life necessary for 99% of the entire world's food production (Jeffery, et al., 2010). The microorganisms and insects in soil are the key to maintaining soil's fertility as well as playing a major role in the world's nutrient cycles (*Ibid*). Soil is host to a myriad of life forms ranging from bacteria to earthworms which in turn support and interact, directly and indirectly, with all the plants and animals that inhabit the biosphere above its surface. In addition biodiversity "enhances the soils stability and resilience" (Racine, 2009).

In many regions this soil biodiversity and therefore the quality of soil is now under threat. In the UK, and elsewhere, many agricultural practices including ploughing and increased use of agro-chemicals due to increasingly intense use of land to produce crops presents a major threat to soil quality.

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[12] A broad regional or global biotic community, such as boreal forest or desert characterized by their flora and fauna and climatic conditions

Soil’s porosity is an important physical quality that helps it resist erosion by wind and water and this can be adversely affected by common practices in agriculture such as compaction due to use of heavy farm machinery. This in term affects its porosity, thereby losing its drainage ability, perhaps becoming infertile with less resilience to flooding and soil loss due to run off.

The use of chemical pesticides may also affect its resilience to erosion, for example by killing the various organisms that help maintain the structure of the soil. Ploughing of the land also results in loss of organic matter and biodiversity in the soil, by exposure of the soil to ultra violet light from the sun as well as releasing sequestered carbon back to the atmosphere. The intensive cultivation of annual crops, including most of those crops currently used for biofuel feedstock, involves more frequent ploughing than perennial crops.

Due to the complexity and invisibility of vast areas of soil hidden beneath the surface, it is relatively difficult to assess the extent of damage to the health of the soil on agricultural land. This has so far been disguised by the utilisation of synthetic fertilisers to provide nutrients, including nitrogen based fertilizers, use of which have increased 800% in the last 50 years (Foley, et al., 2011, *op cit.*, p.338). Such widespread application of synthetic fertiliser “without recognizing consequences on long-term productivity and environmental quality” (Doran, et al., 1996 as cited in Karlen, et al., 1997) has also led to other major environmental consequences relating to water quality and atmospheric pollution.

All intensively farmed monoculture crops also have a negative impact on biodiversity and hence on soil, because of the techniques employed to suppress other naturally occurring plant species. Larger monoculture areas have a correspondingly wider impact on biodiversity. However, certain biofuel feedstocks tend to have a greater effect than others, in terms of above and below ground farmland biodiversity.

Crops that are vulnerable to pests will generally require more pesticide application. These crops include maize, oilseed rape and sorghum in its early stages (EEA, 2006) as well as sugarbeet, which generally requires heavier use of pesticides than other crops, particularly if used in a rotation more frequently than once every four years (JEC, 2011b, p.54)

In recent years, realisation of the importance of soil degradation in the functioning of agriculture has led to attempts to quantify its extent. The European Community Soil Impact Assessment of 2006 has estimated the annual cost of soil degradation in the EU 25 member states at up to €38 billion annually (EC, 2006). However, the loss of biodiversity due to this soil degradation is not included in this estimate as it is regarded as too hard to quantify, nor is it mentioned in the RTFO and RED criteria for soil preservation.

3.1.2.2. Water Impacts

Fresh water is one of the most precious resources on earth and essential to sustaining life and civilisation. The lack of water in the recent drought discussed in section 3.1.1.1 has highlighted how crucial it is to food and bioenergy production. It is thought that lack of water availability could be a major limiting factor in the world's potential food production, with key aquifers being depleted at a rate up to 3.5 times higher than the rate at which replenishment is occurring (Gleeson, et al., 2012).

Irrigation of cropland is the main anthropogenic purpose for water abstraction, responsible for 70% of the world's freshwater abstraction (Foley et al. p.338). More importantly, it is responsible for up to 90% of the world's consumptive extraction of water whereby it is not returned to the ecosystem from which it was taken in a reusable state (*Ibid*). Therefore, biofuels derived from cultivated crops make demands on water resources far higher than fossil fuel equivalents (Hoff, 2011).

The water requirements for soybeans are as high as 10,000 litres of water per litre of fuel (Dominguez-Faus, et al., 2009). This is by far the highest water demand of any common biofuel feedstock as shown in Figure 10 below. This consumptive use of water is primarily due to evapotranspiration at the cultivation stage. Therefore, those fuels derived from waste oils and gases will generally have a far smaller 'water footprint' (*Ibid*).

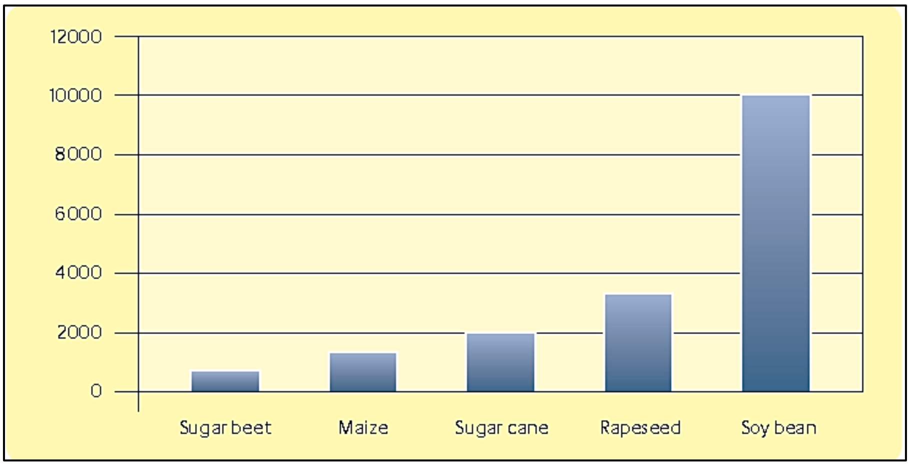

Figure 10: Water use intensity of major biofuels (litres of water evaporated per litre of biofuel produced)

Source: (Hoff, 2001, *op. cit.*, p.20)

As with impacts on soil, the extent to which a particular crop impacts on the availability of freshwater for other uses is largely dependent on the suitability of a particular crop to a particular location thus determining its need for irrigation. Sugar beet, for example, may not require irrigation if grown in Northern Europe, but requires large quantities of irrigation water where it is grown in Southern Europe requiring 571 litres of water per litre fuel produced (Hoogeveen, 2008). Similarly, sugar cane in Brazil is largely rain-fed, whereas 85% of sugar cane grown in India is dependent on irrigation, especially on groundwater withdrawals, requiring over 1300 litres of water per litre of fuel produced (*Ibid*).

Economics, rather than concerns for water preservation and suitability of a particular crop for an area, has been a major factor in unsustainable crop cultivation. This has led to an increase in sugar cane plantations in areas of Africa where the withdrawal of water for biofuels will have a significant negative impact on already water stressed regions. In Ethiopia, for example, large scale irrigation projects involving sugar cane and jatropha for bioethanol projects are taking up a significant share of productive areas, despite the country often suffering from drought and famine (Hoff, 2011). Certain bioenergy crops are more suited to such areas, such as jatropha and sweet sorghum (Woods, 2001).). Such crops are able to be grown in conditions unsuitable for the majority of food crops. However, their yields are relatively low making them uneconomical for large scale biofuel production. (Hoogeven, et al., 2009)

Maize, although highly efficient in its utilisation of water, is also often grown in areas where irrigation is required, including in China, where a total of 40% of the maize is irrigated. Although such water withdrawals only account for a small percentage of total agricultural water consumption, this often adds extra pressure to already water stressed regions *(Ibid)*.

Therefore, water consumption in agriculture is a major challenge for biofuel production and another issue where competition for resources may make biofuel production unsustainable. This may become an increasingly acute problem with rising demands for water use particularly in developing countries reliant on over utilised aquifers.

3.1.3. Economic

There are many factors in determining the potential economic benefit derived from use of a particular fuel. The following section will focus on energy concerns.

