Regional emissions from biofuels cultivation

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Report for the Department for Transport

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Executive Summary

The European Commission (EC) Directive on the promotion of the use of energy from renewable sources (Directive 2009/28/EC, known as the Renewable Energy Directive or RED) requires that by 2020, 20% of the European Community's gross final consumption of energy should come from renewable sources, and 10% of each Member State's transport energy consumption should be from renewable sources. The aims of the Directive are to reduce Community greenhouse gas (GHG) emissions and improve energy security by reducing Europe's dependence on fossil fuels. It is anticipated that biofuels and bioliquids will play a key role in meeting both the overall Community level target and the transport sector target for the deployment of renewable energy. The RED is transposed in the UK through the Renewable Transport Fuel Obligation (RTFO).

Annex V of the RED contains carbon defaults (GHG emissions) for a number of biofuel feedstocks. These defaults are made up of three components, or disaggregated defaults, for cultivation, processing and transport. Article 19 of the RED sets out how GHG emissions savings for biofuels and bioliquids are to be calculated, with specific requirements on the estimation of GHG emissions from the cultivation of agricultural crops for biofuels set out in Article 19(2). This article seeks to identify those areas of the EU where typical GHG emissions from the cultivation of raw materials can be expected to be less than or equal to the disaggregated default for cultivation used in the default values in Annex V of the Directive. Each Member State had to identify these areas and report to the Commission by 31 March 2010. For feedstocks grown in the EU, the use of default values to report GHG emissions is only permitted, if the emissions arising from cultivation in the region the crop was grown have been shown to be typically less than, or equal to, the disaggregated default for cultivation values. For areas where estimated emissions exceed these values actual values for cultivation must be used in GHG emissions calculations.

This report provides updated estimates of GHG emissions arising from cultivation of biofuels feedstocks in the UK at the NUTS 2 level to meet the reporting requirement of the Directive. For each biofuel feedstock it identifies those NUTS 2 regions of the UK for which the disaggregated default for cultivation or the fuel chain carbon default can be reported.

Estimates of regional GHG emissions arising from the cultivation of crops as biofuels feedstocks, made in accordance with the guidance given by the RED methodology, indicate that, for some crops grown in some UK NUTS 2 regions, average GHG emissions exceed the RED disaggregated default for cultivation. Overall, these results indicate that the RED default can be used for winter feed wheat grown in all UK regions except for the NUTS 1 north west and south west regions of England and both Welsh regions. Results for winter barley present a similar pattern to those for winter wheat. Estimated GHG emission values for oilseed rape (OSR) were only greater than the RED disaggregated default for cultivation in both Welsh and Northern Ireland NUTS 2 regions. None of the estimates for sugar beet exceeded the disaggregated default for cultivation in any NUTS 2 regions of the UK where sugar beet is grown.

The greatest emissions from crop cultivation arose from, in order of significance, emissions of: N_2O from soil, the manufacture of fertilizer, fuel used to power machinery during cultivation and harvest, and from crop residues. The greater the amount of dry matter (DM) yield per kg of fertilizer-N applied, the smaller were the GHG emissions per MJ of biofuel. Crops such as oats, which produced the most feedstock per kg N fertilizer applied, produce smaller emissions, expressed as gCO_2-eqv/MJ of biofuel, than crops such as OSR which had a small ratio of DM yield to N fertilizer applied.

The summary table below presents total cultivation emissions for each biofuel feedstock by UK NUTS 2 region. Biofuel suppliers may use the NUTS 2 data as actual cultivation data when reporting under the RTFO. The data is available to two decimal places in tables 7.2.1 - 7.2.7, but that is presented here as the disaggregate defaults for cultivation in RED Annex V are expressed as whole numbers.

Summary table: GHG emissions arising from biofuel cultivation in the UK NUTS 2 regions [gCO_2-eqv./MJ biofuel]. Bold indicates that values are equal to or lower than the Annex V disaggregated default for cultivation values.

Region	Winter wheat	Winter barley	Spring barley	Oats	Triticale	OSR	Sugar beet
N East							
UKC1	**21**	21	24	20	30	**29**	NA
UKC2	**21**	21	24	20	30	**29**	NA
N West							
UKD1	30	25	27	25	31	**29**	NA
UKD2	30	25	27	25	31	**29**	NA
UKD3	30	25	27	25	31	**29**	NA
UKD4	30	25	27	25	31	**29**	NA
UKD5	30	25	27	25	31	**29**	NA
Yorks							
UKE1	**21**	20	22	21	31	**28**	**11**
UKE2	**21**	20	22	21	31	**28**	**12**
UKE3	**21**	20	22	21	31	**28**	**12**
UKE4	**21**	20	22	21	31	**28**	**12**
E Mids							
UKF1	**20**	21	21	20	29	**29**	**11**
UKF2	**20**	21	21	20	29	**29**	**11**
UKF3	**20**	21	21	20	29	**29**	**11**
W Mids							
UKG1	**23**	23	24	22	31	**29**	**12**
UKG2	**23**	23	24	22	31	**29**	NA
UKG3	**23**	23	24	22	31	**29**	NA
Eastern							
UKH1	**21**	21	21	20	30	**28**	**11**
UKH2	**21**	21	21	20	30	**28**	**10**
UKH3	**21**	21	21	20	30	**28**	**11**
S East							
UKJ1	**22**	21	21	20	31	**29**	NA
UKJ2	**22**	21	21	20	31	**29**	NA
UKJ3	**22**	21	21	20	31	**29**	NA
UKJ4	**22**	21	21	20	31	**29**	NA
S West							
UKK1	24	23	24	24	32	**28**	NA
UKK2	24	23	24	24	32	**28**	NA
UKK3	24	23	24	24	32	**28**	NA
UKK4	24	23	24	24	32	**28**	NA
Wales							
UKL1	25	24	25	24	32	30	NA
UKL2	25	24	25	24	32	30	NA
Scotland							
UKM2	**20**	19	21	21	30	**28**	NA
UKM3	**20**	19	21	21	30	**28**	NA
UKM5	**20**	19	21	21	30	**28**	NA
UKM6	**20**	19	21	21	30	**28**	NA
N Ireland							
N Ireland	**23**	20	24	23	30	30	NA
RED default†	23					29	12

†RED disaggregated default for cultivation

NA, not applicable (sugar beet is not currently grown in these regions)

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1 Abbreviations

AFBI	Agri-Food & Biosciences Institute
AN	Ammonium nitrate fertilizer
BSFP	British Survey of Fertiliser Practice
CH_4	Methane
CO_2	Carbon dioxide
CO_2-eqv.	The global warming potential of a GHG expressed as the warming equivalent to that produced by a kg of CO_2 over 100 years
CI	Confidence interval of the mean
DA	Devolved Authority
DARDNI	Department for Agriculture and Rural Development Northern Ireland
Defra	Department for Environment, Food and Rural Affairs
DM	Dry matter
EF	Emission factor
FERA	Food and Environment Research Agency
GHG	Greenhouse gas
IPCC	Inter-Governmental Panel on Climate Change
K	Potassium
K_2O	Potash
LANDIS	Land Information System
LCA	Life cycle analysis
MJ	Megajoules
MLURI	Macaulay Land Use Research Institute
N	Nitrogen
N_2	Nitrogen gas
N_2O	Nitrous oxide
NO_3^-	Nitrate
O_2	Oxygen
OC	Organic carbon
OSR	Oilseed rape
P	Phosphorus
P_2O_5	Phosphate
pH	Indication of soil acidity
RED	Renewable Energy Directive
SD	Standard deviation
SE	Standard error of the mean

2 Introduction

On 23 April 2009, the European Commission adopted a Directive on the promotion of the use of energy from renewable sources (Directive 2009/28/EC). The Renewable Energy Directive (RED) includes a methodology to ensure that biofuels and bioliquids secure reductions in greenhouse gas (GHG) emissions. Article 19 of the RED sets out how GHG emissions savings for biofuels and bioliquids are to be calculated, with specific requirements on estimation of GHG emissions from the cultivation of agricultural crops for biofuels set out in Article 19(2). The article seeks to identify those areas of the EU where typical GHG emissions from the cultivation of raw materials can be expected to be less than or equal to the disaggregated default for cultivation values in the Directive. Each Member State had to identify these areas and report to the Commission by 31 March 2010.

For feedstocks grown in the EU, the use of default values (or the disaggregated default for cultivation) to calculate GHG emissions is only permitted, if the emissions arising from cultivation in the region the crop was grown have been shown to be typically less than, or equal to, the disaggregated default for cultivation values,. For areas with production in excess of these values, either average values for the region or actual values for cultivation must be used in GHG emissions assessments.

This project calculated GHG emissions savings from cultivation of biofuels feedstocks in the UK at the NUTS 2 level to meet the reporting requirement of the Directive and identify those NUTS 2 regions of the UK where default cultivation values can be used.

The figure and accompanying Table 2.1 below show the location of each NUTS 2 region and list the counties and districts comprising each NUTS 2 region in the UK.

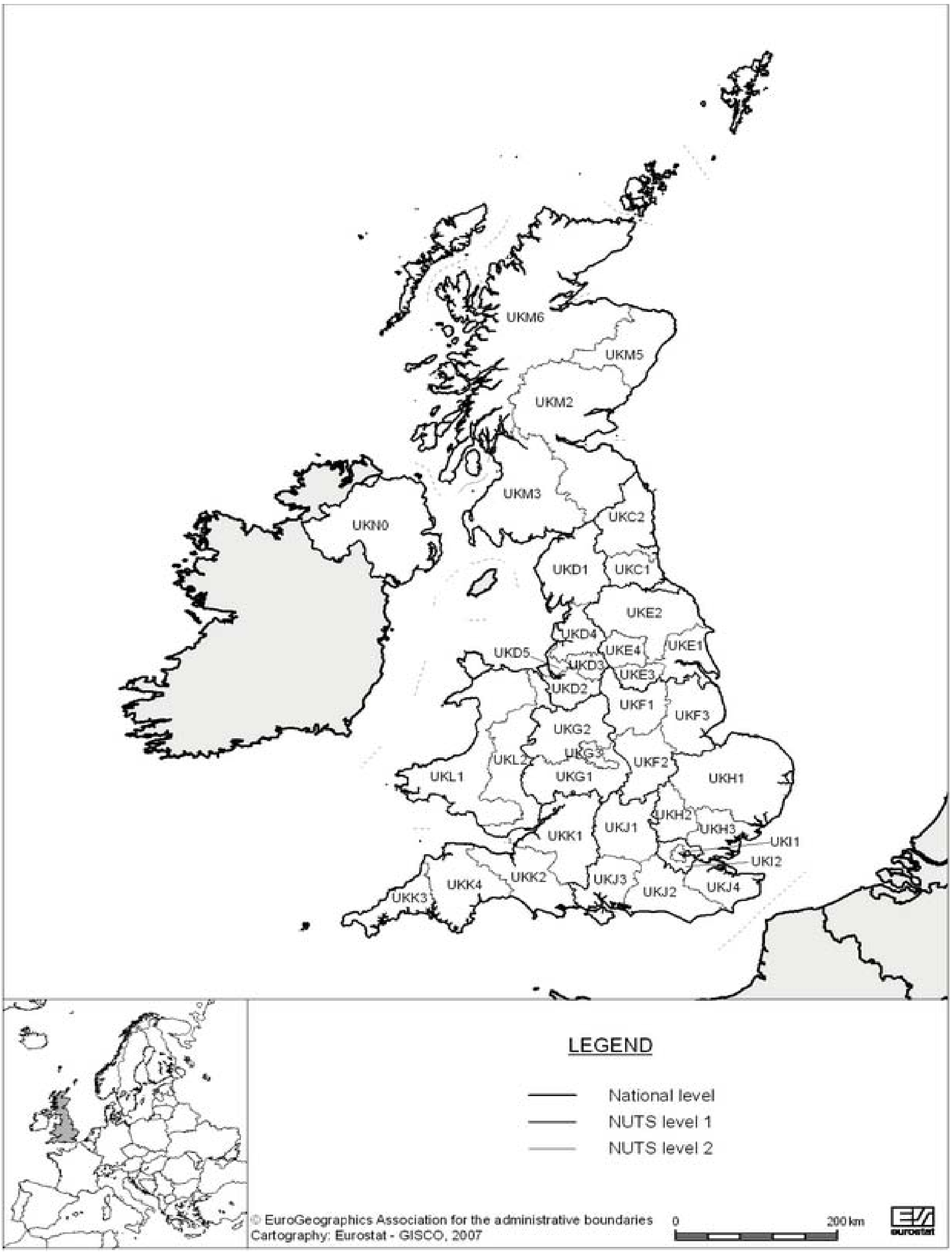

Figure 2.1 Map illustrating the NUTS 2 regions of the UK

Table 2.1 Key to counties and districts comprising the NUTS 1 and NUTS 2 regions in Figure 1 above.

NUTS 1 regions	NUTS 2 regions	Counties and districts comprising the NUTS 2 regions
North east	UKC1	Tees Valley and Durham
	UKC2	Northumberland and Tyne and Wear
North west	UKD1	Cumbria
	UKD2	Cheshire
	UKD3	Greater Manchester
	UKD4	Lancashire
	UKD5	Merseyside
Yorkshire and Humberside	UKE1	East Yorkshire and Northern Lincolnshire
	UKE2	North Yorkshire
	UKE3	South Yorkshire
	UKE4	West Yorkshire
East midlands	UKF1	Derbyshire and Nottinghamshire
	UKF2	Leicestershire, Rutland and Northamptonshire
	UKF3	Lincolnshire
West midlands	UKG1	Herefordshire, Worcestershire and Warwickshire
	UKG2	Shropshire and Staffordshire
	UKG3	West Midlands
East	UKH1	East Anglia
	UKH2	Bedfordshire and Hertfordshire
	UKH3	Essex
London	UKI1	Inner London
	UKI2	Outer London
South east	UKJ1	Berkshire, Buckinghamshire and Oxfordshire
	UKJ2	Surrey, East and West Sussex
	UKJ3	Hampshire and Isle of Wight
	UKJ4	Kent
South west	UKK1	Gloucestershire, Wiltshire and Bristol/Bath area
	UKK2	Dorset and Somerset
	UKK3	Cornwall and Isles of Scilly
	UKK4	Devon
Wales	UKL1	West Wales and The Valleys
	UKL2	East Wales
Scotland	UKM2	Eastern Scotland
	UKM3	South Western Scotland
	UKM5	North Eastern Scotland
	UKM6	The Highlands and islands of Scotland
Northern Ireland	UKN0	Northern Ireland

3 Methodology

The methodology used for calculating GHG emissions from feedstock cultivation must comply with the approach set out in the RED (Directive 2009/28/EC), including the use of similar GHG emission factors (EFs). Whenever possible, the input data used should represent the UK at NUTS 2 level. The RED methodology for calculating the emissions of GHGs from cultivation of crops for biofuel production states that both emissions arising from the cultivation and emissions due to the production of chemicals or other products used during the cultivation should be accounted for.

Another basic condition for the original study was that the results would be representative of the situation in the year 2010, which was the first year following publication of the RED. This condition was fulfilled by using five year average yields recorded in recent years rather than by making projections for the year 2010. This was considered to be the most robust approach given the uncertainties of yield forecasting. This report has now been updated to present a more recent five year average; from 2007 – 2011.

Further details of the methodology, in particular the inputs which should be considered, have been interpreted from information the European Commission has released on the derivation of the default values in Annex V of the RED. Where necessary this guidance has been supplemented using the approach or data as specified in the “Well to wheels” report published by the EC’s Joint Research Centre, CONCAWE and EUCAR (JEC, version 2c, 2007), as the authors of that study were responsible for the calculation of the default values, and informal advice from the Commission. A sensitivity analysis was carried out to test the extent to which estimated GHG emissions would change in consequence of changes to our method of estimating direct soil emissions of the GHG N_2O or our assumptions regarding GHG emissions during the manufacture of N fertilizer.

3.1 Updates in this report

The report *Emissions from Biofuels Cultivation: A report prepared for the Department for Transport* was originally completed on 12 March 2010 and submitted to the European Commission to satisfy the requirements of Article 19(2). It was revised following feedback received from the European Commission, and re-submitted on 15 December 2010. The revised version was accepted by the Commission in March 2011.

This report was subsequently updated again in 2012, to make the following revisions:

- Updated the 5-year average yield data for all crops. Updated to 2007-2011, from Government national statistics, including the proportion of whole crop wheat; and sugar beet yields from British Sugar.
- Updated the oil content of oilseed rape in line with 5-year average. Updated to 2007-2011 average, from UK oilseed industry data; adjusted the lower heating value/net calorific value of rapeseed accordingly.
- Updated nitrogen, phosphorus, potassium and lime fertiliser use and pesticide use data to 5-year average. Updated to 2007-2011 average, to align with 5-year average yields and 5-year average oil content; previous report used a single year’s data.
- Update of fuel consumption figures from Nix Pocket Handbook (2011) and including adjustment for the proportion applied between ploughing and min-till systems using data collated from Defra and Scottish Government surveys.

- Adjusted methodological approach to align with the IPCC guidelines for soil organic content, such that soils should have an organic carbon content of 20% or more by weight before applying the RED default emission factor for cultivation. The previously used threshold of 12% organic carbon content applies only to soils that are either less than 10cm in horizon depth, or subject to water saturation episodes (FAO (1998) World Reference Base for Soil Resources. World Soil Resources Reports 84. FAO, Rome. 88pp).
- Updated the nitrogen content of residues returned/incorporated in to soils. Information from recently published literature used in line with JRC methodology.
- Update of transport losses for oilseed rape and wheat, with data from industry.

The previous revisions in December 2010 included:

- Further analysis of emissions arising from the production of N fertilizer to support the conclusion of the previous report that production plants supplying N fertilizer to the UK have abatement technology fitted, and therefore that reduced N fertilizer production emissions could be used for UK calculations of GHG emissions.
- Emissions arising from crop residues have been added. These emissions have been calculated using UK-specific data on the amounts of above-ground and below-ground residues returned to soil and on the N concentration of those residues.
- The report now includes an estimate of emissions arising from the cultivation of histosols (peaty and peat soils). An estimate of the areas of histosols cultivated for the production of crops which may be used as biofuels feedstocks and the consequent emissions has now been included.
- In this updated report the results are presented in terms of CO_2-equivalents per megajoule of biofuel, in addition to presenting the results per megaojoule of feedstock. This allows for a direct comparison between the model outcomes and the default emissions presented in the tables of Annex V part D of the Renewable Energy Directive.

4 Collection of regional crop data for use in modelling

The methodology used to calculate the cultivation emissions of biofuel feedstock crops followed RED guidelines. Data were collated on the factors used in the RED: UK-specific information was used where practices in the UK were considered likely to vary significantly from those modelled in the RED default values. Information specific to NUTS 1 or NUTS 2 regions was used when such information was agreed to be sufficiently robust. The following sections outline the data used for: crop yields; crop residue returns to soil; fertilizer and pesticide applications; seed rates; lime inputs; and fuel consumption during cultivation.

4.1 Crop yields (tonnes of dry matter per ha) per region

Regional GHG emissions were calculated for the following crops which may be grown as feedstocks for biofuels:

- Winter feed wheat;
- Winter barley;
- Spring barley;
- Oats;
- Triticale;
- Oilseed rape (OSR);
- Sugar beet.

Three of these crops have default values in the RED: wheat, OSR and sugar beet.

Data on yields of cereals and OSR crops, including the confirmed yield data for England, were obtained from Defra (2012):
http://www.defra.gov.uk/statistics/foodfarm/landuselivestock/farmstats/

Sugar beet yield data were provided by British Sugar. Yields were derived from the British Sugar annual field survey 2004-2012, and the mean values reported are based on current beet growing regions.

Defra Statistics branch advised that due to the relatively small overall sample size it was not possible to get robust figures for crop yield at NUTS 2 level. The number of samples collected from within each NUTS 2 region was too small to calculate the statistical significance of any differences. However, it was possible to report yield differences among NUTS 1 regions (Appendix table 2). Consequently, the NUTS 1 level yield data were applied to all NUTS 2-level sub-regions within the NUTS 1 region. The boundaries of NUTS 1 regions, or of counties within those regions, do not correlate with variations in factors that might affect yield, such as soil type or climate. Hence, we concluded that this approach is not likely to introduce error.

The yields were averaged over five years rather than three years, as is standard practice for agricultural life-cycle analysis (LCA) studies, as unusual weather conditions in some recent years had led to some atypical yields. In this updated report, estimates are based on average yields reported for 2007-11.

4.1.1 Wales

Yield data from Defra for Wales as a whole were used for both Welsh NUTS 2 regions. The Welsh yields were estimated on a regional basis within Wales using the provisional results of the June 2011 Survey (Welsh Government, 2012). Where a NUTS 2 region boundary overlapped the England/Wales administrative boundary, the provisional results for Wales were combined with the confirmed yield data for the appropriate English NUTS 1 regions bordering Wales.

4.1.2 Scotland

Yield data for all Scottish NUTS 2 regions were obtained from Defra. These data are consistent with the final estimates of production given in the Scottish Cereal Production Survey produced by Scottish Government.

4.1.3 Northern Ireland

Yield data for Northern Ireland NUTS 2 region were obtained from Defra. These data are consistent with the yield estimates provided by the Department of Agriculture and Rural Development for Northern Ireland (DARDNI, 2012).

4.1.4 Winter feed wheat

The wheat yields reported by Defra are an overall average of milling and feed wheats. Milling wheats typically yield less grain than feed wheats, and hence the average yield reported in the Defra statistics will be less than that achieved by feed wheats. The yield of feed wheat is cited as being typically 8.5% greater than milling wheat (Nix, 2009). Since bioethanol will be made from feed wheat not milling wheat, the wheat yield estimates used in this study were based on the yields and fertilizer-nitrogen (N) application rates applicable to feed wheat only.

4.1.5 Energy content of oilseed rape

The lower heating values (LHV) used in the RED defaults were used for all crops except OSR. This was updated as the oil content of UK OSR has been increasing annually as cultivation practices have been improved, and the RED default does not reflect the UK situation. The new UK figure for OSR of 27,110 MJ/t has been used, compared to the BioGrace figure of 26,400 MJ/t.

4.2 Application of fertilizers and pesticides to crops

Information on fertilizer use was obtained from the British Survey of Fertiliser Practice (BSFP, 2011): (http://www.defra.gov.uk/statistics/foodfarm/enviro/fertiliserpractice/)

Average annual applications of the following fertilizers were collated:

- Nitrogen (N) fertilizer input (kg N per ha).
- Phosphorus (P) fertilizer input (kg P_2O_5 per ha).
- Potassium (K) fertilizer input (kg K_2O per ha).

Although there is relatively little year-to-year fluctuation in fertilizer use and the long term trend is for gradual reductions in fertilizer application, we have used 5 year averaged application rates data to correspond with the 5 year averaged yield data.

The BSFP sample size, which provides data from approximately 1,100 farms, was not large enough to discriminate differences in average fertilizer applications among either NUTS 1 or NUTS 2 regions. We have therefore used national average results (expressed as kg nutrient/ha) to calculate direct soil emissions arising from N fertilizer application. Those for Wales, Northern Ireland and Scotland use the same figure as England.

Less N is applied to feed than to milling wheat. The N application rates for feed wheat and milling wheat are given separately in the BSFP and the data for feed wheat were used.

4.2.1 Greenhouse gas emissions arising from fertilizer manufacture

Indirect GHG emissions arising from the manufacture of equipment and machinery are not included in the RED methodology. However, manufacture of fertilizers is a significant source of GHG emissions, and is therefore included. GHG emissions are expressed in terms of kg of carbon dioxide equivalent (CO_2-eqv), and include emissions of the GHGs CO_2, methane (CH_4) and N_2O.

RED default values were calculated using only one EF for N fertilizer manufacture (representing ammonium nitrate (AN) production). This manufacture of AN generates N_2O, whereas the manufacture of some other N fertilizers, such as urea, does not. Hence GHG emissions from the manufacture of urea are much less than from the manufacture of AN. Around 20% of fertilizer-N applied to combinable crops in the UK is in the form of urea. Hence we considered that the type of N fertilizer applied to crops should be taken into account. The type of N fertilizer applied to the biofuels feedstock crops is given in Appendix Table 1.

In recent years N_2O abatement technology has been developed to reduce N_2O emissions from AN production. Catalysts may be used to break down N_2O under high temperature into nitrogen gas (N_2) and oxygen (O_2). This process enables a reduction in N_2O emissions of up to 70-85%. Using these catalysts reduces the total carbon footprint of AN production to less than 3 tonnes CO_2eqv per tonne AN-N. It is forecast that virtually all operating plants in Europe will have abatement systems by the mid-2010s (Brentrup and Palliere, 2009).

As part of the revisions to the report in 2010, the project team reviewed available information collected so far under the LINK research project ‘MIN-NO’ on the adoption of N_2O abatement technology by N fertilizer manufacturers in the UK. In addition the project team also consulted directly with two UK companies (GrowHow UK Ltd and the Yara plants located in the UK) using well established lines of communication with these organisations. The topic was also discussed informally with a representative of Fertilisers Europe. The information gathered indicated that N fertilizer manufacturing plants operating in the UK and in the countries from which the greatest amounts of N fertilizer are imported to the UK are fitted with N_2O abatement technology.

The Finnish fertilizer manufacturing company Yara estimate the emissions of GHGs during production of AN fertilizer from their plant in Finland, which is equipped with catalysts to remove fugitive N_2O, to be 2.9 kg CO_2-eqv/kg N (Ahlgren et al., 2009), and this is the value used in the calculations of GHG emissions from the manufacture of AN. The default value from manufacture without N_2O abatement cited by Brentrup and Palliere (2009) of 6.0 kg CO_2-eqv/kg N was used to calculate emissions from the unabated manufacture of AN for the sensitivity analysis.

Data on phosphorus (P) and potassium (K) production were taken from LowCVP (2004) cited in Ahlgren et al. (2009) and from Wood and Cowie (2004). The emissions figures used were averages of the values cited in those publications: 0.512 kg CO_2-eq/kg P and 0.470 kg CO_2-eqv/kg K.

4.2.2 Pesticides input (kg total active ingredients per ha)

Annual pesticide usage for each of the crops listed above was taken from the most recent Pesticide Usage Surveys for Great Britain and Northern Ireland (2010) (Garthwaite et al., 2011; Withers et al., 2011). It was not possible to refine the pesticide usage below NUTS 1 level as the information is not sufficiently robust. The most recent data available for arable crops were for 2010. These were compared with the regional area of crops from Government June Census statistics (FERA, 2010; DARDNI, 2010; Defra, 2010; Scotland, 2010; Wales DA, 2010) to give a regional intensity of pesticide use in kg of active substance per ha. These figures were used as a baseline for application to the 2007-11 areas and used to calculate the annual UK energy from the active pesticide ingredients applied to each crop based on figures from Audsley et al. (2009). This was used to calculate the GHG emissions associated with manufacture of pesticides.

4.3 Seed rates (kg per ha)

The rate of application of seeding materials and the GHG emissions due to their production are included in the RED default values for two of the crops included in this study (wheat and OSR). However, these have a very small contribution to the total emissions from feedstock cultivation (*c*. 1% or less) and their omission from the calculations for barley, oats and triticale is not likely to significantly affect the results.

4.4 Lime input (tonnes/ha)

In the RED carbon default value calculations, lime is considered to be applied to only two of the crops of interest to this study: OSR and sugar beet. Data on average lime applications were obtained from the BSFP. For lime, only emissions from the production of the fertiliser were included in the emission calculations, in line with the approach used in the Biograce project.

4.5 Energy required for drying crops

The energy required for drying crops was not taken into account as under the RED GHG calculation methodology, crop drying is included as part of the 'conversion' steps, rather than crop cultivation.

4.6 Diesel fuel consumption during cultivation, harvest and other operations

4.6.1 Variation in power usage for crop cultivation

Power unit size varies considerably among farms. Some features like soil type and field size vary among regions and affect how much fuel power units have to use to complete a given amount of work.

The calculation of fuel usage for the different regions of the UK was based on the following assumptions.

1. The principal fuel-consuming field operations are listed for the crops considered and standard hours/hectare values allocated to each task (Nix, 2012).

2. An average suite of machinery was assumed to be used across the UK with large tractor units typically used for ploughing and cultivation, and medium-sized units for non-tillage field operations. The total power and the number of units sold in 2009 - 2011 reported by

the Agricultural Engineers Association website (AEA, 2012) showed a latest average tractor engine power output of about 107 kW. Mindful that the national tractor fleet is a mix of new and older units, the figures in table 4.1 have been used in this study. The pressure for future increases in the fuel efficiency of new machinery should enable these unit sizes to remain representative for the near future. There is considerable variation in engine efficiencies but a value of 2.40 kWh energy output per litre of fuel consumed (kWh/L) for tractors fitted with engines up to 170 kW power output has been used (NTTL, 2010).

Table 4.1 Average power use, actual power use and fuel efficiency for agricultural machinery

Size	Average power (kW)	Actual power use (kW)	Fuel Efficiency (kWh/L)
Tractors			
Large	104	78 (75%)	2.40
Medium	57	43 (75%)	2.40
Combines			
	167	125 (75%)	2.40

3. Cereal harvesting is done by large-to-average size combines. Fuel consumption for these different size combines has been taken to be the same. The larger combines are usually newer and more efficient than the smaller ones, hence the differences in power requirement are balanced by the differences in fuel efficiency. Sugar beet is harvested by trailed harvester powered by a large tractor.

4. Data on regional soil types (the mix of heavy, medium and light within each region) have been used to produce a relative draught energy factor for each region (derived from Culpin, 1992).

5. Data on regional differences in field size were used to derive a field efficiency factor to account for the more efficient fuel usage in larger fields where less turning and unproductive running time are involved (derived from Butterworth and Nix, 1983).

6. Both regional factors were used to adjust the standard running time for each task so heavier soils and smaller fields increase the time required for ploughing and cultivation. Only the field size adjustment was used to adjust field operations that are not affected by soil type.

7. Assuming a uniform machinery suite with variable running times avoids the problems arising from larger or smaller machinery working at different rates, and allows the regional physical soil and field differences to be expressed through the single variable of variation in the duration of fuel use. Since the same suite of machines has been taken to be used in all regions, differences in fuel use have been estimated based on regional differences in factors such as field size and soil type.

8. In the absence of specific datasets, Scotland has been assumed to be like NE England, its arable operations tending to be in larger well-run farms with a mixed range of soils. Northern Ireland has been taken as having similar soils to Scotland but with field sizes similar to Wales and SW England. South East England field sizes have been taken as average for the UK.