3.1.3.1. Energy Balance

In the case of biofuels, a key limiting factor is the efficiency with which solar energy can be intercepted and transformed into biomass, leading to the growth of the crop with which the biofuel is made. The radiation use efficiency (RUE) with which plants can achieve this transformation via the process of photosynthesis is theoretically limited to a rate of 5%. However, in practice this is no more than 2% with the highest efficiency achieved by sugar cane grown in Africa but only when irrigated in optimum growing conditions. (Murphy, et al., 2011). In the UK where sunlight intensity is far lower than in the tropics, averaging 100W per square metre, no plant achieves more than 1% RUE, with Miscanthus, a promising second generation biofuel crop having an RUE of about 0.75% (MacKay, 2009). David Mackay FRS, calculated that if 75% of the UK's land area (roughly the entire agricultural land area of the UK) was covered with such crops, this would generate only enough energy, in the form of biofuel, to provide 24Kwh/person per day, assuming a 33% loss of energy from the supply chain. This, he points out, is less than the energy required to drive a typical car (*Ibid.*, pp. 29-31).

Therefore, on this basis relying on the large quantities of biomass that would be required to provide a substantial share of transport fuel just is not a viable option in the UK. However, for certain niches of the transport market, such as for fleets of articulated freight vehicles for which electrification is not a currently viable option, certain biofuels can still make a valuable contribution to sustainability of road transport, if they meet all other important criteria and also have a sustainable energy balance. This can be measured in terms of energy produced in the form of biofuel from each unit of energy input from fossil fuel, as has been calculated in the JEC report (JEC, 2011b).

There are major implications for economic sustainability in achieving a good energy balance. Hall et al. , using the concept of 'energy return on investment (EROI)'which is a variation of energy balance taking economic sustainability into account, estimate that the minimum sustainable ratio of energy output to energy input on a WTW basis is approximately 3:1 (Hall, et al., 2009). Therefore, a ratio of less than three to one of renewable energy output to fossil fuel input is not regarded by Hall et al. as economically sustainable for a society. However, many biofuel value chains have a WTW energy balance of less than 3, excluding indirect effects.

US corn ethanol for example is only neutral in terms of energy balance giving a WTW EROI of about 1:1. However, this neutral energy balance of 1:1 is not economically viable without subsidies and more importantly implies heavy reliance on fossil fuels (oil or gas) for the biofuel production process.

Energy balance is particularly important for sustainability in terms of vulnerability to oil and gas price volatility and availability with a dwindling supply (DECC, 2010). The UK and the EU having passed the peak of production for conventionally extracted oil reserves have become increasingly dependent on overseas supplies. This is projected by the Energy Watch Group to become a steadily more extreme deficit, as is shown in Figure 11, pushing up the price of oil, diesel and other commodities including food (Schindler & Zittel, 2008).

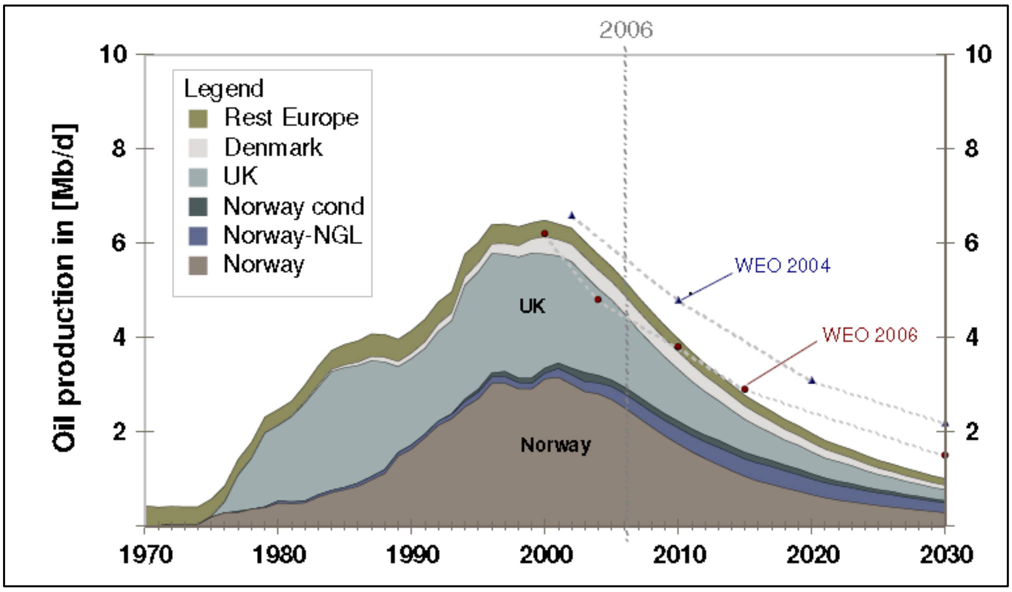

Figure 11: Oil production in OECD Europe

Source: (*Ibid., p.65)*

Unconventional sources of oil are therefore being sought in the EU and across the globe. The energy balance due to the difficulty in extracting depleted old reserves or unconventional new ones is such that in some cases up to three barrels of oil are being consumed in order to extract one new barrel (Tsoskounoglou, et al., 2008).

Conventional gas reserves have also been decreasing, with the UK having become a net importer of gas in 2004 and with increasing reliance on foreign gas imports, this may lead to the possibility of reliance on fracking and other unconventional techniques to extract the dwindling resources. This involves more energy and complexity in extraction technique with lower yields and higher risk of water pollution and other negative environmental impacts (Lechtenbohmer, et al., 2011). Such rising costs and energy involved in extraction is likely to lead to further long term rises in oil and natural gas prices. In this context, therefore, it is likely that the most sustainable biofuel options will also have the least reliance on fossil fuel in their production.

The use of various biofuel pathways showed a wide range of energy balance results, even for the same feedstocks, with co-product end use having a major influence on this outcome, for biodiesel, bioethanol and HVO.

The use of the rapeseed cake co-product as fuel, for example, increases the ratio of energy out / energy in by more than a factor of 17 (JEC, 2011b). Ethanol production pathways produced the lowest EROI results in the case of US corn, wheat and sugar beet when using the co-products as feed. The energy balance more than doubles in each case where the ethanol co-products are utilised for fuel not feed. In the case of sugar beet this is more than a tenfold increase. There is no clear forerunner amongst feedstocks in this category as there is a wide range in potential energy yield per unit of fossil fuel energy input, largely dependant on the chosen use of co-products.

Conventionally farmed corn however, whether used for first generation bioethanol production, or for biogas, is not shown to achieve a sustainable energy balance. Second generation lignocellulosic corn, making use of the corn stover is shown to offer a favourable energy balance, as does organically grown corn used in a double–cropping system in combination with barley improving the energy balance by more than a factor of 13 as compared to monoculture corn used for biogas production (JEC, 2011b).

Table 10: Fuel energy output per unit input of fossil fuel

Feedstock and pathway	WTT Renewable energy output/Fossil fuel input (MJ output / MJ input)
Ethanol from wheat	
NG, CHP, DDGS as feed	1.9
NG, CHP, DDGS as fuel	2.6
NG, CHP, DDGS as biogas	4.8
Ethanol from sugar beet	
Pulp to animal feed, slops unused	1.8
Pulp to heat/ slops to biogas	25.0
Ethanol from sugarcane	
No credit for excess bagasse	5.6
HFO Credit for excess bagasse for fuel	25.0
Ethanol/Butanol from corn	
Corn to bioethanol [a]	1.0
Corn BtOH[a]	1.3
Corn stover lignocellulosic[a]	3.9
Biodiesel from oilseed rape	
Meal as animal feed, glycerine as chemical	2.8
Cake and glycerine to biogas	50.0
HVO from oilseed rape	
Cake as animal feed.	2.9
Cake to biogas	33.3
HVO from palm oil	
Palm oil, CH4 from waste	3.9
Palm oil, no CH4 from waste	3.9
Compressed biogas (biomethane)	
Municipal waste	5.9
Liquid manure	33.3
Corn and barley double cropped, organically farmed	33.3
Maize, whole crop[b]	2.5
DME	
DME from black liquor	33.3
DME from wood waste	16.7

All energy balance figures derived from figures and pathways in **(JEC, 2011a)** other than
[a] corn values derived from (Swana, et al., 2010)
[b] maize to biogas derived from (Börjesson, et al., 2010)

3.2. The role of existing standards and certification schemes

There are a wide range of certification schemes in existence globally, most of which were developed by particular biofuel producers and others specific to a particular type of biomass.

As of July 2011, a system of benchmarking has been carried out by the European

Commission (EC), resulting in seven schemes currently being approved under the RED as meeting all the sustainability criteria (European Commission, 2012). These seven schemes are regarded under the RTFO, FQD and RED requirements, as providing proof of a particular consignment of biofuel having met all RED sustainability requirements. Such voluntary sustainability certification schemes are designed to function at a localised level, ensuring a particular supply chain is examined and confirmed as meeting specific environmental and social sustainability criteria (European Commission, 2011).

Many of these voluntary schemes have been set up by operators in a particular area of the biofuel industry. However, some have emerged from a different perspective, such as the Roundtable on Sustainable Biofuels (RSB) which originated from a Swiss energy centre and the International Sustainability & Carbon Certification (ISCC) scheme set up by the German government. These two schemes are more generic in terms of the feedstocks they cover and make use of stakeholder engagement to work to improve standards. They currently work in conjunction with the World Wide Fund for Nature (WWF) which has a representative on the steering board of the RSB. The RSB sets a higher threshold for GHG savings than other schemes, choosing the 50% CO_2e savings which will be introduced as compulsory for meeting sustainability standards for the RED from 2017.

By providing a market for biofuels produced in a relatively sustainable manner, in terms of direct impacts, such schemes may, if properly administered and audited, help promote better practice in the industry.

However, the niche market created by such certification of particular biomass or biofuels as sustainable creates extra aggregate demand for a particular feedstock, which may lead to further indirect land use pressures (while animal product consumption patterns remain as at present) despite a particular value chain being optimised. For example, the growing demand for certification of sustainable palm oil has led to further deforestation to replace the palm oil subsequently displaced from the non- certified market as documented by Friends of the Earth Europe (Griffiths, 2010).

In addition, certification schemes and standards have not been able to address the overarching regional and global impacts caused by the increase in demand for cultivation of biofuel feedstocks or the issue of competition for land, water and energy resources with the food industry. Therefore, many key global sustainability issues relating to biofuels are not able to be addressed by voluntary certification schemes.

The voluntary nature of the schemes and the wide variety of schemes allow producers to pick and choose schemes. This may also lead to confusion. There have been developments by the European Committee for Standardization (CEN) and International Organization for Standardization (ISO) to devise sustainability standards that would be more widely applicable, providing more consistency. The ISO standard, although globally applicable would not be required by law. By contrast, the CEN scheme (CEN, 2012) would be compulsory but only applicable to the EU market.

These voluntary standards however would still not address the problems associated with growing demand for cropland, energy or water. Therefore, the following section addresses the assessment of sustainability at a level that takes those factors into account.

4. Results

4.1. Assessment matrix of fuel options

In order to compare the various pathways in terms of overall sustainability a matrix was devised taking into account all the sustainability criteria considered in this research project. This included GHG savings potential, social impacts in terms of the food versus fuel issue, impacts on soil and water as well as energy balance. As there was a clear differentiation between fuels at the GHG emissions calculation stage, further quantification was not necessary in order to determine which fuels to consider in terms of attaining a net climate benefit. Nevertheless, the fuels were compared to attain an overall quantification of their impacts.

The key criteria for the sustainability of the biofuels were presented in a matrix in order to rank the fuels in terms of their overall sustainability, with a score allocated to each fuel.

A degree of generalisation was necessary in order to achieve this, negating the many factors in the production of each biofuel that may vary the impact they have. However, the aim of the matrix was not to assess the sustainability of individual suppliers and supply chains, which certification schemes and standards combined with thorough auditing are able to better ascertain. Instead, this evaluates key regional, national and global impacts likely from use of each fuel, on a life cycle basis, taking into account the characteristics of each feedstock and biofuel pathways, as examined in this report and other research.

In order to achieve this, a risked based assessment was employed to categorise the various biofuel pathways, using five risk levels :

1)Low risk– L

2)Low to medium risk – L/M

3)Medium risk – M

4)Medium/high risk – M/H

5)High risk – H

The low risk (L) category means the particular fuel is unlikely to have a negative impact in that particular area. The high risk (H) category means it has been shown by a large body of evidence, and documented by peer reviewed research, to pose a high risk of causing severe negative effects in that category. The other three categories are incremental steps between those extremes, with medium risk signifying the need for further information to be required to determine if the impact is high or low risk in that category. This may be determined by individual management and production practices. A scoring system was then devised with the following score allocation, reflecting risk level:

L = 1 , L/M = 2 , M = 3, M/H = 4, H = 5. The scores for the 5 different categories were then totalled for each pathway and the final scores determined, with a high number indicating a high risk. The highest theoretical risk level = a total score of 25.

The results reflected the low comparative risk of using fuels derived from waste, as they remove the risks relating to cultivation emissions. The total set of the 4 tables showing the risk based results can be seen in Appendix 2.

A screen shot of the resulting matrix is shown below:

HYDROTREATED VEGETABLE OIL (HVO)

BIOFUEL CATEGORY	BIOFUEL FEEDSTOCK	WTW CO2 Including exhaust emissions and credits if derived from waste / degraded land	SOCIAL IMPACTS/ Food price & availability	FARMLAND BIODIVERSITY AND SOIL IMPACTS	WATER IMPACTS - consumption/ eutrophication /acidification/ pollution	ENERGY BALANCE / Supply chain Reliance on fossil fuel	L	L/M	M	M/H	H	Final Score Total
Hydrotreated Vegetable Oil	Oil seed rape 1 Meal as livestock feed	H	M/H	M/H	M	M	0	0	2	2	1	19
	Oil seed rape 2 Meal as fuel	H	M/H	M/H	M	L/M	0	1	1	2	1	18
	Sunflower 1	H	M/H	M/H	M	M	0	0	2	2	1	19
	Palm Oil 1	H	M/H	H	M	M	0	0	2	1	2	20
	Palm oil 2	M/H	M/H	M	M	M	0	0	3	2	0	17
	UCO from unknown source, unaudited	M	M	L/M	L/M	M	0	2	3	0	0	13
	UCO from known source in UK or EU, audited	L/M	L/M	L	L	L	3	2	0	0	0	7
	Tallow	L/M	L/M	L/M	L	L/M	1	4	0	0	0	9
	Tall oil	L	L	L/M	L	L	4	1	0	0	0	6

Figure 12: Extract of Sustainability Matrix.

Quantitative values for the farmland biodiversity, soil and water impacts used in the matrix were based on (Börjesson, et al., 2010), (EEA, 2006) and (Sunde, et al., 2011). Energy balance results were based on (JEC, 2011a) .

4.2. Biofuel Sustainability Scorecard

A simplified scorecard was then devised, based on the findings of the sustainability matrix, displaying the final score for each biofuel pathway.

BIOFUEL SUSTAINABILITY SCORECARD								
Biofuel Category	**Biofuel Feedstock**	**Final Score**	**Biofuel Category**	**Biofuel Feedstock**	**Final Score**	**Biofuel Category**	**Biofuel Feedstock**	**Final Score**
Biomethane	Landfill gas	5	**Biodiesel**	Soy	23	**HVO**	Oil seed rape 1 Meal as livestock feed	19
	Food waste 1	10		Oilseed rape 1 Meal as livestock feed	21		Oil seed rape 2 Meal as fuel	18
	Food waste 2	6		Oilseed rape 2 Meal as fuel	19		Sunflower 1	19
	Dry Manure	5		Sunflower	16		Palm Oil 1	20
	Wet Manure	5		Oil Palm	20		Palm oil 2	17
	Chicken manure	6		Oil Palm (CH4 capture)	17		UCO from unknown source, unaudited	13
	Sewage sludge	7		UCO from unknown source, unaudited	14		UCO from known source in UK or EU, audited	7
	Maize silage	21		UCO from known source in UK or EU, audited	7		Tallow	9
	Rye Grass	14		Tallow	9		Tall oil	6
	Switch grass	11		Tall oil	6			
	Hemp	13	**Bioethanol**	Corn 1 (from outside EU)	24	**Biobutanol**	Corn	24
	Miscanthus	12		Corn 2 (from UK)	22		Corn 2 (from UK)	23
	Ley plants/ wild flowers	13		Wheat 1 (DDGS as feed)	22		Wheat 1 (DDGS as feed)	23
	Maize + barley double cropped	13		Wheat 2 (DDGS as fuel)	21		Wheat 2 (DDGS as fuel)	22
	Maize + ley crops double cropped	10		Sugar beet	18		Sugar beet	19
	Mixture 1 100% waste mix	8		Sugar beet slops for biogas	14		Sugar beet slops for biogas	17
	Mixture 2 80% waste / 20% PGCs	8		Sugar cane 1 (irrigated)	20		Sugar cane 1 (irrigated)	21
	Mixture 3 60% waste / 40% PGCs	10		Sugar cane 2 (rain-fed)	14		Sugar cane 2 (rain-fed)	15
	Mixture 4 20% waste 80% PGCs	16						

Figure 13: Biofuel Sustainability Scorecard

5. Discussion and Recommendations

This research project has determined that the only way significant GHG reductions can be achieved by John Lewis and by the road haulage industry is by limiting the extent to which biofuels are utilised when they are derived from intensely cultivated farmland. Those fuels that are totally derived from such feedstock have been shown to fail to meet the sustainability thresholds set. Such fuels will not achieve the required decrease in total fleet emissions if their full well to wheel emissions or their major indirect impacts are considered. This is however within a context of consumption patterns which create unsustainable pressures on land, energy and water resources for the production of meat and dairy products. If these pressures are reduced to a sustainable level, then such bioenergy crops could play a useful role in sustainable farmland management.