9. Based on the amounts of pesticide reported to be applied (Appendix table 4), winter barley has been taken to receive 75% of the pesticide applications that wheat receives. Triticale, spring barley and oats were taken to be given half the number of sprays applied to wheat.

Minimum tillage and direct drilling operations are widely used on a range of soil types across all regions for the establishment of cereals. The exact set of operations varies with soil type and equipment and the prevailing weather. Ploughing energy requirements are adjusted based on the proportion of the crop for which minimum tillage practices are applied in each region. Data sets for areas cultivated using minimum tillage were derived from information provided by Defra and Scottish Government.

4.7 Crop residue returns

Emissions arising from crop residues are also included in line with the methodology used in the BioGrace default value calculations. Data specific to the UK were collated on the fraction of above-ground crop residues that are removed and how much N is left in above-ground residues. This research made use of published ADAS papers and reports as well as wider literature. Published data are scarce for some of these cereal species (notably triticale, and to an extent, oats) and there was a need to make use of unpublished reports and datasets from recent trials carried out for the Home Grown Cereals Authority (HGCA), plant breeders and the OATLINK project.

Published literature was reviewed to quantify the amount of N residues in plant roots, making use of a model of root distribution developed by ADAS. Due to the paucity of literature on the amount of root N per hectare, information was used on the concentration of N in root dry matter (DM) together with DM information to help to quantify the amount of root N per hectare. The data used were as follows (further details can be found in the tables on Annex 1):

- **Fresh yield (t/ha)** was taken from the UK national average of Defra statistics (average from 2007 to 2011).

- **Percentage DM of fresh yield** was used to calculate the DM content of a crop yield from the marketable fresh weight of the yield.

- **Dry matter yield (t/ha)** is the dry weight of the saleable yield calculated as follows:

  Fresh yield X proportion DM of fresh yield / 100

- **Harvest index (HI)** is the ratio between DM grain yield and the total above ground crop dry weight at harvest. Data from Stoddart & Watts (2012) was used for harvest Index, apart from for sugar beet for which the HI was calculated based on data from British Sugar.

- **Total dry straw yield (t/ha)** was calculated as the product of the inverse HI and the total crop dry weight. This includes the chaff and pod walls for cereals and OSR respectively, and represents the leaf and stalks of sugar beet.

- **Ratio of baled straw to total straw yield.** In practice straw is harvested 10 to 20 cm above ground level and it is impossible to collect all of the straw and chaff in the baling process. Only a proportion of the above-ground non-grain material would equate to a farmer's straw yield. The best estimate available for the proportion of farmer's straw yield to above-ground non-grain material for modern cereal varieties is 0.6, and 0.5 for OSR (Stoddart & Watts, 2012).

- **Dry straw remaining after baling (t/ha)** accounts for the likely inefficiencies of the baling process and was calculated as a product of the total dry straw yield and the ratio of baled straw to total straw yield.

- **Percentage N in non-yield above ground residues** was taken as the mean of several values from different sources of UK data (specific to the different crops). IPCC figures have been used where appropriate, OSR and SBt values have come from Biograce and British Sugar, respectively.

- **Total N in straw (kg/ha)** was calculated as the product of the straw yield and the percentage N in unharvested above-ground residues.

- **Total N in straw after baling (kg/ha)** was calculated as the product of dry straw remaining after baling (t/ha) and the percentage N in non-yield above ground residues.

- **Below ground biomass (t/ha)** is the total weight of below-ground biomass at harvest. IPCC figures have been used where appropriate, OSR and SBt values have come from Biograce and British Sugar, respectively.

- **%N in root biomass**. Values were not available for any of the crops except wheat, which was used as the default value for all crops.

- **N in roots (kg/ha)** was calculated as the product of % N in root biomass and the below ground biomass.

- **Proportion of root biomass to dry yield** was calculated as the fraction of below-ground biomass over the DM yield. Only the yields that corresponded with the below-ground biomass or root length data were used.

The data gathered were used to calculate emissions arising from crop residues returned to soil.

5 Nitrous oxide emissions from soil

5.1 Direct soil emissions

5.1.1 Default approach

Paragraph 83 of the RED states that:

> *'It is appropriate for the data used in the calculation of the default values to be obtained from independent, scientifically expert sources and to be updated as appropriate as those sources progress their work. The Commission should encourage those sources to address, when they update their work, emissions from cultivation, the effect of regional and climatological conditions,'.*

We interpret this as referring to soil and climate effects on crop yields, GHG emissions from soils, and also differences in crop husbandry, which will depend on soils and climate.

The Inter-Governmental Panel on Climate Change (IPCC) Guidelines provide three Tiers, or levels of complexity, for the methodologies which may be employed to compile inventories of GHG emissions from agriculture.

- Tier 1 is the basic method, designed to use readily-available national statistics (also known as activity data) in combination with default EFs and additional parameters that are provided. This approach is straightforward and transparent. The default EFs are derived from very large datasets and hence give an accurate representation of 'average' emissions at the global scale. However, a Tier 1 methodology is less accurate in representing the effects that regional or local variations in management and/or environment within a given source category may have on GHG emissions from soils and on the effects of implementing GHG mitigation methods.

- Tier 2 represents an intermediate level of complexity, where source categories are broken down into more detail (e.g. sub-categories for livestock types and/or management stages) and country-specific data are used instead of default parameters.

- Tier 3 represents the greatest complexity; for example, the use of mechanistic or process-based models to derive EFs.

With the increasing level of detail, Tier 2 and Tier 3 methodologies have the potential to yield more accurate estimates, especially for discrete locations/situations, and the ability to reflect changing practices and the implementation of mitigation methods. However, the requirement for input parameters (e.g. characterisation of soils and climate and the interactions among them as well as activity data) is greater for these methodologies and, in many cases, their application at larger scale, such as NUTS 2 regions, becomes less accurate due to the need to average or approximate key inputs.

For example, a Tier 3 model can accurately estimate soil N_2O emissions from a field or farm where the soil types, weather and farm practice are recorded in detail. At a larger scale, however, (e.g. an area the size of a UK county) taking account of the often very large ranges in soil type, weather and farm practice becomes increasingly complex. In these cases, reliance on expert opinion to fill the gaps in activity data may lead to emission estimates with a level of uncertainty equal to, or greater than, those using a Tier 1 methodology.

The complexity of Tier 3 models means robust validation is essential prior to their use. The complexities of scaling up from field-scale models to regional or national scale are not to be underestimated, particularly with respect to relating regional soil properties and climate to emissions of N_2O. While much work has been done on this topic, and large programmes of model development are in place or being commissioned, much remains to be done in finalising and validating the approaches. In particular, the outputs of modelled estimates need validation against actual field measurements. These do not currently exist in sufficient detail for the UK to enable the validation of the emissions estimated by models. Although a robust and reliable approach is likely to be agreed in the future, it is not currently available.

In view of the foregoing considerations we concluded that, at present, it is not justified to derive Tier 2 or Tier 3 EFs to estimate default soil emissions of N_2O in UK NUTS 2 regions as they cannot be validated. We concluded that the most justifiable approach is to use the generic IPCC EFs, applied to more local fertilizer-N use data. In consequence, to deliver the project, we used Tier 1 default IPCC EFs to calculate N_2O emissions from soils.

We recognise that the use of a Tier 1 methodology does not allow us to fully consider the regional differences in soil and climate. However it is a standardised, internationally accepted methodology that can be applied now, and does not preclude future use of more sophisticated models to take account of climate and soil once these are validated. The UK has a large programme to improve GHG emission estimates from soils. More refined estimates taking into account soils and climate should be achievable within the next three to five years.

To ensure consistency with the RED methodology we also estimated the likely impacts of regional differences in soil type and climate on N_2O emissions from soils (a Tier 2 approach) and include the results from these calculations as part of the sensitivity analysis.

5.1.2 Sensitivity analysis

As part of the sensitivity analysis undertaken in the initial project, emissions of N_2O were calculated using the publicly-available spreadsheet model reported by Stehfest and Bouwman (2006). Soils derived from the LANDIS database (Proctor et al., 1998) were used for NUTS 2 regions in England and Wales. Soil data for the four NUTS 2 regions in Scotland were provided by the Macaulay Land Use Research Institute (MLURI) based on their national soil database. For the single NUTS 2 region in Northern Ireland the soil data were provided by the Agri-Food & Biosciences Institute (AFBI) based on their agricultural soils database.

For England and Wales the information for arable soils was summarized for each 5 by 5 km grid square within each NUTS 2 region using the methodology developed for the MEASURES model (Anon, 2004). This model was developed from the finding that using the nine dominant soil types in each 5 by 5 km grid square accounts for the soil properties of 80% of land area. The proportion of each of these soil types that would give the area under arable land use (taken from European Environment Agency's CORINE land cover database, Bossard et al., 2000) was calculated and used to weight the following soil properties; percentage organic carbon (OC) content; pH; and texture.

In order to fully examine the application of the Stehfest and Bouwman empirical model to calculate direct soil N_2O emissions from soils in the UK, two approaches were used to estimate regional soil N_2O emissions.

- First, soils data were averaged (using the area under arable as weights) for each NUTS 2 region and soil N_2O emissions for the region calculated from those averaged data.

- Secondly, data for each soil type within each region were used in the model to calculate N_2O emissions for each soil type. An estimate of mean N_2O emissions for each region was then calculated as a weighted mean of the emissions from each soil type within that region.

The input data required were as follows.

- **Fertilizer-N application rate.** This is required as kg/ha/year and was obtained from the BSFP as outlined above.

- **Soil carbon concentration.** The Stehfest and Bouwman model divides soils into three classes according to the soil organic matter content (referred to as soil OC content): <1.0%; 1.0-3.0%; >3.0% soil OC. These data were obtained from the LANDIS, MLURI and AFBI databases for UK NUTS 2 regions.

- **Soil pH.** The Stehfest and Bouwman model divides soils into three groups according to soil acidity (reported as pH: as acidity increases pH decreases). The groups are pH <5.5; pH 5.5-7.3; pH >7.3. These data were obtained from the LANDIS, MLURI and AFBI databases for UK NUTS 2 regions.

- **Soil texture.** The Stehfest and Bouwman model divides soils into three soil textures. Soil texture is mainly a function of clay content. The three soil texture classes are: coarse (little clay); medium (moderate clay); fine (greatest clay content). These data were obtained from the LANDIS, MLURI and AFBI databases for UK NUTS 2 regions.

- **Climate.** The Stehfest and Bouwman model divides the world into four climatic zones: temperate maritime; temperate continental; sub-tropical and tropical. All UK regions were included in the temperate maritime zone.

- **Baseline reference.** An estimate is needed of reference, or baseline, soil N_2O emissions, and this estimate is subtracted from the estimate of emissions arising from crop cultivation in order to calculate net emissions arising from crop cultivation. To be consistent with the approach required by RED, the baseline used in this study was 'managed, unfertilized grass' (WTW, 2009).

5.2 Emissions from cultivation of histosols

The areas of histosols on which relevant crops are grown were taken from The European Commission Joint Research Centre (JRC) dataset on organic carbon content in topsoils (Jones et al., 2004). A refined pedo-transfer rule for calculating the OC content of topsoil in Europe was applied to a 1 km soil dataset, derived from the European Soils Database (Hiederer et al., 2004). The ADAS land use database at 1 km resolution (Comber et al., 2008) was used to estimate the area of each of the target crops within 1 km cells having at least an organic carbon content of 20% or more by weight in line with the IPCC guidelines for soil organic content (FAO (1998) World Reference Base for Soil Resources. World Soil Resources Reports 84. FAO, Rome. 88pp).

Both of these datasets are at 1 km resolution. For the purpose of this analysis, it was therefore assumed that the entire 1 km cell has at least 20% OC, whereas in reality this is unlikely to be the case. Scotland and Northern Ireland cropping data are only available at 1 km resolution for 2004 and were therefore scaled to 2009 using national totals. There will therefore be a greater degree of uncertainty in the figures for these regions.

There is no evidence of No crops considered in this report are grown on high organic carbon content soils (of 20% OC or more) and thus this component has been excluded from the calculation.

5.3 Indirect soil emissions

The IPCC Tier 1 approach (IPCC, 2006) was used to estimate direct soil N_2O-N emissions. The IPCC Tier 1 method estimates direct losses of N_2O-N as 1.0% of N applied (IPCC, 2006). Indirect N_2O emissions, arising from the following processes were calculated:

- denitrification of fertilizer-N lost from the soil by leaching to ground and surface waters as nitrate (NO_3^-);
- nitrification and denitrification following deposition to land of fertilizer-N emitted as NH_3 after application

Indirect losses arising from NO_3^- leaching were calculated using the IPCC default EFs for the fraction fertilizer-N lost by leaching (0.30) and for the fraction of leached N subsequently denitrified to N_2O-N (0.0075).

The EFs for the proportion of fertilizer-N lost as NH_3 were taken as the average EFs for tillage land for AN and urea as reported in the UK Ammonia Emissions Inventory (Misselbrook et al., 2009). These were 1.7% of N applied as AN and 10.0% of N applied as urea. Emissions following deposition of NH_3-N to land were calculated as 1.0% of the N deposited (IPCC, 2006).

6 Results of data collection

6.1 Crop data

Appendix Table 2 reports crop yields at NUTS 1 level, as t/ha DM, collated to calculate regional EFs for biofuels crop cultivation. As indicated in section 4.1 above, the yields reported at NUTS 1 level where used for each NUTS 2 region within the NUTS 1 region.

Yield variation among regions was greatest for winter wheat, and least for OSR (only an overall national estimate was possible for triticale). The large wheat and barley yields obtained in Scotland are considered to be due to the favourable combination of long day length with a reasonable proportion of sunlight in the arable areas providing a very large potential for yield. The moderate temperatures mean the yield potential is less likely to be limited by moisture stress and also reduces the need for the plant to use energy for cooling. The much smaller crop yields obtained in the NW of England are a consequence of rotational practices as well as unfavourable climate in some seasons. Rotational practices include being sown between horticultural crops (between the Ribble and the Mersey), which can lead to sowing later in the season than recommended for optimum yield and in some cases into poorly-structured seedbeds. Similar problems can arise as a consequence of crops being grown in predominantly livestock-based systems. Table 6.1 below reports the Average UK reported crop yields, t/ha DM, 2007-11.

Table 6.1 Average UK reported crop yields, t/ha DM, 2007-11

Source	Winter wheat	Winter barley	Spring barley	Oats	Triticale	OSR	Sugar beet
UK average	6.62	5.26	4.34	4.7	3.50	2.99	16.05

6.2 Fertilizer application data

Average fertilizer applications are given in Appendix table 3.

6.3 Pesticides

The biggest impacts in pesticide use (Appendix table 4) are associated with growing different crops, with some such as triticale receiving much less pesticide than other cereals. Spring barley also receives substantially less than the winter counterpart.

6.4 Machinery use

Average diesel usage for power machinery during cultivation is given in Appendix table 5.

7 Estimated GHG emissions from cultivation of biofuel crops in different regions of the UK

7.1 Uncertainty

All scientific measurements and models contain some uncertainty. The inputs used to make these estimates of the GHG emissions associated with cultivating crops for biofuels are no exception and some inputs are more uncertain than others. Greenhouse gas emissions from all agricultural systems are particularly variable with very large uncertainties associated with N_2O emissions in particular. These are central to any comparison. The way in which these are aggregated in studies such as this, and in many other environmental assessments, tends to reduce the errors, but the way in which these should be treated in a comparison is still the subject of debate. This is not simply an experimental comparison in which two normal distributions may be compared using a conventional statistical test.