Those fuels that may be derived from a mixture of waste sources and purpose grown crops offer more potential for sustainable use in the JLP HGV fleet however.

The sustainability and availability of genuine UCO based diesel and HVO, will however be a growing challenge. This is due to the emerging demand for biofuels in the aviation industry utilising the same feedstocks and the lack of HVO production facilities. (see appendix 1). There is no such competition between different modes of transport for biomethane however. For the car industry is not set to increase production of gas powered passenger vehicles, nor is biomethane being added incrementally to petrol or diesel for all road transport unlike biodiesel and bioethanol. Instead, biomethane will continue to be a niche market for the foreseeable future, especially with the lack of infrastructure and refuelling facilities. The competition for waste derived biomethane will instead be between fleet operators of HGVs. However, if a supply can be assured, with full control or transparency of the supply chain, then this is likely to be the most sustainable option as long as the biomethane is derived primarily from waste.

However, the mixture of three feedstocks including a third derived from PGCs (shown in table 9) also obtained significant WTW GHG savings of 70% when compared to fossil fuel diesel. In its relative versatility in terms of mixes of feedstock for anaerobic co-digestion, this enables impacts to be far less in terms of farmland biodiversity and soil health, as it enables a wide variety of crop combinations as feedstock, including utilisation of double cropping organic methods. Therefore this particular biomethane mix has been applied to the John Lewis Partnership fleet specifically to the data provided for their articulated lorries in excess of 30 tonnes Gross vehicle weight (GVW). A sample of this data is provided in Appendix 3.

The total mileage travelled by such vehicles was over 40 million miles, resulting in total CO2 emissions of approximately 50,200 tonnes[13].

Therefore, if the whole fleet was fuelled by biomethane from the mixture of the three sources shown in table 9, this would achieve GHG savings of approximately 35,000 tonnes. The percentage savings of CO2 emissions obtained by fuelling the whole fleet with 100% biomethane is not a realistic situation for the foreseeable future however. Due to lack of infrastructure and assured supply, the central transport department at John Lewis Partnership is considering, as are many other operators in the industry, the utilisation of duel fuel diesel engines for its fleet utilising a ratio of approximately 60% biomethane and 40% diesel. Therefore, if such an engine is utilised for the entire JLP articulated HGV fleet, this would result in savings of 21,000 tonnes CO2 per annum based on 2011 figures. This equates to savings of 42% of total emissions. However, such theoretical results do not account for loss of efficiency as a result of using the dual fuel engine, nor do they account for potential leakage of methane at certain points of the supply chain and in use. However, if proper checks and precautions are made to ensure that such methane losses are minimised, this should still result in significant GHG emission savings.

[13] The Defra emissions factor for diesel from 2011 was used. This was equal to 2.5725 kg CO2 eq/litre diesel. This was then multiplied by the number of litres used by the whole fleet, approximately 19,521,000 litres of diesel.

6. Conclusions

Having assessed the various biofuel options available for John Lewis Partnership and other UK retailers for use in HGVs, it was clear from the analysis that fuels derived from waste were by far the most sustainable option. However, by careful use of purpose grown crops for co-digestion with other sources of biomethane, a reasonably sustainable mixture of feedstock can be utilised. However, the extent to which such a fuel can aid GHG emissions reductions sustainably will be determined by availability and competition for resources. Growing demand for such feedstocks may increase the uncertainty of their positive impact.

Additional actions will also be required in order to ensure sustainable road freight transportation. These include the continued implementation of fuel efficiency measures and optimised truck design as well as logistics planning. However, until the wider issue of overconsumption, particularly of animal derived products, is addressed by government and society, the reduction of transportation related impacts alone will be inadequate in achieving a sustainable future for the UK and the wider global community.

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8. Appendices

8.1. Appendix 1

Further technical details and background information on biofuels.

1) Biodiesel:

Biodiesel has up until now been the most prevalent biofuel used in heavy goods vehicles. It has also been blended with conventional diesel sold in the UK at an incrementally increasing percentage since 2008, to help meet the fuel carbon reduction requirements of the Fuel Quality Directive, RTFO and RED.

Production

Biodiesel can be produced from various crops that yield oil, including palm, rapeseed and soy and can also be made from tallow (waste animal fats) or from used cooking oil (UCO) which is often derived from palm oil, the most popular form of vegetable oil . It is produced by a process known as transesterification. This describes the chemical reaction between triglycerides in the oil with methanol to form fatty-acid methyl esters (FAME). This process gives the oil a lower viscosity, enabling it to flow more easily through an unmodified compression ignition engine than untreated vegetable oil. Ethanol may also be used in place of the methanol in the esterification process to produce biodiesel, resulting in fatty-acid ethyl ester (FAEE) biodiesel as opposed to FAME. However, the production technology with ethanol is seldom used and there are no accepted quality standards or specifications with regard to FAEE, therefore, for the purposes of this analysis, only methyl esters will be considered. Glycerol is the main by-product of this process, but is not considered a particularly valuable by-product.

Availability

Biodiesel is currently the most abundantly supplied biofuel in the UK. Due to the wide range of feedstocks that can produce biodiesel, supply should be assured in the foreseeable future. However, feedstocks used in the making of biodiesel are also greatly in demand for other uses. Recently, the aviation industry has started to use HVO which utilises the same feedstocks as biodiesel. This could limit its availability for road transport **(DfT, 2011d)**.

Oilseed rape is the largest purpose grown feedstock utilised for transesterified oil biodiesel in the EU. However, used cooking oil (UCO) became the most commonly utilised source of biodiesel in 2010 and 2011 despite being a lower quality feedstock. This was mainly due to two policy decisions. Firstly, the categorisation of UCO and tallow based biodiesel as a waste product under the RED has enabled qualification for double accreditation under the RTFO certification scheme. This effectively enables RED renewable targets to be met by producers with half the volume of renewables supplied. A further, more significant fiscal policy boost for UCO biodiesel occurred in April 2010, when a 20p duty differential for biofuels (in comparison to fossil diesel) was revoked for all biofuels except UCO. When this occurred, UCO significantly increased its share of the UK biofuel market. However, as of April 2012, this duty differential ceased, despite protestation and lobbying from the industry. This may well greatly reduce the volume of UCO biodiesel supplied in the UK for the foreseeable future. However, large corporations such as McDonalds with their own plentiful supply of used cooking oil from deep frying, continue to use UCO biodiesel, enabling them to meet transport sustainability targets with ease.

Most UCO supplied in the UK was imported from the Netherlands and further afield. Greenergy, up to recently the largest producer of biodiesel from UCO in the UK sources their UCO from 15 different countries, potentially presenting auditing challenges to ensure it is genuinely used cooking oil. However, several schemes whereby waste cooking oil is collected from the catering industry and transformed into biodiesel are now in place. Convert2Green is a major supplier, working in tandem with the catering supplier 3663. Another company Agri, has recently opened the largest biodiesel plant specialising in UCO in the UK (Agri, 2012). Despite the lower quality of the feedstock as compared to pure plant oil, both companies produce fuel that meets the EN 14214 (EC, 2003) quality standard for biodiesel.

Usage

In 2011, biodiesel accounted for a total of 3.6% of diesel used in the UK domestic transport sector (by volume), with a total of 925 milion litres consumed (DECC, 2012b). There has been a general trend of increased diesel consumption in the last five years, leading to an increase in imported biodiesel to the UK.

Currently, diesel can only contain a maximum of 7% biodiesel, mixed with 93%

conventional diesel in order to meet the diesel industry standard EN590. Higher proportions would often necessitate engine modifications, and would void many manufacturers' warrantees, where used in standard diesel engines. This is due to concerns over the stability and reliability of FAME biodiesel, as it contains higher levels of olefins, molecules which may lead to degradation and instability of the oil, resulting in a relatively short shelf life. Microbial growth can also affect the reliability of the biodiesel, especially in the presence of moisture. Also, it is susceptible to low temperature related flow problems, much higher cold filter plug point (CFPP) than fossil diesel. However, certain fleets have successfully made engine modifications in order to use higher percentage mixes of biodiesel, enabling it to be used under warranty in specific compatible diesel engines.

In terms of end of pipe emissions, particulates are much lower than conventional diesel, however, NOx emissions are generally increased and relatively high levels of calcium and phosphorus may also interfere with exhaust after-treatment technologies such as EGR.

2) Pure plant oil (PPO)

Some truck fleets have also utilised pure, unesterified vegetable oil. This has the advantage of not requiring the esterification process. Because of its high oxygen content (10 – 12 %) (Nordic Folkecenter for Renewable Energy, 2012) it can burn efficiently, helping to reduce visible exhaust emissions such as particulates and hydrocarbons.

John Lewis Partnership have previously run a small scale trial using 100% pure rapeseed oil in a diesel engine. However, the removal of the 20p differential in 2010 (DECC, 2011b) and the unexpectedly low price of the RTFCs have, together with a rise in cost of the feedstock, reduced the economic viability of this biofuel, leading to an abandonment of the trial.

There are also many concerns over the sustainability of this variety of biofuel, particularly relating to impacts on the food industry and indirect impacts due to its substitution by palm oil (see Chapter 2 and 3). Also, pure vegetable oil is prone to many of the same issues affecting FAME biodiesel at higher percentage blends.

3) Hydrotreated Vegetable Oil (HVO)

Production

Another alternative to FAME biodiesel is hydrotreated vegetable oils (HVO). HVO can be produced from the same feedstocks as used for biodiesel; however, the reaction of the triglycerides in vegetable oil with hydrogen, in the presence of a catalyst, removes the oxygen and produces high quality paraffinic oil. This results in many technical advantages over biodiesel.

Usage

Due to its superior technical quality and stability, HVO can be mixed with diesel at a far higher concentration (up to about 30%) and still meet the requirements for EN590. It can also be added to diesel that contains the 7% FAME biodiesel limit with no technical or regulatory issues.

As HVO's quality is more consistent, independent of the feedstock oil quality, it can effectively use a wider range of feedstocks (Nylund, et al., 2011).

HVO also has a much higher cetane number than FAME or conventional diesel, enabling more efficient ignition in a diesel engine. It is also more chemically more stable than FAME, enabling it to be stored much longer without deterioration. It is also far less susceptible to low temperature flow issues, and has been successfully used in Alaska in temperatures of as low as -44oC (*Ibid*) without reliability problems. Another major advantage is that its end of exhaust emissions are lower in regulated pollutants than either FAME or fossil diesel. HVO also has a much lower end of distillation temperature than FAME, presenting less trouble for exhaust after treatment systems (*Ibid*). Energy density of HVO,at 34.4 MJ (Lower heating value) per litre is slightly lower than diesel and higher than that of biodiesel.

Availability

Elsewhere in Europe, HVO is currently produced by the company Neste at its plant in the Netherlands, at a capacity of 800,000tonnes/ annum. This is almost all currently used as a blending component in Neste's 'Green Diesel' product, mixed in at a 10% concentration with conventional diesel and available on garage forecourts in Finland. However, as yet, HVO is not currently marketed, produced or utilised in the UK. This is perhaps due to the lack of incentive to supply this fuel in the UK.

This is due to its classification as 'partially renewable' **(DfT, 2011d)** under the RTFO as the hydrogen is most commonly derived from fossil fuel. The RTFO therefore would not recognise it as a renewable fuel until after the amendments in November 2011 *(Ibid)* came into effect. Since then, only the renewable element of the HVO will count towards the RTFO. This is despite the counting of FAME biodiesel as 100% renewable, though its methanol constituent is usually derived from fossil fuels.

Availability of HVO for HGV's may be limited due to the growing demand for this fuel from the aviation industry (DfT, 2011d) who are also aiming to utilise biofuels to reach 2020 emissions targets (*Ibid*).

4) **Bioethanol:**

Bioethanol is another biofuel with the potential to reduce GHG emissions by its blending with or replacement of fossil fuel. For many years, bioethanol has been blended with petrol, helping achieve emissions targets under the RED. However, its use in diesel engines is still an emerging area, with two main potential approaches to its use: in low concentrations combined with conventional diesel, or as a fuel exclusively in the form of ED-95.

Production

Bioethanol can, in principle be produced from any organic material containing sugar or substances that can be broken down into sugars (starch or cellulose). The subsequent fermentation process breaks down the sugars into ethanol and CO_2. Brazil and the USA are the two largest bioethanol producers in the world, with sugarcane being the primary feedstock in Brazil and corn (maize) grain being the primary feedstock in the USA. However, in Europe, wheat and sugarbeet are the two most common feedstocks (JEC, 2007).

The main by-product in bioethanol production, when wheat is the feedstock, is DDGS, a potential high protein ingredient for animal feed, with a significant economic value as an alternative to soy for farmed cattle, pigs and poultry. However the substantial CO_2 by-product of the fermentation process can be captured and used in the food, beverage and horticultural industries, as is the case at the ENSUS plant in the UK (Ensus Group, 2012a).

Usage -Low Ethanol Blends:

When added to diesel, ethanol acts as an effective oxygenate (Kleinová & Cvengroš, 2011) resulting in more efficient combustion of the fuel. As a result it has been found to significantly reduce the PM and other regulated emissions arising from combustion of Fossil fuel diesel. E-diesel may consist of ethanol levels up to 15%. However, the addition of ethanol to diesel causes significant changes in the properties of the diesel, presenting safety and reliability issues (Chacartegui, et al., 2007). E-diesel is not recognised in the EU as meeting the EN590 standard and is not currently available in the UK.

Usage -ED95

Ethanol is not currently utilised in HGVs in the UK, due to its technical characteristics, such as a low cetane number and energy density, plus its low flash point, making it unsuitable for use in unmodified diesel engines or for long distances between refills. For its lower energy density of (21.2MJ/liter) is considerably lower than that of diesel, HVO or FAME biodiesel (Aatola, et al., 2008).

However, the Swedish company, Sekab (Sekab, 2012) has patented and produced an additive that when mixed with ethanol, compensates for its low cetane number, improving ignition properties and enabling it to be utilised in a CI engine. This additive is blended with ethanol at a ratio of 5% additive and 95% hydrous ethanol. ED95 can be used as a fuel in its own right in a CI engine without blending of any diesel. It also contains denaturants including EBTE, to comply with regulations to prevent its potential use in alcoholic drinks.

However, the low energy density and other properties of ED95 still requires a specialised engine with a much higher compression ratio than a conventional CI engine. When used in such a purpose designed engine, the high octane number and relatively clean burning characteristics of bioethanol are maximised. Scania have worked in a partnership with Sekab to optimise this fuel /powertrain combination, and are thus far the only manufacturer of such an engine.

If and when, ED95 and the compatible engine become available in the UK, the efficiency and operational benefits and costs for use in HGVs will depend on the particular duty cycle of the trucks for which it is utilised. For ED95 has approximately 60% less energy density than diesel. Therefore, to accommodate the extra volume of fuel required to travel the same distance would necessitate substantially more space and weight for storage. ED95 may, however be suitable for a fleet with frequent returns to a central depot, where a refuelling infrastructure could be provided as is the case with many retail regional delivery trucks. However, due to the current lack of previous proven usage in articulated lorries, such a fuel would initially need to be used on a trial basis to assess performance and potential for UK fleets.

With regard to exhaust emissions, both high and low ethanol blend fuel results in reduced particulate and NOx emissions, with only one problematic rise in emissions, that of acetaldehyde which is a suspected carcinogen. Another safety concern is the increased risk of explosion due to bioethanol being explosive at a far greater range of temperatures then diesel with a much lower flashpoint (Rehnlund, et al., 2007). This is the case with both ED95 and low ethanol blend diesel.