Below we provide an appraisal of the likely uncertainty in the factors used to calculate the regional emissions and a conclusion in the overall uncertainty of our estimates.

7.1.1 Crop yields

Crop yield estimates are the means of yields recorded over the last five years. Hence it was possible to calculate standard errors of the means (SEs) and these are presented in Appendix table 2. For wheat, for example, mean SEs for the NUTS 1 regions are between 0.2 and 0.5 t/ha, meaning that not all differences among regions are statistically significant.

7.1.2 Fertilizer applications

The BSFP reports SEs of 1-3% of fertilizer application; these estimates therefore have little uncertainty.

7.1.3 Pesticide use

Garthwaite et al. (2011) do not quote SEs in their results. The pesticide data were those collected by the Pesticide Usage Survey team at FERA (Garthwaite et al., 2011). The sample size used is large enough to be statistically robust, and of the surveyed area, wheat comprised 47% of the area of all arable crops grown in 2010, oilseed rape 15%, spring barley 13%, winter barley 9%, oats, sugar beet 3% and triticale and linseed less than 1% each. The level of uncertainty arising from this survey process is considered acceptable by the Office for National Statistics and international pesticide surveying standards.

7.1.4 Machinery fuel use

The estimates of actual fuel use were based on a combination of reported data of machinery purchased, working rates and fuel consumption, combined with expert judgement on the way in which machines are used on farms. Hence the uncertainty underlying these estimates cannot be quantified.

7.1.5 Direct soil N_2O emissions

There is considerable uncertainty over estimates of N_2O emissions from soil. This study concluded that the IPCC Tier 1 methodology to calculate direct soil N_2O emissions provides the most robust estimates of GHG emissions from UK soils. The uncertainty range of the IPCC Tier 1 EF for N_2O emissions of 1.0% is considered to be between 0.3 and 3.0% (Table 11.1, IPCC, 2006). No estimate of standard deviation (SD) or SE is provided by IPCC.

The average 95% confidence interval (CI) for N_2O emissions calculated by Stehfest and Bouwman (2006) was cited as -51% to +107%. This interval cannot be converted to a SE as their model is based on estimating the log N_2O emission so is not symmetric about the mean N_2O emission. However, they state that this CI is comparable to that used as an uncertainty range by IPCC. Stehfest and Bouwman (2006) cited a global mean EF of 0.9% of N applied emitted as N_2O-N, which is similar to the IPCC Tier 1 default EF of 1.0%.

As a general guide, in other similar system models the uncertainty (quantified as the SD or SE/mean) for N_2O emissions is in the region of 50%, or more. All the results presented should, therefore, be read with the qualification that calculated statistical significance is not implied in any statement.

7.2 Results expressed as total grams CO_2-eqv/MJ biofuel

Results in the tables below are expressed as g CO_2-eqv/MJ of biofuel. Results expressed per g CO_2-eqv/MJ of feedstock are presented in the Appendix to enable comparison with the results submitted previously. Figures in tables 7.2.1 - 7.2.7 are presented to two decimal places to aid suppliers wishing to include these values in their GHG calculations, although the disaggregate defaults for cultivation in RED Annex V are expressed as whole numbers.

7.2.1 Winter wheat

The results for winter wheat are given in Table 7.1. Overall these results indicate that the RED defaults or disaggregated defaults for cultivation can be used for winter feed wheat grown as a biofuels feedstock in most UK regions. The estimates exceed the disaggregated default for cultivation only in the NW and SW regions of England, and both regions of Wales.

Table 7.1 GHG emissions arising from the cultivation of winter wheat in the UK regions (gCO_2-eqv./MJ biofuel).

	Soil N_2O emissions		Crop Residues	Manufacturing emissions		Machinery fuel use	Seed	Total
Region	Direct	Indirect		Fertilizer	Pesticide			
N East								
UKC1	7.75	2.62	2.05	4.92	0.61	3.16	0.25	**21.35**
UKC2	7.75	2.62	2.05	4.92	0.61	3.16	0.25	**21.35**
N West								
UKD1	10.78	3.65	2.05	6.85	0.85	5.36	0.34	29.89
UKD2	10.78	3.65	2.05	6.85	0.85	5.36	0.34	29.89
UKD3	10.78	3.65	2.05	6.85	0.85	5.36	0.34	29.89
UKD4	10.78	3.65	2.05	6.85	0.85	5.36	0.34	29.89
UKD5	10.78	3.65	2.05	6.85	0.85	5.36	0.34	29.89
Yorks								
UKE1	7.64	2.59	2.05	4.85	0.60	3.14	0.22	**21.09**
UKE2	7.64	2.59	2.05	4.85	0.60	3.14	0.22	**21.09**
UKE3	7.64	2.59	2.05	4.85	0.60	3.14	0.22	**21.09**
UKE4	7.64	2.59	2.05	4.85	0.60	3.14	0.22	**21.09**
E Mids								
UKF1	7.53	2.55	2.05	4.79	0.59	2.74	0.22	**20.47**
UKF2	7.53	2.55	2.05	4.79	0.59	2.74	0.22	**20.47**
UKF3	7.53	2.55	2.05	4.79	0.59	2.74	0.22	**20.47**
W Mids								
UKG1	8.33	2.82	2.05	5.29	0.65	3.87	0.24	**23.26**
UKG2	8.33	2.82	2.05	5.29	0.65	3.87	0.24	**23.26**
UKG3	8.33	2.82	2.05	5.29	0.65	3.87	0.24	**23.26**
Eastern								
UKH1	7.64	2.59	2.05	4.85	0.60	2.74	0.22	**20.69**
UKH2	7.64	2.59	2.05	4.85	0.60	2.74	0.22	**20.69**
UKH3	7.64	2.59	2.05	4.85	0.60	2.74	0.22	**20.69**
S East								
UKJ1	7.97	2.70	2.05	5.06	0.63	3.27	0.23	**21.90**
UKJ2	7.97	2.70	2.05	5.06	0.63	3.27	0.23	**21.90**
UKJ3	7.97	2.70	2.05	5.06	0.63	3.27	0.23	**21.90**
UKJ4	7.97	2.70	2.05	5.06	0.63	3.27	0.23	**21.90**
S West								
UKK1	8.46	2.86	2.05	5.38	0.66	4.33	0.26	24.00
UKK2	8.46	2.86	2.05	5.38	0.66	4.33	0.26	24.00
UKK3	8.46	2.86	2.05	5.38	0.66	4.33	0.26	24.00
UKK4	8.46	2.86	2.05	5.38	0.66	4.33	0.26	24.00
Wales								
UKL1	9.02	3.05	2.05	5.73	0.71	4.58	0.29	25.42
UKL2	9.02	3.05	2.05	5.73	0.71	4.58	0.29	25.42
Scotland								
UKM2	7.33	2.48	2.05	4.66	0.58	3.10	0.23	**20.43**
UKM3	7.33	2.48	2.05	4.66	0.58	3.10	0.23	**20.43**
UKM5	7.33	2.48	2.05	4.66	0.58	3.10	0.23	**20.43**
UKM6	7.33	2.48	2.05	4.66	0.58	3.10	0.23	**20.43**
N Ireland								
N Ireland	8.21	2.78	2.05	5.21	0.64	3.40	0.26	**22.55**
RED disaggregated default for cultivation								**23**

7.2.2 Winter barley

The GHG emissions from cultivation of winter barley show a similar distributional pattern to those for winter wheat.

Table 7.2 GHG emissions arising from the cultivation of winter barley in the UK regions [g CO_2-eqv./MJ biofuel]

	Soil N_2O emissions		Crop Residues	Manufacturing emissions		Machinery fuel use	Seed	Total
Region	Direct	Indirect		Fertilizer	Pesticide			
N East								
UKC1	7.04	2.38	1.93	4.92	0.60	4.12	NA	21.00
UKC2	7.04	2.38	1.93	4.92	0.60	4.12	NA	21.00
N West								
UKD1	8.24	2.79	1.93	5.76	0.70	5.52	NA	24.94
UKD2	8.24	2.79	1.93	5.76	0.70	5.52	NA	24.94
UKD3	8.24	2.79	1.93	5.76	0.70	5.52	NA	24.94
UKD4	8.24	2.79	1.93	5.76	0.70	5.52	NA	24.94
UKD5	8.24	2.79	1.93	5.76	0.70	5.52	NA	24.94
Yorks								
UKE1	6.79	2.30	1.93	4.75	0.58	3.99	NA	20.34
UKE2	6.79	2.30	1.93	4.75	0.58	3.99	NA	20.34
UKE3	6.79	2.30	1.93	4.75	0.58	3.99	NA	20.34
UKE4	6.79	2.30	1.93	4.75	0.58	3.99	NA	20.34
E Mids								
UKF1	7.17	2.43	1.93	5.02	0.61	3.89	NA	21.05
UKF2	7.17	2.43	1.93	5.02	0.61	3.89	NA	21.05
UKF3	7.17	2.43	1.93	5.02	0.61	3.89	NA	21.05
W Mids								
UKG1	7.45	2.52	1.93	5.21	0.63	5.06	NA	22.81
UKG2	7.45	2.52	1.93	5.21	0.63	5.06	NA	22.81
UKG3	7.45	2.52	1.93	5.21	0.63	5.06	NA	22.81
Eastern								
UKH1	7.30	2.47	1.93	5.11	0.62	3.86	NA	21.31
UKH2	7.30	2.47	1.93	5.11	0.62	3.86	NA	21.31
UKH3	7.30	2.47	1.93	5.11	0.62	3.86	NA	21.31
S East								
UKJ1	7.17	2.43	1.93	5.02	0.61	4.18	NA	21.33
UKJ2	7.17	2.43	1.93	5.02	0.61	4.18	NA	21.33
UKJ3	7.17	2.43	1.93	5.02	0.61	4.18	NA	21.33
UKJ4	7.17	2.43	1.93	5.02	0.61	4.18	NA	21.33
S West								
UKK1	7.45	2.52	1.93	5.21	0.63	5.41	NA	23.16
UKK2	7.45	2.52	1.93	5.21	0.63	5.41	NA	23.16
UKK3	7.45	2.52	1.93	5.21	0.63	5.41	NA	23.16
UKK4	7.45	2.52	1.93	5.21	0.63	5.41	NA	23.16
Wales								
UKL1	7.74	2.62	1.93	5.42	0.66	5.77	NA	24.14
UKL2	7.74	2.62	1.93	5.42	0.66	5.77	NA	24.14
Scotland								
UKM2	6.24	2.11	1.93	4.37	0.53	3.60	NA	18.79
UKM3	6.24	2.11	1.93	4.37	0.53	3.60	NA	18.79
UKM5	6.24	2.11	1.93	4.37	0.53	3.60	NA	18.79
UKM6	6.24	2.11	1.93	4.37	0.53	3.60	NA	18.79
N Ireland								
N Ireland	6.68	2.26	1.93	4.67	0.57	3.79	NA	19.90

7.2.3 Spring barley

The GHG emissions data for cultivation of spring barley also present a similar pattern to the data for winter wheat (Table 7.3).

Table 7.3 GHG emissions arising from the cultivation of spring barley in the UK regions [g CO_2-eqv./MJ biofuel]

	Soil N_2O emissions		Crop Residues	Manufacturing emissions		Machinery fuel use	Seed	Total
Region	Direct	Indirect		Fertilizer	Pesticide			
N East								
UKC1	7.41	2.18	1.84	6.72	0.38	5.53	NA	24.06
UKC2	7.41	2.18	1.84	6.72	0.38	5.53	NA	24.06
N West								
UKD1	8.21	2.42	1.84	7.45	0.42	6.71	NA	27.05
UKD2	8.21	2.42	1.84	7.45	0.42	6.71	NA	27.05
UKD3	8.21	2.42	1.84	7.45	0.42	6.71	NA	27.05
UKD4	8.21	2.42	1.84	7.45	0.42	6.71	NA	27.05
UKD5	8.21	2.42	1.84	7.45	0.42	6.71	NA	27.05
Yorks								
UKE1	6.75	1.99	1.84	6.12	0.35	5.04	NA	22.09
UKE2	6.75	1.99	1.84	6.12	0.35	5.04	NA	22.09
UKE3	6.75	1.99	1.84	6.12	0.35	5.04	NA	22.09
UKE4	6.75	1.99	1.84	6.12	0.35	5.04	NA	22.09
E Mids								
UKF1	6.60	1.94	1.84	5.99	0.34	4.58	NA	21.30
UKF2	6.60	1.94	1.84	5.99	0.34	4.58	NA	21.30
UKF3	6.60	1.94	1.84	5.99	0.34	4.58	NA	21.30
W Mids								
UKG1	7.07	2.08	1.84	6.41	0.36	5.95	NA	23.71
UKG2	7.07	2.08	1.84	6.41	0.36	5.95	NA	23.71
UKG3	7.07	2.08	1.84	6.41	0.36	5.95	NA	23.71
Eastern								
UKH1	6.60	1.94	1.84	5.99	0.34	4.39	NA	21.11
UKH2	6.60	1.94	1.84	5.99	0.34	4.39	NA	21.11
UKH3	6.60	1.94	1.84	5.99	0.34	4.39	NA	21.11
S East								
UKJ1	6.46	1.90	1.84	5.86	0.33	4.98	NA	21.38
UKJ2	6.46	1.90	1.84	5.86	0.33	4.98	NA	21.38
UKJ3	6.46	1.90	1.84	5.86	0.33	4.98	NA	21.38
UKJ4	6.46	1.90	1.84	5.86	0.33	4.98	NA	21.38
S West								
UKK1	6.90	2.03	1.84	6.26	0.35	6.31	NA	23.71
UKK2	6.90	2.03	1.84	6.26	0.35	6.31	NA	23.71
UKK3	6.90	2.03	1.84	6.26	0.35	6.31	NA	23.71
UKK4	6.90	2.03	1.84	6.26	0.35	6.31	NA	23.71
Wales								
UKL1	7.23	2.13	1.84	6.56	0.37	6.67	NA	24.81
UKL2	7.23	2.13	1.84	6.56	0.37	6.67	NA	24.81
Scotland								
UKM2	6.46	1.90	1.84	5.86	0.33	4.67	NA	21.08
UKM3	6.46	1.90	1.84	5.86	0.33	4.67	NA	21.08
UKM5	6.46	1.90	1.84	5.86	0.33	4.67	NA	21.08
UKM6	6.46	1.90	1.84	5.86	0.33	4.67	NA	21.08
N Ireland								
N Ireland	7.41	2.18	1.84	6.72	0.38	5.32	NA	23.85

7.2.4 Oats

Emissions from the cultivation of oats were generally less than those of other cereals in all UK regions (Table 7.4).