Therefore extra safety procedures would have to be in place for its use, as well as specific licencing procedures.

Availability –ED95

In Sweden, ED95 has been utilised for buses in Stockholm and one Swedish retail freight truck operator, Kylofrysexpessen has articulated lorries utilising ED95. Nevertheless, so far, ED95 is not commercially available in the UK market due to several reasons. Due to its high alcohol content, the UK HMRC Excise regulations would view ED95, if produced in the UK as potable alcohol unless it is was specifically denatured with methanol or gasoline. Therefore, ED95 would not be recognised as a fuel in this country if produced here (Nottingham City Council, 2010). However, MTBE the ‘denaturing’ agent in ED95, is legally accepted as a denaturant in Sweden, therefore ED95 is accepted as an import. It is currently prohibitively expensive however, costing twice as much as diesel without subsidies *(Ibid).*

However, several large processing plants have been producing ethanol from wheat in the UK, including the Vivergo and Ensus plants in the North East of England. Therefore, should the regulatory framework be adapted to allow ED95 as a fuel in the UK, the Sekab additive could, in principle, be combined with UK sourced bioethanol. However, domestic production is currently not at sufficient levels to currently meet demand, even for low blend ethanol diesel fuels. Therefore, use of ED95 would necessitate reliance on imports of ethanol from outside the EU, from such sources as the US and Brazil. This is already the case just to meet lower blend ethanol used in petrol. With uncertainty over yields and prices in the world grain and bioethanol supply, without major change in fiscal incentives to favour ethanol blends, they are unlikely to be utilised in diesel engines as using biodiesel or conventional diesel is currently considerable less expensive (Nottingham City Council, 2010).

2nd Generation fuels in the pipeline:

5) **Lignocellulosic Fuels**

Much investment and research has gone into the commercialisation of cellulosic and lignocellulosic fuels including bioethanol. Cellulosic bioethanol involves breaking down the complex carbohydrates in the cell walls of the plants into simpler molecules used as substrate for fermentation. This technology if effectively developed, offers the opportunity for a much higher energy yield per hectare. Energy grasses, miscanthus and short rotation coppice are amongst the energy crops being considered as feedstock for this second generation fuel. There are several lignocellulosic fuel pilate plants in the process of construction which will use lignocellulosic feedstocks to produce biofuel. BP are constructing an ethanol plant in Florida using several feedstocks including perennial energy grasses which grow up to 15 feet high and only requires replanting every 7-8 years. Such a fuel should offer the chance to avoid the use of food and feed crops and offer better energy and GHG balance than first generation fuels.

However, such technology is still at the pilot stage and is not likely to be commercialised in the UK for the next few years.

6) **Biobutanol**

Other significant lignocellulosic fuel production projects in the US include biobutanol demonstration plants. Another demonstration plant, jointly constructed by two companies, Rhodia and Cobalt, will aim to produce n-butanol from sugar cane bagasse. This demonstration plant is expected to open by the middle of 2013.

Biobutanol production is one of the potential pathways for lignocellulosic biomass to be converted to biofuel and can also use the same starchy feedstocks as first generation bioethanol.

Although butanol has been commercially available since the 1950s, it is produced predominantly from fossil fuel petroleum sources and is still used by the chemical industry in the large scale production of paints, polymers and plastics.

However, in the last few years there have been technological advances enabling this four carbon alcohol to be produced from biomass, using a bacterial fermentation method known as the ABE (Acetone, butanol, and ethanol) process. This refers to the three main chemicals (other than the CO_2 released) that are products of the process. As yet biobutanol has not been used as a transport biofuel. However, partly driven by the US mandate for cellulosic and advanced biofuels, several companies have spurred ahead with trials and are now in the process of developing industrial scale production facilities, including the retrofitting of bioethanol refineries.

Up until now, relatively low biobutanol yields of between 0.1 and 0.3g/gram carbohydrate were such that it was unlikely to economically compete with bioethanol as a vehicle fuel. However, many recent developments promise to bring new production possibilities through non-traditional methods of fermentation. These developments use enzymes that would potentially bring a higher yield of butanol per unit of biomass feedstock, while lessening the production of acetone, the other main co-product of ABE fermentation (Cobalt Technologies, 2012).

Two main isomers of butanol can be produced. N-butanol and iso- butanol. Currently, the majority of demand is for n-butanol, as it is more flexible in its industrial application. Both n-butanol and iso-butanol have potentially good properties as a fuel. However, n-butanol is more compatible with diesel (Green, et al., 2012)

Compared to ethanol, biobutanol is less corrosive and is more compatible with the existing infrastructure of oil pipelines. It also is much less miscible with water, offering greater stability should the diesel be contaminated with water. However, although it has a higher cetane number than ethanol (12CN as opposed to 8CN), this is much lower than that of diesel.

Availability

Although there is a biobutanol pilot plant at the site of the Vivergo feed wheat ethanol plant in the North of England, it is likely to produce iso-butanol, a less favourable isomer than n-butanol for vehicle applications. Once this does occur, it will only be at the demonstration stage and therefore, availability of biobutanol for HGVs does not appear likely for the next few years.

7) Bio-DME

Bio Di-Methyl-Ether (DME) is a second generation gaseous biofuel which can be maintained as a liquid at 5 bars of pressure at room temperature. It can therefore be stored and handled in a similar way to LPG, enabling the same infrastructure to be used. DME can be produced from a wide variety of sources by a process of gasification. It has been commercialised on a small scale in Scandinavia, with truck manufacturer Volvo having successfully conducted a two year small scale trial in Sweden in conjunction with the European Commission and the Swedish Energy Agency, using DME in HGV trucks with modified diesel engines.

The feedstock utilised to make the DME in Sweden, 'black liquor' is a by-product of the paper and pulp industry. Although 'black liquor' is not readily available in the UK in sufficient volumes to replicate such a trial, DME can be produced from a wide range of other feedstocks, including organic waste and energy crops such as switchgrass (JEC, 2007). The potential for UK production of DME is enhanced by the emergence of several gasification plants, including the recently confirmed construction of the largest gasification plant in the world in Teeside by the company 'Air Products'. This 50MW capacity energy-from–waste plant could potentially produce DME as a co-product, in addition to other valuable co-products such as hydrogen. Several studies have shown DME to have many benefits over first generation biofuels and other biomass to liquid (BTL) fuels (JEC, 2007).

Unlike biobutanol DMR is thought to be non-toxic. It is for this reason it has been used as a propellant in place of CFCs. It has a cetane rating of 55 -60, which is significantly higher than diesel and giving it similar ignition characteristics. It also has a low boiling point of 25ºC, enabling good fuel – air mixing characteristics. In terms of emissions, it burns without any particulate emissions and very low NOx. It is also highly efficient as a fuel. However, DME has approximately half the energy density of diesel, which would require more refuelling or larger tank. It is also more corrosive and flammable than diesel (Birath, et al., 2008).

8) Biomethane

Biomethane can be used in heavy goods vehicles either on its own, in an engine designed to run on CNG, or in a dual fuel engine, combined with diesel. Use of biomethane significantly reduces particulates and NOx emissions as well as CO2 emissions. Like DME, biomethane can be formed as a product of gasification (National Grid, 2009). However, it is more commonly derived from biogas, which is formed as a result of anaerobic digestion (AD), a naturally occurring process that involves the decomposition of organic material due to bacterial activity in the absence of oxygen. Such a process, which results in methane emissions, occurs in the stomachs of ruminants and as an unintended consequence of the breakdown of organic waste, including in landfill sites and from the storage or spreading on land of animal manure and slurry. However, methane is a potent greenhouse gas, with a global warming potential (GWP) approximately 23 times higher than CO2. Therefore, in many circumstances; its capture for use as an energy source is far preferable to letting it leak to the atmosphere, environmentally and economically. Therefore, the capture of biogas and its utilisation for energy production including the development of industrial AD plants has become widespread but is still on a small scale compared to liquid biofuels and is only expected to play a small role in the transport industry as a whole, partly due to a lack of infrastructure for its deployment as a fuel.

Production and capture of biogas originates from from five main categories of feedstock:

- Landfill sites, where organic matter gives off biogas as it decomposes in anaerobic conditions.
- Sewage sludge (from waste water treatment plants)
- Agricultural Manure, slurry and waste.
- Food and drink waste (commercial /municipal and from catering and retail industry).
- Purpose grown crops (PGCs).