Table 7.4 GHG emissions arising from the cultivation of oats in the UK regions [g CO_2-eqv./MJ biofuel]

	Soil N_2O emissions		Crop Residues	Manufacturing emissions		Machinery fuel use	Seed	Total
Region	Direct	Indirect		Fertilizer	Pesticide			
N East								
UKC1	6.41	2.17	2.59	4.25	0.32	4.69	NA	20.43
UKC2	6.41	2.17	2.59	4.25	0.32	4.69	NA	20.43
N West								
UKD1	7.82	2.65	2.59	5.18	0.39	6.36	NA	24.99
UKD2	7.82	2.65	2.59	5.18	0.39	6.36	NA	24.99
UKD3	7.82	2.65	2.59	5.18	0.39	6.36	NA	24.99
UKD4	7.82	2.65	2.59	5.18	0.39	6.36	NA	24.99
UKD5	7.82	2.65	2.59	5.18	0.39	6.36	NA	24.99
Yorks								
UKE1	6.82	2.31	2.59	4.52	0.34	4.61	NA	21.19
UKE2	6.82	2.31	2.59	4.52	0.34	4.61	NA	21.19
UKE3	6.82	2.31	2.59	4.52	0.34	4.61	NA	21.19
UKE4	6.82	2.31	2.59	4.52	0.34	4.61	NA	21.19
E Mids								
UKF1	6.54	2.22	2.59	4.34	0.32	4.26	NA	20.27
UKF2	6.54	2.22	2.59	4.34	0.32	4.26	NA	20.27
UKF3	6.54	2.22	2.59	4.34	0.32	4.26	NA	20.27
W Mids								
UKG1	6.68	2.26	2.59	4.43	0.33	5.39	NA	21.68
UKG2	6.68	2.26	2.59	4.43	0.33	5.39	NA	21.68
UKG3	6.68	2.26	2.59	4.43	0.33	5.39	NA	21.68
Eastern								
UKH1	6.41	2.17	2.59	4.25	0.32	3.97	NA	19.71
UKH2	6.41	2.17	2.59	4.25	0.32	3.97	NA	19.71
UKH3	6.41	2.17	2.59	4.25	0.32	3.97	NA	19.71
S East								
UKJ1	6.29	2.13	2.59	4.17	0.31	4.87	NA	20.35
UKJ2	6.29	2.13	2.59	4.17	0.31	4.87	NA	20.35
UKJ3	6.29	2.13	2.59	4.17	0.31	4.87	NA	20.35
UKJ4	6.29	2.13	2.59	4.17	0.31	4.87	NA	20.35
S West								
UKK1	7.12	2.41	2.59	4.72	0.35	6.71	NA	23.92
UKK2	7.12	2.41	2.59	4.72	0.35	6.71	NA	23.92
UKK3	7.12	2.41	2.59	4.72	0.35	6.71	NA	23.92
UKK4	7.12	2.41	2.59	4.72	0.35	6.71	NA	23.92
Wales								
UKL1	7.12	2.41	2.59	4.72	0.35	6.30	NA	23.50
UKL2	7.12	2.41	2.59	4.72	0.35	6.30	NA	23.50
Scotland								
UKM2	6.54	2.22	2.59	4.34	0.32	4.50	NA	20.51
UKM3	6.54	2.22	2.59	4.34	0.32	4.50	NA	20.51
UKM5	6.54	2.22	2.59	4.34	0.32	4.50	NA	20.51
UKM6	6.54	2.22	2.59	4.34	0.32	4.50	NA	20.51
N Ireland								
N Ireland	7.29	2.47	2.59	4.83	0.36	5.17	NA	22.71

7.2.5 Triticale

Emissions from the cultivation of triticale were generally less than those arising from the cultivation of wheat and barley, but greater than those from the cultivation of oats (Table 7.5).

Table 7.5 GHG emissions arising from the cultivation of triticale in the UK regions [g CO_2-eqv./MJ biofuel]

	Soil N_2O emissions		Crop Residues	Manufacturing emissions		Machinery fuel use	Seed	Total
Region	Direct	Indirect		Fertilizer	Pesticide			
N East								
UKC1	11.10	3.76	1.90	6.92	0.13	6.67	NA	30.48
UKC2	11.10	3.76	1.90	6.92	0.13	6.67	NA	30.48
N West								
UKD1	11.10	3.76	1.90	6.92	0.13	7.42	NA	31.23
UKD2	11.10	3.76	1.90	6.92	0.13	7.42	NA	31.23
UKD3	11.10	3.76	1.90	6.92	0.13	7.42	NA	31.23
UKD4	11.10	3.76	1.90	6.92	0.13	7.42	NA	31.23
UKD5	11.10	3.76	1.90	6.92	0.13	7.42	NA	31.23
Yorks								
UKE1	11.10	3.76	1.90	6.92	0.13	6.74	NA	30.55
UKE2	11.10	3.76	1.90	6.92	0.13	6.74	NA	30.55
UKE3	11.10	3.76	1.90	6.92	0.13	6.74	NA	30.55
UKE4	11.10	3.76	1.90	6.92	0.13	6.74	NA	30.55
E Mids								
UKF1	11.10	3.76	1.90	6.92	0.13	5.32	NA	29.13
UKF2	11.10	3.76	1.90	6.92	0.13	5.32	NA	29.13
UKF3	11.10	3.76	1.90	6.92	0.13	5.32	NA	29.13
W Mids								
UKG1	11.10	3.76	1.90	6.92	0.13	7.53	NA	31.34
UKG2	11.10	3.76	1.90	6.92	0.13	7.53	NA	31.34
UKG3	11.10	3.76	1.90	6.92	0.13	7.53	NA	31.34
Eastern								
UKH1	11.10	3.76	1.90	6.92	0.13	6.19	NA	30.00
UKH2	11.10	3.76	1.90	6.92	0.13	6.19	NA	30.00
UKH3	11.10	3.76	1.90	6.92	0.13	6.19	NA	30.00
S East								
UKJ1	11.10	3.76	1.90	6.92	0.13	7.00	NA	30.80
UKJ2	11.10	3.76	1.90	6.92	0.13	7.00	NA	30.80
UKJ3	11.10	3.76	1.90	6.92	0.13	7.00	NA	30.80
UKJ4	11.10	3.76	1.90	6.92	0.13	7.00	NA	30.80
S West								
UKK1	11.10	3.76	1.90	6.92	0.13	8.59	NA	32.40
UKK2	11.10	3.76	1.90	6.92	0.13	8.59	NA	32.40
UKK3	11.10	3.76	1.90	6.92	0.13	8.59	NA	32.40
UKK4	11.10	3.76	1.90	6.92	0.13	8.59	NA	32.40
Wales								
UKL1	11.10	3.76	1.90	6.92	0.13	8.25	NA	32.06
UKL2	11.10	3.76	1.90	6.92	0.13	8.25	NA	32.06
Scotland								
UKM2	11.10	3.76	1.90	6.92	0.13	6.60	NA	30.41
UKM3	11.10	3.76	1.90	6.92	0.13	6.60	NA	30.41
UKM5	11.10	3.76	1.90	6.92	0.13	6.60	NA	30.41
UKM6	11.10	3.76	1.90	6.92	0.13	6.60	NA	30.41
N Ireland								
N Ireland	11.10	3.76	1.90	6.92	0.13	5.84	NA	29.65

7.2.6 Oilseed rape

Estimated emissions from cultivation of OSR are only greater than RED disaggregated default value for cultivation in both regions of Wales, and Northern Ireland.

Table 7.6 GHG emissions arising from the cultivation of oilseed rape in the UK regions [g CO_2-eqv./MJ biofuel].

	Soil N_2O emissions		Crop Residues	Manufacturing emissions		Machinery fuel use	Seed	Total
Region	Direct	Indirect		Fertilizer	Pesticide			
N East								
UKC1	10.73	4.42	2.56	6.72	0.60	3.88	0.01	**28.93**
UKC2	10.73	4.42	2.56	6.72	0.60	3.88	0.01	**28.93**
N West								
UKD1	10.39	4.28	2.56	6.51	0.58	4.62	0.01	**28.96**
UKD2	10.39	4.28	2.56	6.51	0.58	4.62	0.01	**28.96**
UKD3	10.39	4.28	2.56	6.51	0.58	4.62	0.01	**28.96**
UKD4	10.39	4.28	2.56	6.51	0.58	4.62	0.01	**28.96**
UKD5	10.39	4.28	2.56	6.51	0.58	4.62	0.01	**28.96**
Yorks								
UKE1	10.39	4.28	2.56	6.51	0.58	3.88	0.01	**28.22**
UKE2	10.39	4.28	2.56	6.51	0.58	3.88	0.01	**28.22**
UKE3	10.39	4.28	2.56	6.51	0.58	3.88	0.01	**28.22**
UKE4	10.39	4.28	2.56	6.51	0.58	3.88	0.01	**28.22**
E Mids								
UKF1	10.73	4.42	2.56	6.72	0.60	3.51	0.01	**28.55**
UKF2	10.73	4.42	2.56	6.72	0.60	3.51	0.01	**28.55**
UKF3	10.73	4.42	2.56	6.72	0.60	3.51	0.01	**28.55**
W Mids								
UKG1	10.39	4.28	2.56	6.51	0.58	4.31	0.01	**28.65**
UKG2	10.39	4.28	2.56	6.51	0.58	4.31	0.01	**28.65**
UKG3	10.39	4.28	2.56	6.51	0.58	4.31	0.01	**28.65**
Eastern								
UKH1	10.73	4.42	2.56	6.72	0.60	3.31	0.01	**28.36**
UKH2	10.73	4.42	2.56	6.72	0.60	3.31	0.01	**28.36**
UKH3	10.73	4.42	2.56	6.72	0.60	3.31	0.01	**28.36**
S East								
UKJ1	10.73	4.42	2.56	6.72	0.60	3.75	0.01	**28.79**
UKJ2	10.73	4.42	2.56	6.72	0.60	3.75	0.01	**28.79**
UKJ3	10.73	4.42	2.56	6.72	0.60	3.75	0.01	**28.79**
UKJ4	10.73	4.42	2.56	6.72	0.60	3.75	0.01	**28.79**
S West								
UKK1	10.08	4.15	2.56	6.31	0.57	4.53	0.01	**28.21**
UKK2	10.08	4.15	2.56	6.31	0.57	4.53	0.01	**28.21**
UKK3	10.08	4.15	2.56	6.31	0.57	4.53	0.01	**28.21**
UKK4	10.08	4.15	2.56	6.31	0.57	4.53	0.01	**28.21**
Wales								
UKL1	10.73	4.42	2.56	6.72	0.60	4.87	0.01	29.92
UKL2	10.73	4.42	2.56	6.72	0.60	4.87	0.01	29.92
Scotland								
UKM2	10.39	4.28	2.56	6.51	0.58	4.14	0.01	**28.48**
UKM3	10.39	4.28	2.56	6.51	0.58	4.14	0.01	**28.48**
UKM5	10.39	4.28	2.56	6.51	0.58	4.14	0.01	**28.48**
UKM6	10.39	4.28	2.56	6.51	0.58	4.14	0.01	**28.48**
N Ireland								
N Ireland	10.73	4.42	2.56	6.72	0.60	5.45	0.01	30.49
RED default								**29**

7.2.7 Sugar beet

Estimated emissions from cultivation of sugar beet are less than the RED disaggregated default for cultivation for all UK regions The RED default can therefore be reported.

Table 7.7 GHG emissions arising from the cultivation of sugar beet in the UK regions [g CO_2-eqv./MJ biofuel]

	Soil N_2O emissions		Crop Residues	Manufacturing emissions		Machinery fuel use	Seed	Total
Region	Direct	Indirect		Fertilizer	Pesticide			
N East								
UKC1	NA	NA	NA	NA	NA	NA	NA	NA
UKC2	NA	NA	NA	NA	NA	NA	NA	NA
N West								
UKD1	NA	NA	NA	NA	NA	NA	NA	NA
UKD2	NA	NA	NA	NA	NA	NA	NA	NA
UKD3	NA	NA	NA	NA	NA	NA	NA	NA
UKD4	NA	NA	NA	NA	NA	NA	NA	NA
UKD5	NA	NA	NA	NA	NA	NA	NA	NA
Yorks								
UKE1	2.24	1.66	2.98	1.70	0.36	2.41	NA	**11.35**
UKE2	2.36	1.75	2.98	1.79	0.38	2.54	NA	**11.80**
UKE3	2.34	1.74	2.98	1.78	0.38	2.52	NA	**11.74**
UKE4	2.36	1.75	2.98	1.79	0.38	2.54	NA	**11.80**
E Mids								
UKF1	2.33	1.73	2.98	1.76	0.37	2.32	NA	**11.50**
UKF2	2.23	1.65	2.98	1.69	0.36	2.22	NA	**11.13**
UKF3	2.15	1.59	2.98	1.63	0.34	2.14	NA	**10.83**
W Mids								
UKG1	2.30	1.71	2.98	1.74	0.37	2.78	NA	**11.88**
UKG2	NA	NA	NA	NA	NA	NA	NA	NA
UKG3	NA	NA	NA	NA	NA	NA	NA	NA
Eastern								
UKH1	2.13	1.58	2.98	1.62	0.34	2.12	NA	**10.78**
UKH2	1.97	1.46	2.98	1.49	0.32	1.95	NA	**10.17**
UKH3	2.08	1.55	2.98	1.58	0.33	2.07	NA	**10.59**
S East								
UKJ1	NA	NA	NA	NA	NA	NA	NA	NA
UKJ2	NA	NA	NA	NA	NA	NA	NA	NA
UKJ3	NA	NA	NA	NA	NA	NA	NA	NA
UKJ4	NA	NA	NA	NA	NA	NA	NA	NA
S West								
UKK1	NA	NA	NA	NA	NA	NA	NA	NA
UKK2	NA	NA	NA	NA	NA	NA	NA	NA
UKK3	NA	NA	NA	NA	NA	NA	NA	NA
UKK4	NA	NA	NA	NA	NA	NA	NA	NA
Wales								
UKL1	NA	NA	NA	NA	NA	NA	NA	NA
UKL2	NA	NA	NA	NA	NA	NA	NA	NA
Scotland								
UKM2	NA	NA	NA	NA	NA	NA	NA	NA
UKM3	NA	NA	NA	NA	NA	NA	NA	NA
UKM5	NA	NA	NA	NA	NA	NA	NA	NA
UKM6	NA	NA	NA	NA	NA	NA	NA	NA
N Ireland								
N Ireland	NA	NA	NA	NA	NA	NA	NA	NA
RED default								**12**

8 Sensitivity analysis

The sensitivity analysis was carried out for the December 2010 version of this report. As the IPCC methodological approach for estimates of direct soil N_2O emissions has not been changed for this version, this section of the report remains unchanged.

Sensitivity analysis was carried out to assess the impacts of both the method to estimate direct soil N_2O emissions and the method of calculating emissions arising from the manufacture of N fertilizer on our estimates of the carbon intensity of cultivating arable crops for biofuels feedstocks.

The sensitivity analysis was carried out for all UK NUTS 2 regions, but to make this report concise results are only cited for some UK NUTS 2 regions considered typical for the crops concerned. These were East Anglia and Essex, two regions where husbandry and outputs are similar, but with some differences in soil types.

Results are reported of estimates of direct soil N_2O emissions and for emissions from fertilizer manufacture with and without N_2O abatement for the manufacture of AN using the following three approaches:

- IPCC Tier 1, (IPCC);
- Stehfest and Bouwman model output based on average soil properties for each region (SB1);
- Stehfest and Bouwman weighted mean of emissions from each soil type within each region (SB2).

8.1 Estimates of direct emissions of N_2O from soil

Table 8.1 below presents a comparison of the estimates of direct N_2O emissions from cultivation of winter wheat calculated by each of the three methods in the UK NUTS 2 regions East Anglia and Essex.