The term ‘biomethane’ is given to the biogas following its undergoing an industrial cleansing process to remove contaminants such as hydrogen sulphide, siloxanes and other contaminants as well as the CO2 that constitutes approximately 40% of the biogas. This 'upgrade' to biomethane can be carried out by a number of methods, most commonly by water scrubbing, use of organic solvents or pressure swing adsorption. This results in a gas with very high (around 97%) methane content which is then suitable for use as a vehicle fuel or for injection to the national gas grid, having almost identical characteristics to natural (fossil) gas. The upgraded Biogas has an energy content of approximately (36MJ per m^3) which is equivalent to 50MJ per kg (Biogas Väst, 2012).

This can then be fed into the gas grid, compressed to form Compressed Biomethane Gas (CBG) or cryogenically cooled to its liquid form at about -160^oC, Liquified Biomethane Gas (LBG) which can then be transported and stored in canisters to a depot and used for transport fuel.

Availability

Although biomethane from AD has been harnessed in the UK for many years, it has not as yet been utilised on a wide scale for the purpose of providing transport fuel, providing only 0.01% of renewable transport fuels (Parliamentary Office of Science and Technology, 2011). This has been partly due to the comparatively low price of the RTFCs in comparison to other fiscal incentives, (*Ibid*) leading to biogas being mainly used for electricity instead. Despite this, biomethane has already been utilised by several freight companies and retailers including John Lewis Partnership as well as Sainsbury in a small number of trucks. This has been possible as such retailers use centralised refuelling facilities at distribution centres.

However, the introduction of a new fiscal incentive, the Renewable Heat Incentive(RHI) in November 2011, offers a new opportunity for wider use of biomethane in for HGVs. Upgraded gas from AD plants can now be injected into the gas grid, providing the guaranteed payment associated with the RHI, with the equivalent mass of gas taken out of the grid at fuelling depots. The Green Gas Certification scheme has been devised in order to track the biomethane from producer to end user using a digital system.

However, there are other approaches to biomethane use that have been utilised:

Landfill Sites

Since 2008, the company Gasrec, the UK's first and still the only commercial liquid biomethane producer, has been capturing landfill gas from a landfill site in Surrey, upgrading it to biomethane, then liquefying the gas. The gas from this landfill site provides enough upgraded gas to provide a fuel supply to 150 trucks. Companies including Waitrose, Sainsbury, Tesco and Coca Cola have all trialled the utilisation of this liquefied gas (LBG) in their vehicles. Sainsbury and Tesco continue to use this fuel in a number of their trucks and Coca Cola Enterprises used it in 14 vehicles operating within the Olympic site, so as to comply with the strict low emissions criteria.

In most cases, delivery of the LBG canisters is made to depots run by the companies to which they are supplied.

Providing the biomethane in a liquid form has the advantage of considerably reduced volume, making storage more practical, especially where space is limited. This scheme also entitles the supplier to double RTFCs for each unit of fuel supplied as it is derived from waste. However, it has several drawbacks, including the need to maintain the methane at a temperature of -162^{o}C. This presents many challenges for storage and the refuelling process, as well as a health and safety issue.

Sewage treatment plants

In the UK, most major wastewater treatment plants (WWTPs) utilise industrial AD plants as an effective way to deal with the large volume of sludge produced as a by-product of the 'activated sludge' wastewater treatment process. The sewage sludge, is greatly reduced in volume and mass by the AD process. Utilising this treatment of the sludge also helps to stabilise it, resulting in a valuable by-product ('biosolids') that can be applied to agricultural land as a an alternative to synthetic fertiliser. AD from sewage sludge results in a yield of biomethane ranging between 40 to 75 m^3 per tonne of sludge. Yield of biogas can, however, be greatly improved by effective pretreatment of the substrate or by use of a multi stage digestion technology. It is estimated that between 270 and 639 million m3 of biomethane could be produced in the UK from digestion of sewage sludge by 2020 (National Grid, 2009, p.4)

Up until now, most biogas produced at wastewater treatment plants has been utilised in Combined Heat and Power (CHP) Plants to provide heat to maintain the anaerobic digestion and power to the various other waste water treatment processes. However, the recent introduction of the fiscal incentive, the Renewable Heat Incentive, has made the upgrading of the biogas and injection into the national gas grid a viable option. As a result, the Didcot WWT plant run by Thames Water became the first WWTP to choose biomethane gas grid injection over the CHP route. Others are expected to follow suite, especially as the ROC scheme will now exclude plants up to 5MW (which includes all current AD plants in the UK.

Agricultural waste, manure and purpose grown crops

Agricultural utilisation of anaerobic digestion has the potential to produce a significant controlled supply of biomethane. There is a wide range of yield depending on the specific feedstock used. For instance, pig manure slurry yields between 14 -18 m3 methane per tonne of feedstock whereas poultry litter yields are far higher, yielding between 50 and 115 m3 per tonne of feedstock. There are already several agricultural AD plants in the UK including one at the Duchy site in Cornwall, which utilises a mixture of all these feedstocks, combining potato waste from food processing with maize silage, grass silage, and chicken manure.

Availability

The manure and slurry are not in short supply. However, the limiting factor is the ability to collect the waste from disparate sources to provide a consistent feedstock throughout the year.

A national grid report estimates the potential for up to 5.45 billion m3 of biomethane to be supplied via the national gas grid by 2020 from the three main feedstocks, agricultural waste, manure and energy crops (National Grid, 2009), if supported by policy and implementation.

Agricultural anaerobic digestion has been implemented in Germany on a wide scale utilising maize as the main feedstock. Although using purpose grown crops such as maize and sugar beet produces a comparatively high yield of biogas, providing more energy per hectare than most other current biofuels there are still concerns over its impact on the environment, particularly for potentially adverse effects on biodiversity. Even the use of grass as a feedstock, although potentially positive in terms of carbon balance, may mean loss of biodiversity from the harsh mowing regime necessary to collect this substrate. Also, the practical issues relating to location in relation to the gas grid may mean the opportunity cost of utilising such biomethane for transport via the grid may be higher than in the case of the other major sources.

Food and catering industry waste

Food waste arisings from the UK could potentially provide up to 1.3bn m3 of biomethane by 2020 (National Grid, 2009).

This is a potential source of energy of particular interest to a retailer such as John Lewis Partnership whose 280 Waitrose stores alone currently produce a total of well over 6000 tonnes of food waste per year. This could yield well over 420,000 m^3 of biomethane, enough to make a significant contribution to its energy needs.

However, In the case of Waitrose, their policy in line with the EU Waste Framework Directive is to reduce such food waste.

Such policies, across the UK and EU, are likely to drive the diminishment of organic waste available for AD.

Nevertheless, the food waste left over that is not suitable for human or animal consumption offers a positive potential boost to yields of biomethane in co-digestion with other feedstocks. However, to obtain biogas from food waste in co-digestion with other sources can be more complex and costly than combining many other sources. This is due to the regulatory framework requiring segregation of the food waste at source. If any of the food waste is classed as animal by-products then the PAS110 standard applies, limiting the ability to deal with the digestate.

8.2. Appendix 2

Extracts of Sustainability Assessment Matrix for four categories of biofuel

BIOMETHANE

BIOFUEL CATEGORY	BIOFUEL FEEDSTOCK	WTW CO2 Including exhaust emissions and credits if derived from waste / degraded land	SOCIAL IMPACTS/ Food price & availability	FARMLAND BIODIVERSITY AND SOIL IMPACTS	WATER IMPACTS - consumption/ eutrophication /acidification/ pollution	ENERGY BALANCE / Supply chain Reliance on fossil fuel	L	L/M	M	M/H	H	Final Score Total
Biomethane from waste	Landfill gas	L	L	L	L	L	5	0	0	0	0	5
	Food waste 1	L/M	L/M	L/M	L/M	L/M	0	5	0	0	0	10
	Food waste 2	L	L	L	L	L/M	4	1	0	0	0	6
	Dry Manure	L	L	L	L	L	5	0	0	0	0	5
	Wet Manure	L	L	L	L	L	5	0	0	0	0	5
	Chicken manure	L	L	L/M	L	L	4	1	0	0	0	6
	Sewage sludge	L	L	L/M	L/M	L	3	2	0	0	0	7
Biomethane from Purpose Grown Crops (PGCs)	Maize silage	H	M/H	H	L/M	H	0	1	0	1	3	21
	Rye Grass	M/H	M	L/M	L/M	M	0	2	2	1	0	14
	Switch grass	M	L/M	L/M	L	M	1	2	2	0	0	11
	Hemp	M	L/M	L/M	M	M	0	2	3	0	0	13
	Miscanthus	M	L/M	L/M	L/M	M	0	3	2	0	0	12
	Ley plants/ wild flowers	M	L/M	L/M	M	M	0	2	3	0	0	13
	Maize + barley double cropped	M	L/M	M	L/M	M	0	2	3	0	0	13
	Maize + ley crops double cropped	L/M	L	L/M	L/M	M	1	3	1	0	0	10
Biomethane from Mixed Feedstock	Mixture 1 100% waste mix	L	L	L/M	L/M	L/M	2	3	0	0	0	8
	Mixture 2 80% waste / 20% PGCs	L	L	L/M	L/M	L/M	2	3	0	0	0	8
	Mixture 3 60% waste / 40% PGCs	L/M	L/M	L/M	L/M	L/M	0	5	0	0	0	10
	Mixture 4 20% waste 80% PGCs	M/H	M	M/H	M	L/M	0	1	2	2	0	16

About | Biomethane | Biodiesel | HVO | Bioethanol_Biobutanol | SCORECARD

BIODIESEL - FAME (Methyl ester)

BIOFUEL CATEGORY	BIOFUEL FEEDSTOCK	WTW CO2 Including exhaust emissions and credits if derived from waste / degraded land	SOCIAL IMPACTS/ Food price & availability	FARMLAND BIODIVERSITY AND SOIL IMPACTS	WATER IMPACTS - consumption/ eutrophication /acidification/ pollution	ENERGY BALANCE / Supply chain Reliance on fossil fuel	L	L/M	M	M/H	H	Final Score Total
BIODIESEL	Soy	H	H	H	M	H	0	0	1	0	4	23
	Oilseed rape 1 Meal as livestock feed	H	M/H	M/H	M	H	0	0	1	2	2	21
	Oilseed rape 2 Meal as fuel	H	M/H	M/H	M	M	0	0	2	2	1	19
	Sunflower	H	M	L/M	M	M	0	1	3	0	1	16
	Oil Palm	H	H	M	M/H	M	0	0	2	1	2	20
	Oil Palm (CH4 capture)	M/H	M	M	M	M/H	0	0	3	2	0	17
	UCO from unknown source, unaudited	M	M	M	L/M	M	0	1	4	0	0	14
	UCO from known source in UK or EU, audited	L	L/M	L	L	L/M	3	2	0	0	0	7
	Tallow	M	L	L	L/M	L/M	2	2	1	0	0	9
	Tall oil	L	L	L	L	L/M	4	1	0	0	0	6

HYDROTREATED VEGETABLE OIL (HVO)

BIOFUEL CATEGORY	BIOFUEL FEEDSTOCK	WTW CO2 Including exhaust emissions and credits if derived from waste / degraded land	SOCIAL IMPACTS/ Food price & availability	FARMLAND BIODIVERSITY AND SOIL IMPACTS	WATER IMPACTS - consumption/ eutrophication /acidification/ pollution	ENERGY BALANCE / Supply chain Reliance on fossil fuel						**Final Score**
							L	L/M	M	M/H	H	Total
Hydrotreated Vegetable Oil	Oil seed rape 1 Meal as livestock feed	H	M/H	M/H	M	M	0	0	2	2	1	19
	Oil seed rape 2 Meal as fuel	H	M/H	M/H	M	L/M	0	1	1	2	1	18
	Sunflower 1	H	M/H	M/H	M	M	0	0	2	2	1	19
	Palm Oil 1	H	M/H	H	M	M	0	0	2	1	2	20
	Palm oil 2	M/H	M/H	M	M	M	0	0	3	2	0	17
	UCO from unknown source, unaudited	M	M	L/M	L/M	M	0	2	3	0	0	13
	UCO from known source in UK or EU, audited	L/M	L/M	L	L	L	3	2	0	0	0	7
	Tallow	L/M	L/M	L/M	L	L/M	1	4	0	0	0	9
	Tall oil	L	L	L/M	L	L	4	1	0	0	0	6

BIOETHANOL AND BIOBUTANOL

BIOFUEL CATEGORY	BIOFUEL FEEDSTOCK	WTW CO2 Including exhaust emissions and credits if derived from waste / degraded land	SOCIAL IMPACTS/ Food price & availability	FARMLAND BIODIVERSITY AND SOIL IMPACTS	WATER IMPACTS - consumption / eutrophication / acidification/ pollution	ENERGY BALANCE / Supply chain Reliance on fossil fuel						**Final Score**
							L	L/M	M	M/H	H	Total
Bioethanol	Corn 2 from outside EU	H	H	H	H	M/H	0	0	0	1	4	24
	Corn 1 from UK/ EU	H	H	M/H	M/H	M/H	0	0	0	3	2	22
	Wheat 1 (DDGS as feed)	H	H	M/H	M/H	M/H	0	0	0	3	2	22
	Wheat 2 (DDGS as fuel)	H	H	M/H	M/H	M	0	0	1	2	2	21
	Sugar beet	H	M	M	M/H	M	0	0	3	1	1	18
	Sugar beet slops for biogas	M/H	M	M	L/M	L/M	0	2	2	1	0	14
	Sugar cane 1	H	M	M/H	H	M	0	0	2	1	2	20
	Sugar cane 2	M	M	M	M	L/M	0	1	4	0	0	14
Biobutanol	Corn	H	H	H	H	M/H	0	0	0	1	4	24
	Wheat 1 (DDGS as feed)	H	H	M/H	H	M/H	0	0	0	2	3	23
	Wheat 2 (DDGS as fuel)	M/H	H	M/H	H	M/H	0	0	0	3	2	22
	Sugar beet	H	M	M	H	M	0	0	3	0	2	19
	Sugar beet slops for biogas	M	M	M	H	M	0	0	4	0	1	17
	Sugar cane 1 (irrigated)	H	H	M/H	M/H	M	0	0	1	2	2	21
	Sugar cane 2 (rainfed)	M/H	M	M	M	L/M	0	1	3	1	0	15
	Energy grass 1											
Lignocellulosic ethanol	Energy grass 2 Grown on degraded land											
	Corn stover											
	Sweet sorghum											
Alternative crops	Cashew apple											

8.3. Appendix 3

Extract of John Lewis HGV fleet data

	Miles Travelled			Fuel Used			
			Variance	(Gallons)		Variance	Branch
	2010	2011	%	2010	2011	%	M.P.G
Production							
Internal Distribution Transport							
Distribution	17,257,152	19,550,732	13.3	1,748,445	1,847,065	5.6	10.58
Scottish Branch Distribution	1,182,679	1,116,427	-5.6	112,422	111,753	-0.6	9.99
Pure Plant Oil Vehicles	545,334	378,663	-30.6	54,677	38,998	-28.7	9.71
Sub Total	**18,985,165**	**21,045,822**	**10.9**	**1,915,544**	**1,997,816**	**4.3**	**10.53**
External Distribution Transport							
K & N - Bardon	5,530,284	6,395,693	15.6	597,223	647,788	8.5	9.87
K & N - Brinklow	6,898,396	7,251,659	5.1	733,872	759,899	3.5	9.54
K & N - Theale	958,483	621,501	-35.2	99,842	69,324	-30.6	8.97
Sub Total	**13,387,163**	**14,268,853**	**6.6**	**1,430,937**	**1,477,011**	**3.2**	**9.66**
WAITROSE Distribution by Articulated Lorries.	**32,372,328**	**35,314,675**	**9.1**	**3,346,481**	**3,474,827**	**3.8**	**10.16**
JOHN LEWIS Distribution by Articulated Lorries	9,266,149	8,673,762	-6.4	947,459	884,921	-6.6	9.80
TOTAL ARTICULATED LORRY FLEET	**41,638,477**	43,988,437	**5.6**	4,293,940	4,359,748	**1.5**	**10.08**
Km travelled	**66,996,309**		Litres fuel used	**19,520,681**			
	Diesel	Ltrs	Gallons	4.5461	Diesel Co2	2.5725	
	Gas	Kgs	Gallon Eq	3.4157	CNG Co2	0.005	

8.4. Appendix 4

Screenshot of Biograce GHG emissions calculator, version 4b.