Table 8.1 Direct soil emissions arising from the cultivation of winter wheat calculated using IPCC Tier 1 and the Stehfest and Bouwman model by two approaches, g CO_2-eqv./MJ feedstock

NUTS 2 region	IPCC	SB1	SB2	Soil OC	pH	Texture
UKH1 (East Anglia)	6.58	11.57	7.63	3.05	7.2	medium
UKH3 (Essex)	6.58	6.47	7.30	2.77	7.0	medium

The IPCC approach gave the same estimate of direct N_2O emissions from cultivation of winter wheat for both regions, as would be expected since fertilizer-N inputs and average yield were the same for both regions. The estimates for the SB model differed between regions and also between the two different approaches. For East Anglia, estimates of emissions derived using the SB1 approach were greater than those obtained with either of the other two methods. The SB1 estimates were 75% greater than those obtained using the IPCC approach and 52% greater than those obtained using the SB2 approach. However, the SB1 model gave the smallest estimated emission for Essex, approximately 1.5% less than obtained using IPCC and 11% less than obtained using SB2.

The reason for this effect is that the amount of soil OC and soil acidity (pH) exert a large influence on N_2O emissions from soil in the Stehfest and Bouwman model. Emissions of N_2O increase with increasing soil OC and decrease with increasing pH. However, the Stehfest and Bouwman model introduces step changes in the effect of these properties on N_2O emissions, rather than treating the changes are continuous.

The effect of these step changes is that estimated emissions increase by a factor of around two as soil OC increases from less than 3.0% to greater than 3.0%. Thus, a 10% increase in soil OC between UKH3 and UKH1 results in an 80% increase in emissions.

The SB2 approach, based on a weighted mean for each major soil type within each region, smoothes the effect of these step changes. Hence, using the SB2 approach the estimates of emissions from the two regions are similar and, although slightly greater, approximate the values obtained with the IPCC methodology.

The implications of the SB model for the UK are considered further below.

Soil texture, principally determined by the clay content of soil, also influences emissions, which are least from soils of medium soil texture and greater from soils of coarse or fine soil texture.

8.2 Calculation of direct soil N_2O emissions from average soil properties for each NUTS 2 region

Average soil properties, for all UK NUTS 2 regions, with respect to soil OC, pH and soil texture are presented in Appendix table 6. Twenty three of the regions have mean OC values greater than 3.0%. This implies that if emissions are estimated using the Stehfest and Bouwman model there will be a much larger contribution to emissions from those regions than from those with less than 3.0% OC. The results for East Anglia and Essex (Table 9.1) illustrate this point. For an increase in average soil OC from 2.77 (Essex) to 3.05% (East Anglia) the Stehfest and Bouwman model calculates that soil N_2O emissions almost double. Since the average soil pH in all NUTS 2 regions in England and Wales is between 5.5 and 7.3 and the most common average texture (mode) within a NUTS 2 region was medium, the mean soil OC is usually the only soil property affecting estimates of direct soil emissions.

The distribution of OC content of agricultural soils in England and Wales is shown in Figure 8.1. It can be seen that 3% is about the median of the distribution.

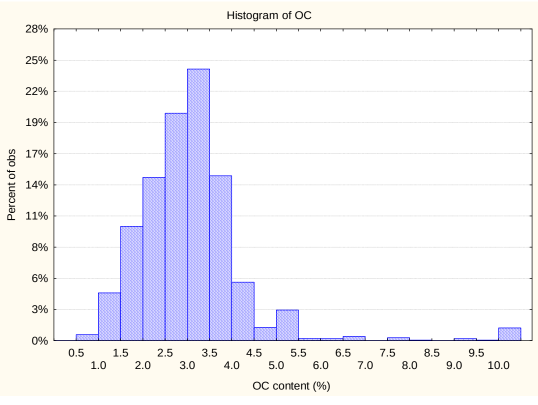

Figure 8.1 The distribution of OC in arable soils in England and Wales

The data used by Stehfest and Bouwman to build their model had a very different distribution (Figure 8.2) and the boundaries of their OC classes, of 1.0% and 3.0%, reflect the distribution of soil OC in the dataset on which their empirical model was based.

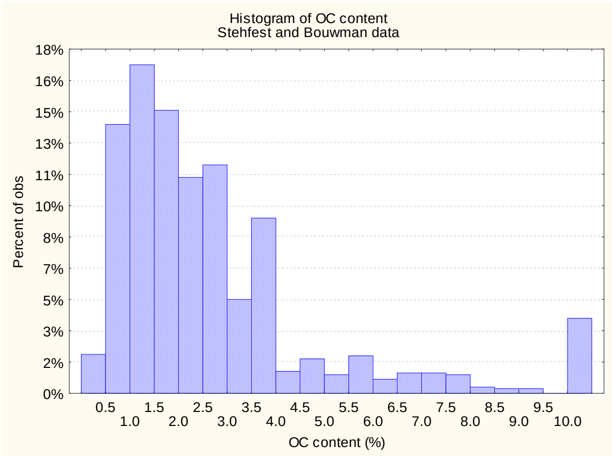

Figure 8.2 Soil OC data for the soils used by Stehfest and Bouwman to build their model

8.3 Calculation of direct soil N_2O emissions from weighted means of emissions from each soil type within each NUTS 2 region

The Stehfest and Bouwman (2006) model depends on three soil parameters: soil OC; pH; and texture. In estimating the emissions for all individual soil types within a region all three parameters will have an effect on the resulting mean emission. The regions that have been affected most by the recalculation are those with large numbers of coarse soils (in some cases nearly as many as medium soils) and also include some fine soils. In the model the medium soils have the least emissions (less than coarse and much less than fine).

We conclude from this sensitivity analysis that the use of the empirical model, developed from a global dataset, by Stehfest and Bouwman (2006), is not appropriate for calculating direct soil N_2O emissions from the UK as the relevant UK soil properties demonstrate a very different distribution to the soils used in the development of the Stehfest and Bouwman model.

8.4 Comparison with results estimated by JRC

Table 8.2 below presents a comparison of estimates of direct soil N_2O emissions estimated by JRC from the cultivation of feedstocks for biofuels cultivation in the UK. The JRC study estimated direct soil N_2O emissions using the Stehfest and Bouwman model.

Table 8.2 Estimates of fertilizer-N applied and calculated direct soil N2O emissions

Crop	N Applied		Emissions			
	JRC	UK (England)	JRC	UK IPCC	UK 1[1]	UK 2[2]
W. Wheat	183	181	9.33	6.88	10.43	7.63
W. Barley	116	131	8.75	6.55	9.60	7.86
Triticale	116	128	9.32	10.09	10.29	7.60
OSR	160	193	26.40	10.67	29.17	23.89
Sugar beet	100	95	1.56	1.63	4.60	4.12

The estimates calculated using the IPCC Tier 1 default were generally less than those reported by JRC. In some cases this would be due, at least in part, to JRC using greater estimates of fertilizer-N application than reported by BSFP.

Emissions from the manufacture of nitrogen fertilizer

Table 8.3 below reports the results from the 'typical' regions for each crop, in terms of the difference in emissions arising from fertilizer application with and without abatement of N_2O emissions during the manufacture of AN.

Table 8.3 Calculation of emissions arising from N fertilizer manufacture with and without abatement

Crop	Region	Emissions from fertilizer manufacture	
		Abated	Unabated
W. Wheat	UKH1, East Anglia	4.14	7.61
W. Barley	UKH1, East Anglia	4.17	7.27
Sp. Barley	UKK3, Devon	5.11	7.28
Oats	UKJ4, Kent	3.40	6.27
Triticale	UKF1, Notts and Derbyshire	6.07	11.17
OSR	UKH1, East Anglia	6.35	11.64
Sugar beet	UKH1, East Anglia	1.03	1.81

Using AN fertilizer manufactured without N_2O abatement typically increases the carbon intensity of cereal cultivation by 2-3 g CO_2-eqv/MJ of feedstock. For OSR the increase is much greater. This reflects the much smaller ratio of yield to fertilizer-N input recorded for OSR compared with cereals. In contrast emissions arising from the cultivation of sugar beet, which has the greatest ratio of DM yield to fertilizer-N input, are increased by < 1 g CO_2-eqv/MJ of feedstock if the AN is manufactured without N_2O abatement.

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Appendices

Appendix 1: Results of Data Collation and revised results reported per MJ of feedstock to enable comparison with the report submitted in March.

Appendix 2: Results of Sensitivity Analysis

Appendix 1

Results of data collation

Appendix table 1. Average Nitrogen fertilizer application rates (BSFP, 2007 - 2011), EFs from manufacture of the main types of N fertilizer (as kg CO_2-eqv. per kg of N) and calculated mean EF for each crop for GHG emissions from manufacture of applied N

N fertilizer	Winter wheat	Winter barley	Spring barley	Oilseed rape	Sugarbeet
AN, kg/ha	144.80	104.80	91.49	150.38	76.16
Urea, kg/ha	36.20	26.20	11.31	42.42	19.04
Total N, kg/ha	181.00	131.00	102.80	192.80	95.20
EF, kg CO_2-eqv./kg N, AN	2.90	2.90	2.90	2.90	2.90
EF, kg CO_2-eqv./kg N, Urea	1.71	1.71	1.71	1.71	1.71
EF, kg CO_2-eqv./kg N, Compound	5.38	5.38	5.38	5.38	5.38
Average EF, kg CO_2-eqv./kg N	2.80	2.96	3.84	2.77	2.95

Appendix table 2. Crop yields, t/ha DM. Values are the arithmetic mean of harvests over the 5-year period 2007 - 2011 – inclusive

Region	Winter wheat	Winter barley	Spring barley	Oats	Triticale	Oilseed rape	Sugarbeet*
	Yield	Yield	Yield	Yield	Yield	Yield	Yield
N East	7.10	5.50	4.10	5.00	3.50	3.10	NA
N West	5.10	4.70	3.70	4.10	3.50	3.20	NA
Yorks	7.20	5.70	4.50	4.70	3.50	3.20	15.33
E Mids	7.30	5.40	4.60	4.90	3.50	3.10	15.97
W Mids	6.60	5.20	4.30	4.80	3.50	3.20	15.50
Eastern	7.20	5.30	4.60	5.00	3.50	3.10	17.30
S East	6.90	5.40	4.70	5.10	3.50	3.10	NA
S West	6.50	5.20	4.40	4.50	3.50	3.30	NA
Wales	6.10	5.00	4.20	4.50	3.50	3.10	NA
Scotland	7.50	6.20	4.70	4.90	3.50	3.20	NA
N Ireland	6.70	5.80	4.10	4.40	3.50	3.10	NA

*British Sugar measure sugar yield per hectare, and not biomass/ha. The above DM yields per ha were calculated by converting to yields at a fixed sugar content.

Appendix table 3. UK average overall fertilizer applications, kg nutrient per ha, from BSFP 2007 - 2011. N is nitrogen, P_2O_5 is phosphate, K_2O is potash

	Winter wheat	Winter barley	Spring barley	Oats	Triticale	Oilseed rape	Sugar beet
N	181.0	131.0	102.8	104.8	127.6	192.8	95.2
P_2O_5	26.2	31.0	33.8	25.0	7.8	26.8	29.4
K_2O	32.4	47.4	45.8	36.4	19.4	30.8	84.2

Appendix table 4. UK average pesticide use, kg active ingredient per ha, for relevant crops

Region	Winter wheat	Winter barley	Spring barley	Oats	Triticale	Oilseed rape	Sugar beet
UK ave.	3.83	3.01	1.42	1.40	0.41	2.92	4.11

NA, not applicable

Appendix table 5. Machinery use: litres of diesel per hectare

Region	Winter wheat	Winter barley	Spring barley	Oats	Triticale	Oilseed rape	Sugar beet
N East	99	103		103	103	103	94
N West	121	118		113	114	114	115
Yorks	100	103		103	95	104	97
E Mids	88	95		96	92	82	85
W Mids	113	120		116	114	116	107
Eastern	87	93		92	87	95	80
S East	100	102		106	109	108	90
S West	124	128		126	133	133	116
Wales	124	131		127	124	127	118
Scotland	103	101		100	97	102	103
N Ireland	101	100		99	100	90	131
UK ave.	105	109		107	106	107	103

NA, not applicable

Appendix table 6. GHG emissions arising from the cultivation of winter wheat in the UK regions [g CO2-eqv./MJ feedstock]

Region	Soil N_2O emissions		Crop Residues	Manufacturing emissions		Machinery fuel use	Seed	Total
	Direct	Indirect		Fertilizer	Pesticide			
N East								
UKC1	6.98	2.36	1.84	4.43	0.55	2.85	0.22	19.23
UKC2	6.98	2.36	1.84	4.43	0.55	2.85	0.22	19.23
N West								
UKD1	9.71	3.29	1.84	6.17	0.76	4.83	0.31	26.91
UKD2	9.71	3.29	1.84	6.17	0.76	4.83	0.31	26.91
UKD3	9.71	3.29	1.84	6.17	0.76	4.83	0.31	26.91
UKD4	9.71	3.29	1.84	6.17	0.76	4.83	0.31	26.91
UKD5	9.71	3.29	1.84	6.17	0.76	4.83	0.31	26.91
Yorks								
UKE1	6.88	2.33	1.84	4.37	0.54	2.83	0.20	18.99
UKE2	6.88	2.33	1.84	4.37	0.54	2.83	0.20	18.99
UKE3	6.88	2.33	1.84	4.37	0.54	2.83	0.20	18.99
UKE4	6.88	2.33	1.84	4.37	0.54	2.83	0.20	18.99
E Mids								
UKF1	6.78	2.30	1.84	4.31	0.53	2.47	0.20	18.43
UKF2	6.78	2.30	1.84	4.31	0.53	2.47	0.20	18.43
UKF3	6.78	2.30	1.84	4.31	0.53	2.47	0.20	18.43
W Mids								
UKG1	7.50	2.54	1.84	4.77	0.59	3.48	0.22	20.95
UKG2	7.50	2.54	1.84	4.77	0.59	3.48	0.22	20.95
UKG3	7.50	2.54	1.84	4.77	0.59	3.48	0.22	20.95
Eastern								
UKH1	6.88	2.33	1.84	4.37	0.54	2.47	0.20	18.63
UKH2	6.88	2.33	1.84	4.37	0.54	2.47	0.20	18.63
UKH3	6.88	2.33	1.84	4.37	0.54	2.47	0.20	18.63
S East								
UKJ1	7.18	2.43	1.84	4.56	0.56	2.94	0.21	19.72
UKJ2	7.18	2.43	1.84	4.56	0.56	2.94	0.21	19.72
UKJ3	7.18	2.43	1.84	4.56	0.56	2.94	0.21	19.72
UKJ4	7.18	2.43	1.84	4.56	0.56	2.94	0.21	19.72
S West								
UKK1	7.62	2.58	1.84	4.84	0.60	3.90	0.23	21.61
UKK2	7.62	2.58	1.84	4.84	0.60	3.90	0.23	21.61
UKK3	7.62	2.58	1.84	4.84	0.60	3.90	0.23	21.61
UKK4	7.62	2.58	1.84	4.84	0.60	3.90	0.23	21.61
Wales								
UKL1	8.12	2.75	1.84	5.16	0.64	4.13	0.26	22.89
UKL2	8.12	2.75	1.84	5.16	0.64	4.13	0.26	22.89
Scotland								
UKM2	6.60	2.24	1.84	4.20	0.52	2.79	0.21	18.40
UKM3	6.60	2.24	1.84	4.20	0.52	2.79	0.21	18.40
UKM5	6.60	2.24	1.84	4.20	0.52	2.79	0.21	18.40
UKM6	6.60	2.24	1.84	4.20	0.52	2.79	0.21	18.40

N Ireland								
N Ireland	7.39	2.50	1.84	4.70	0.58	3.06	0.24	20.31
***UK typical**	6.88	2.33	1.84	4.37	0.54	2.47	0.20	18.63
% of total	37%	13%	10%	23%	3%	13%	1%	

Appendix table 7. GHG emissions arising from the cultivation of winter barley in the UK regions [g CO2-eqv./MJ feedstock]

	Soil N_2O emissions		Crop Residues	Manufacturing emissions		Machinery fuel use	Seed	Total
Region	Direct	Indirect		Fertilizer	Pesticide			
N East								
UKC1	6.31	2.14	1.73	4.41	0.54	3.69	NA	18.82
UKC2	6.31	2.14	1.73	4.41	0.54	3.69	NA	18.82
N West								
UKD1	7.38	2.50	1.73	5.16	0.63	4.95	NA	22.35
UKD2	7.38	2.50	1.73	5.16	0.63	4.95	NA	22.35
UKD3	7.38	2.50	1.73	5.16	0.63	4.95	NA	22.35
UKD4	7.38	2.50	1.73	5.16	0.63	4.95	NA	22.35
UKD5	7.38	2.50	1.73	5.16	0.63	4.95	NA	22.35
Yorks								
UKE1	6.09	2.06	1.73	4.26	0.52	3.57	NA	18.23
UKE2	6.09	2.06	1.73	4.26	0.52	3.57	NA	18.23
UKE3	6.09	2.06	1.73	4.26	0.52	3.57	NA	18.23
UKE4	6.09	2.06	1.73	4.26	0.52	3.57	NA	18.23
E Mids								
UKF1	6.42	2.18	1.73	4.49	0.55	3.49	NA	18.86
UKF2	6.42	2.18	1.73	4.49	0.55	3.49	NA	18.86
UKF3	6.42	2.18	1.73	4.49	0.55	3.49	NA	18.86
W Mids								
UKG1	6.67	2.26	1.73	4.67	0.57	4.54	NA	20.44
UKG2	6.67	2.26	1.73	4.67	0.57	4.54	NA	20.44
UKG3	6.67	2.26	1.73	4.67	0.57	4.54	NA	20.44
Eastern								
UKH1	6.55	2.22	1.73	4.58	0.56	3.46	NA	19.09
UKH2	6.55	2.22	1.73	4.58	0.56	3.46	NA	19.09
UKH3	6.55	2.22	1.73	4.58	0.56	3.46	NA	19.09
S East								
UKJ1	6.42	2.18	1.73	4.49	0.55	3.74	NA	19.12
UKJ2	6.42	2.18	1.73	4.49	0.55	3.74	NA	19.12
UKJ3	6.42	2.18	1.73	4.49	0.55	3.74	NA	19.12
UKJ4	6.42	2.18	1.73	4.49	0.55	3.74	NA	19.12
S West								
UKK1	6.67	2.26	1.73	4.67	0.57	4.85	NA	20.75
UKK2	6.67	2.26	1.73	4.67	0.57	4.85	NA	20.75
UKK3	6.67	2.26	1.73	4.67	0.57	4.85	NA	20.75
UKK4	6.67	2.26	1.73	4.67	0.57	4.85	NA	20.75
Wales								
UKL1	6.94	2.35	1.73	4.85	0.59	5.17	NA	21.64
UKL2	6.94	2.35	1.73	4.85	0.59	5.17	NA	21.64
Scotland								
UKM2	5.60	1.89	1.73	3.91	0.48	3.22	NA	16.84
UKM3	5.60	1.89	1.73	3.91	0.48	3.22	NA	16.84
UKM5	5.60	1.89	1.73	3.91	0.48	3.22	NA	16.84
UKM6	5.60	1.89	1.73	3.91	0.48	3.22	NA	16.84
N Ireland								

N Ireland	5.98	2.03	1.73	4.18	0.51	3.39	NA	17.83
***UK typical**	6.55	2.22	1.73	4.58	0.56	3.46	NA	19.09
% of total	34%	12%	9%	24%	3%	18%	NA	

Appendix table 8. GHG emissions arising from the cultivation of spring barley in the UK regions [g CO2-eqv./MJ feedstock]

	Soil N_2O emissions		Crop Residues	Manufacturing emissions		Machinery fuel use	Seed	Total
Region	Direct	Indirect		Fertilizer	Pesticide			
N East								
UKC1	6.64	1.95	1.65	6.02	0.34	4.95	NA	21.56
UKC2	6.64	1.95	1.65	6.02	0.34	4.95	NA	21.56
N West								
UKD1	7.36	2.16	1.65	6.67	0.38	6.01	NA	24.24
UKD2	7.36	2.16	1.65	6.67	0.38	6.01	NA	24.24
UKD3	7.36	2.16	1.65	6.67	0.38	6.01	NA	24.24
UKD4	7.36	2.16	1.65	6.67	0.38	6.01	NA	24.24
UKD5	7.36	2.16	1.65	6.67	0.38	6.01	NA	24.24
Yorks								
UKE1	6.05	1.78	1.65	5.49	0.31	4.52	NA	19.80
UKE2	6.05	1.78	1.65	5.49	0.31	4.52	NA	19.80
UKE3	6.05	1.78	1.65	5.49	0.31	4.52	NA	19.80
UKE4	6.05	1.78	1.65	5.49	0.31	4.52	NA	19.80
E Mids								
UKF1	5.92	1.74	1.65	5.37	0.30	4.10	NA	19.09
UKF2	5.92	1.74	1.65	5.37	0.30	4.10	NA	19.09
UKF3	5.92	1.74	1.65	5.37	0.30	4.10	NA	19.09
W Mids								
UKG1	6.33	1.86	1.65	5.74	0.32	5.33	NA	21.25
UKG2	6.33	1.86	1.65	5.74	0.32	5.33	NA	21.25
UKG3	6.33	1.86	1.65	5.74	0.32	5.33	NA	21.25
Eastern								
UKH1	5.92	1.74	1.65	5.37	0.30	3.93	NA	18.92
UKH2	5.92	1.74	1.65	5.37	0.30	3.93	NA	18.92
UKH3	5.92	1.74	1.65	5.37	0.30	3.93	NA	18.92
S East								
UKJ1	5.79	1.70	1.65	5.25	0.30	4.46	NA	19.16
UKJ2	5.79	1.70	1.65	5.25	0.30	4.46	NA	19.16
UKJ3	5.79	1.70	1.65	5.25	0.30	4.46	NA	19.16
UKJ4	5.79	1.70	1.65	5.25	0.30	4.46	NA	19.16
S West								
UKK1	6.19	1.82	1.65	5.61	0.32	5.66	NA	21.24
UKK2	6.19	1.82	1.65	5.61	0.32	5.66	NA	21.24
UKK3	6.19	1.82	1.65	5.61	0.32	5.66	NA	21.24
UKK4	6.19	1.82	1.65	5.61	0.32	5.66	NA	21.24
Wales								
UKL1	6.48	1.91	1.65	5.88	0.33	5.98	NA	22.23
UKL2	6.48	1.91	1.65	5.88	0.33	5.98	NA	22.23
Scotland								
UKM2	5.79	1.70	1.65	5.25	0.30	4.19	NA	18.89
UKM3	5.79	1.70	1.65	5.25	0.30	4.19	NA	18.89
UKM5	5.79	1.70	1.65	5.25	0.30	4.19	NA	18.89
UKM6	5.79	1.70	1.65	5.25	0.30	4.19	NA	18.89

N Ireland								
N Ireland	6.64	1.95	1.65	6.02	0.34	4.77	NA	21.38
***UK typical**	6.19	1.82	1.65	5.61	0.32	5.66	NA	21.24
% of total	29%	9%	8%	26%	1%	27%	NA	

Appendix table 9. GHG emissions arising from the cultivation of oats in the UK regions [g CO2-eqv./MJ feedstock]

	Soil N_2O emissions		Crop Residues	Manufacturing emissions		Machinery fuel use	Seed	Total
Region	Direct	Indirect		Fertilizer	Pesticide			
N East								
UKC1	5.77	1.96	2.34	3.83	0.29	4.22	NA	18.40
UKC2	5.77	1.96	2.34	3.83	0.29	4.22	NA	18.40
N West								
UKD1	7.04	2.38	2.34	4.67	0.35	5.73	NA	22.51
UKD2	7.04	2.38	2.34	4.67	0.35	5.73	NA	22.51
UKD3	7.04	2.38	2.34	4.67	0.35	5.73	NA	22.51
UKD4	7.04	2.38	2.34	4.67	0.35	5.73	NA	22.51
UKD5	7.04	2.38	2.34	4.67	0.35	5.73	NA	22.51
Yorks								
UKE1	6.14	2.08	2.34	4.07	0.30	4.15	NA	19.08
UKE2	6.14	2.08	2.34	4.07	0.30	4.15	NA	19.08
UKE3	6.14	2.08	2.34	4.07	0.30	4.15	NA	19.08
UKE4	6.14	2.08	2.34	4.07	0.30	4.15	NA	19.08
E Mids								
UKF1	5.89	1.99	2.34	3.90	0.29	3.83	NA	18.25
UKF2	5.89	1.99	2.34	3.90	0.29	3.83	NA	18.25
UKF3	5.89	1.99	2.34	3.90	0.29	3.83	NA	18.25
W Mids								
UKG1	6.02	2.04	2.34	3.99	0.30	4.85	NA	19.53
UKG2	6.02	2.04	2.34	3.99	0.30	4.85	NA	19.53
UKG3	6.02	2.04	2.34	3.99	0.30	4.85	NA	19.53
Eastern								
UKH1	5.77	1.96	2.34	3.83	0.29	3.57	NA	17.75
UKH2	5.77	1.96	2.34	3.83	0.29	3.57	NA	17.75
UKH3	5.77	1.96	2.34	3.83	0.29	3.57	NA	17.75
S East								
UKJ1	5.66	1.92	2.34	3.75	0.28	4.38	NA	18.33
UKJ2	5.66	1.92	2.34	3.75	0.28	4.38	NA	18.33
UKJ3	5.66	1.92	2.34	3.75	0.28	4.38	NA	18.33
UKJ4	5.66	1.92	2.34	3.75	0.28	4.38	NA	18.33
S West								
UKK1	6.42	2.17	2.34	4.25	0.32	6.05	NA	21.54
UKK2	6.42	2.17	2.34	4.25	0.32	6.05	NA	21.54
UKK3	6.42	2.17	2.34	4.25	0.32	6.05	NA	21.54
UKK4	6.42	2.17	2.34	4.25	0.32	6.05	NA	21.54
Wales								
UKL1	6.42	2.17	2.34	4.25	0.32	5.67	NA	21.16
UKL2	6.42	2.17	2.34	4.25	0.32	5.67	NA	21.16
Scotland								
UKM2	5.89	1.99	2.34	3.90	0.29	4.05	NA	18.47
UKM3	5.89	1.99	2.34	3.90	0.29	4.05	NA	18.47
UKM5	5.89	1.99	2.34	3.90	0.29	4.05	NA	18.47
UKM6	5.89	1.99	2.34	3.90	0.29	4.05	NA	18.47
N Ireland								

N Ireland	6.56	2.22	2.34	4.35	0.33	4.66	NA	20.45
***UK typical**	5.66	1.92	2.34	3.75	0.28	4.38	NA	18.33
% of total	31%	10%	13%	20%	2%	24%	NA	

Appendix table 10. GHG emissions arising from the cultivation of triticale in the UK regions [g CO_2-eqv./MJ feedstock]

	Soil N_2O emissions		Crop Residues	Manufacturing emissions		Machinery fuel use	Seed	Total
Region	Direct	Indirect		Fertilizer	Pesticide			
N East								
UKC1	10.09	3.42	1.73	6.29	0.12	6.06	NA	27.72
UKC2	10.09	3.42	1.73	6.29	0.12	6.06	NA	27.72
N West								
UKD1	10.09	3.42	1.73	6.29	0.12	6.74	NA	28.40
UKD2	10.09	3.42	1.73	6.29	0.12	6.74	NA	28.40
UKD3	10.09	3.42	1.73	6.29	0.12	6.74	NA	28.40
UKD4	10.09	3.42	1.73	6.29	0.12	6.74	NA	28.40
UKD5	10.09	3.42	1.73	6.29	0.12	6.74	NA	28.40
Yorks								
UKE1	10.09	3.42	1.73	6.29	0.12	6.13	NA	27.78
UKE2	10.09	3.42	1.73	6.29	0.12	6.13	NA	27.78
UKE3	10.09	3.42	1.73	6.29	0.12	6.13	NA	27.78
UKE4	10.09	3.42	1.73	6.29	0.12	6.13	NA	27.78
E Mids								
UKF1	10.09	3.42	1.73	6.29	0.12	4.84	NA	26.49
UKF2	10.09	3.42	1.73	6.29	0.12	4.84	NA	26.49
UKF3	10.09	3.42	1.73	6.29	0.12	4.84	NA	26.49
W Mids								
UKG1	10.09	3.42	1.73	6.29	0.12	6.85	NA	28.50
UKG2	10.09	3.42	1.73	6.29	0.12	6.85	NA	28.50
UKG3	10.09	3.42	1.73	6.29	0.12	6.85	NA	28.50
Eastern								
UKH1	10.09	3.42	1.73	6.29	0.12	5.63	NA	27.28
UKH2	10.09	3.42	1.73	6.29	0.12	5.63	NA	27.28
UKH3	10.09	3.42	1.73	6.29	0.12	5.63	NA	27.28
S East								
UKJ1	10.09	3.42	1.73	6.29	0.12	6.36	NA	28.01
UKJ2	10.09	3.42	1.73	6.29	0.12	6.36	NA	28.01
UKJ3	10.09	3.42	1.73	6.29	0.12	6.36	NA	28.01
UKJ4	10.09	3.42	1.73	6.29	0.12	6.36	NA	28.01
S West								
UKK1	10.09	3.42	1.73	6.29	0.12	7.81	NA	29.46
UKK2	10.09	3.42	1.73	6.29	0.12	7.81	NA	29.46
UKK3	10.09	3.42	1.73	6.29	0.12	7.81	NA	29.46
UKK4	10.09	3.42	1.73	6.29	0.12	7.81	NA	29.46
Wales								
UKL1	10.09	3.42	1.73	6.29	0.12	7.50	NA	29.15
UKL2	10.09	3.42	1.73	6.29	0.12	7.50	NA	29.15
Scotland								
UKM2	10.09	3.42	1.73	6.29	0.12	6.00	NA	27.65
UKM3	10.09	3.42	1.73	6.29	0.12	6.00	NA	27.65
UKM5	10.09	3.42	1.73	6.29	0.12	6.00	NA	27.65
UKM6	10.09	3.42	1.73	6.29	0.12	6.00	NA	27.65

N Ireland								
N Ireland	10.09	3.42	1.73	6.29	0.12	5.31	NA	26.96
***UK typical**	10.09	3.42	1.73	6.29	0.12	4.84	NA	26.49
% of total	38%	13%	7%	24%	0%	18%	NA	

Appendix table 11. GHG emissions arising from the cultivation of oilseed rape in the UK regions [g CO_2-eqv./MJ feedstock]

	Soil N_2O emissions		Crop Residues	Manufacturing emissions		Machinery fuel use	Seed	Total
Region	Direct	Indirect		Fertilizer	Pesticide			
N East								
UKC1	10.67	4.39	2.55	6.69	0.60	3.86	0.01	28.77
UKC2	10.67	4.39	2.55	6.69	0.60	3.86	0.01	28.77
N West								
UKD1	10.34	4.26	2.55	6.48	0.58	4.59	0.01	28.80
UKD2	10.34	4.26	2.55	6.48	0.58	4.59	0.01	28.80
UKD3	10.34	4.26	2.55	6.48	0.58	4.59	0.01	28.80
UKD4	10.34	4.26	2.55	6.48	0.58	4.59	0.01	28.80
UKD5	10.34	4.26	2.55	6.48	0.58	4.59	0.01	28.80
Yorks								
UKE1	10.34	4.26	2.55	6.48	0.58	3.86	0.01	28.07
UKE2	10.34	4.26	2.55	6.48	0.58	3.86	0.01	28.07
UKE3	10.34	4.26	2.55	6.48	0.58	3.86	0.01	28.07
UKE4	10.34	4.26	2.55	6.48	0.58	3.86	0.01	28.07
E Mids								
UKF1	10.67	4.39	2.55	6.69	0.60	3.49	0.01	28.40
UKF2	10.67	4.39	2.55	6.69	0.60	3.49	0.01	28.40
UKF3	10.67	4.39	2.55	6.69	0.60	3.49	0.01	28.40
W Mids								
UKG1	10.34	4.26	2.55	6.48	0.58	4.29	0.01	28.50
UKG2	10.34	4.26	2.55	6.48	0.58	4.29	0.01	28.50
UKG3	10.34	4.26	2.55	6.48	0.58	4.29	0.01	28.50
Eastern								
UKH1	10.67	4.39	2.55	6.69	0.60	3.29	0.01	28.21
UKH2	10.67	4.39	2.55	6.69	0.60	3.29	0.01	28.21
UKH3	10.67	4.39	2.55	6.69	0.60	3.29	0.01	28.21
S East								
UKJ1	10.67	4.39	2.55	6.69	0.60	3.73	0.01	28.64
UKJ2	10.67	4.39	2.55	6.69	0.60	3.73	0.01	28.64
UKJ3	10.67	4.39	2.55	6.69	0.60	3.73	0.01	28.64
UKJ4	10.67	4.39	2.55	6.69	0.60	3.73	0.01	28.64
S West								
UKK1	10.02	4.13	2.55	6.28	0.56	4.50	0.01	28.06
UKK2	10.02	4.13	2.55	6.28	0.56	4.50	0.01	28.06
UKK3	10.02	4.13	2.55	6.28	0.56	4.50	0.01	28.06
UKK4	10.02	4.13	2.55	6.28	0.56	4.50	0.01	28.06
Wales								
UKL1	10.67	4.39	2.55	6.69	0.60	4.85	0.01	29.76
UKL2	10.67	4.39	2.55	6.69	0.60	4.85	0.01	29.76
Scotland								
UKM2	10.34	4.26	2.55	6.48	0.58	4.11	0.01	28.33
UKM3	10.34	4.26	2.55	6.48	0.58	4.11	0.01	28.33
UKM5	10.34	4.26	2.55	6.48	0.58	4.11	0.01	28.33
UKM6	10.34	4.26	2.55	6.48	0.58	4.11	0.01	28.33

N Ireland								
N Ireland	10.67	4.39	2.55	6.69	0.60	5.42	0.01	30.33
UK typical**	10.67	4.39	2.55	6.69	0.60	3.49	0.01	28.40
% of total	38%	15%	9%	24%	2%	12%	0%	

Appendix table 12. GHG emissions arising from the cultivation of sugar beet in the UK regions [g CO_2-eqv./MJ feedstock]

Region	Soil N_2O emissions		Crop Residues	Manufacturing emissions		Machinery fuel use	Seed	Total
	Direct	Indirect		Fertilizer	Pesticide			
N East								
UKC1	NA	NA	NA	NA	NA	NA	NA	NA
UKC2	NA	NA	NA	NA	NA	NA	NA	NA
N West								
UKD1	NA	NA	NA	NA	NA	NA	NA	NA
UKD2	NA	NA	NA	NA	NA	NA	NA	NA
UKD3	NA	NA	NA	NA	NA	NA	NA	NA
UKD4	NA	NA	NA	NA	NA	NA	NA	NA
UKD5	NA	NA	NA	NA	NA	NA	NA	NA
Yorks								
UKE1	1.71	1.27	2.27	1.29	0.27	1.84	NA	8.66
UKE2	1.80	1.34	2.27	1.36	0.29	1.93	NA	8.99
UKE3	1.79	1.33	2.27	1.35	0.29	1.92	NA	8.95
UKE4	1.80	1.34	2.27	1.36	0.29	1.93	NA	8.99
E Mids								
UKF1	1.78	1.32	2.27	1.35	0.28	1.77	NA	8.77
UKF2	1.70	1.26	2.27	1.29	0.27	1.69	NA	8.48
UKF3	1.64	1.22	2.27	1.24	0.26	1.63	NA	8.26
W Mids								
UKG1	1.75	1.30	2.27	1.33	0.28	2.12	NA	9.05
UKG2	NA	NA	NA	NA	NA	NA	NA	NA
UKG3	NA	NA	NA	NA	NA	NA	NA	NA
Eastern								
UKH1	1.63	1.21	2.27	1.23	0.26	1.62	NA	8.22
UKH2	1.50	1.11	2.27	1.14	0.24	1.49	NA	7.76
UKH3	1.59	1.18	2.27	1.20	0.25	1.58	NA	8.08
S East								
UKJ1	NA	NA	NA	NA	NA	NA	NA	NA
UKJ2	NA	NA	NA	NA	NA	NA	NA	NA
UKJ3	NA	NA	NA	NA	NA	NA	NA	NA
UKJ4	NA	NA	NA	NA	NA	NA	NA	NA
S West								
UKK1	NA	NA	NA	NA	NA	NA	NA	NA
UKK2	NA	NA	NA	NA	NA	NA	NA	NA
UKK3	NA	NA	NA	NA	NA	NA	NA	NA
UKK4	NA	NA	NA	NA	NA	NA	NA	NA
Wales								
UKL1	NA	NA	NA	NA	NA	NA	NA	NA
UKL2	NA	NA	NA	NA	NA	NA	NA	NA
Scotland								
UKM2	NA	NA	NA	NA	NA	NA	NA	NA
UKM3	NA	NA	NA	NA	NA	NA	NA	NA
UKM5	NA	NA	NA	NA	NA	NA	NA	NA
UKM6	NA	NA	NA	NA	NA	NA	NA	NA

N Ireland								
N Ireland	NA	NA	NA	NA	NA	NA	NA	NA
***UK typical**	1.59	1.18	2.27	1.20	0.25	1.58	NA	8.08
% of total	20%	15%	28%	15%	3%	20%	NA	

Appendix 2

Results of sensitivity analysis

Appendix table 13. Average soil properties for UK NUTS 2 regions

Region	Soil OC		pH		Texture
	Mean	Standard deviation	Mean	Standard deviation	
N East					
UKC1	3.31	10.87	6.35	3.33	Medium
UKC2	3.42	20.85	6.29	4.43	Medium
N West					
UKD1	3.24	20.78	6.15	4.90	Medium
UKD2	2.85	8.85	6.34	3.29	Medium
UKD3	3.13	8.81	6.27	2.19	Medium
UKD4	3.51	17.84	6.25	3.73	Medium
UKD5	3.59	8.14	6.29	1.87	Medium
Yorks					
UKE1	2.96	14.63	7.08	5.48	Medium
UKE2	3.14	17.77	6.53	6.54	Medium
UKE3	3.07	7.99	6.56	4.24	Medium
UKE4	3.22	12.26	6.40	5.33	Medium
E Mids					
UKF1	2.89	9.92	6.49	4.06	Medium
UKF2	3.02	9.74	6.91	7.08	Medium
UKF3	3.15	21.30	7.11	6.79	Medium
W Mids					
UKG1	2.54	8.94	6.36	4.88	Medium
UKG2	2.69	9.73	6.24	4.13	Medium
UKG3	2.73	4.18	6.36	1.88	Medium
Eastern					
UKH1	3.05	36.71	7.16	8.46	Medium
UKH2	2.89	7.80	7.17	5.15	Medium
UKH3	2.77	8.73	7.03	6.54	Medium
S East					
UKJ1	3.10	11.14	6.96	6.76	Medium
UKJ2	2.70	11.35	6.54	6.78	Medium
UKJ3	2.93	9.58	6.96	6.07	Medium
UKJ4	2.92	9.72	6.83	6.12	Medium
S West					
UKK1	3.36	12.25	7.04	6.47	Medium
UKK2	3.28	13.22	6.72	6.51	Medium
UKK3	3.50	12.51	5.97	4.68	Medium
UKK4	3.30	11.62	6.14	4.89	Medium
Wales					
UKL1	3.74	19.64	5.99	4.87	Medium
UKL2	3.21	10.33	6.00	4.24	Medium

Regional emissions from biofuels cultivation

Summary of updates in December 2012 revision

Annex to the revised report of December 2012

Introduction

This annex explains in detail the updates made in this revision of the report 'Regional Emissions from Biofuels Cultivation.' This should be read in conjunction with the revised report in order to understand: a) what components have been updated, b) why they have been updated, c) how they have been updated, and d) where in the main report each component is discussed. Section 10 of this annex covers these points, while section 11 discusses the impact the updates have had on emission results for each crop.

10 Updates in this revision

Table 1 lists the updates implemented in this revision and briefly outlines why they have been made. A detailed explanation of how each of these updates has been implemented is presented in this section.

#	Update	Reason for update	Section in main report
10.1	5-year average yield updated based on 2007-2011 data	Updated to reflect the most up-to-date information available on UK crop yields	4.1
10.2	5-year average fertiliser and pesticide use updated based on 2007-2011 data	Updated to reflect the most up-to-date information on UK fertiliser and pesticide use and to align with the years considered for the yield data (2007-2011)	4.2
10.3	Oil content of oilseed rape updated to match 2007-2011 UK industry average	The average oil content of UK oilseed has been increasing annually as cultivation practices have been optimised, and the Biograce default value does not reflect the UK situation	4.1.5
10.4	Fuel consumption in cultivation and harvesting updated	Differing regional practices in ploughing and minimum tillage were not captured in the calculations in the original report	4.6
10.5	Emissions arising from the cultivation of high organic content soils removed	The definition of high organic content soils in the previous report was not aligned with the IPCC guidelines	5.2
10.6	Nitrogen content of crop residues updated	Updated to align with most recent literature and datasets	4.7
10.7	Transport losses for wheat and oilseed rape updated to align with UK industry data	The Biograce default value previously used was not considered a fair reflection of UK practices	3.1

Table 1: List of updates made in this revision

10.1 5-year average yield

Having been submitted in March 2010, the original report uses yield data averaged over the 5-year period from 2005-2009. Given the overall trend for yields to increase as agricultural practices are improved, it was considered appropriate in this revision to use the most up-to-date crop yield information in order to reflect this. Thus the 5-year average yield for the period 2007-2011 has now been used, based on the data sources described in section 4.1 of the report.

10.2 5-year average fertiliser and pesticide use

The previous report used fertiliser and pesticide application data from a single year (2008). Given the use of a multiple-year average for yields, and also given that fertiliser and pesticide use has increased with time, it was deemed necessary to align the assumptions regarding yields and fertilisers. Thus the 2007-2011 5-year averages are used for application of nitrogen, phosphorus, potassium and lime fertiliser, and for pesticides, based on the data sources described in section 4.2 of the report.

10.3 Oil content of oilseed rape

For several parameters used in the original calculations, an absence of UK-specific data led the consortium to use standard default values from Biograce (Biograce, 2012a). This includes the crop lower heating values (LHV) which are important parameters since they are used in calculations when converting emissions from $gCO_2e/kg_{feedstock}$ to $gCO_2e/MJ_{feedstock}$. The Biograce LHV for rapeseed is 26.4MJ/kg (at 0% moisture content) which corresponds to a 40.5% oil content of rapeseed (at 10% moisture content). However the oil content of UK oilseed rape is appreciably higher than this, and has increased annually as cultivation practices have been improved. Thus the average LHV of UK oilseed rape will be slightly higher than the Biograce default. Since it is the intention of the report to reflect the cultivation emissions specific to UK biofuel feedstocks, the LHV was adjusted based on UK industry data for rapeseed oil content. The UK average rapeseed oil content for 2007-2011 was used (43.9%, SCOPA, A Bowden 2012, *pers. comm*. 21st June) and the LHV adjusted accordingly (see Table 2). Other Member State reports have used lower heating values for the national averages where appropriate (e.g. Portugal, Slovenia).

	Oil content	Meal content	Meal moisture content	LHV meal (MJ/kg) (wet basis)	Rapeseed LHV at 10% m.c. (MJ/kg)	Rapeseed LHV at 0% m.c. (MJ/kg)
Biograce	40.5%	59.5%	16.81%	15.52	23.81	26.46
UK Specific	43.9%	56.1%	17.83%	15.33	24.40	27.11

Table 2: Adjustment of oilseed rape LHV. Meal LHV is 18.65MJ/kg (at 0% m.c.), Oil LHV is 36MJ/kg (at 0% m.c.).

10.4 Fuel consumption in cultivation and harvesting

It was recognised that minimum tillage practices will greatly reduce the machinery energy requirements. The original report assumed that minimum tillage practices applied only to cereal crops and that the practice is uniform across all NUTS2 regions. In this revision, data at NUTS2 level is used, indicating the proportion of each crop in each region for which minimum tillage is applied. This allows for a much more accurate understanding of how fuel consumption varies across the UK and for each crop. The calculation of fuel consumption is described in section 4.6 of the main report.

10.5 Emissions from high organic content soils

It was noted that the definition of high organic content soils in the previous report was not aligned with the IPCC guidelines. Soils should have an organic carbon content of 20% or more by weight before applying the RED default emission factor for cultivation. The threshold applied in the previous report was 12% organic carbon content, which in fact applies only to soils that are either less than 10cm in horizon depth, or subject to water saturation episodes (FAO, 1998). Analysis of the ADAS land use database indicates that none of the relevant crops are grown on such soils, and thus the organic soils component is now excluded from the emissions calculation. This is explained in section 5.2 of the main report.

10.6 Nitrogen content of crop residues

Emissions arising from crop residue returns were calculated in the original report based on a combination of several sources taken from the wider agricultural literature. UK-specific information on the parameters affecting the Nitrogen content of residues is scarce, but since the submission of the original report some relevant sources have come to light. The following sources have been used for each parameter in the crop residue emission calculations for winter wheat, winter barley, spring barley, oats, triticale and oilseed rape:

- Harvest Index: Stoddart & Watts (2012)
- Ratio of baled straw to total straw yield: Stoddart & Watts (2012)
- Nitrogen content of above ground residues: IPCC (2006) and Biograce (2012b)
- Ratio of below-ground residues to above-ground biomass: IPCC (2006) and Biograce (2012b)

Crop	Harvest Index	Ratio of baled straw to total straw yield	N content of above ground residues	Ratio of below-ground residues to above-ground biomass	%N in root biomass
Winter feed wheat	0.51	0.6	0.58%	0.23	1.00%
Winter barley	0.51	0.6	0.58%	0.22	1.00%
Spring barley	0.51	0.6	0.50%	0.22	1.00%
Oats	0.47	0.6	0.70%	0.25	1.00%
Triticale	0.51	0.6	0.50%	0.22	1.00%
Oilseed rape	0.35	0.5	1.02%	0.19	1.00%
Sugar beet	0.95	-	2.33%	-	-

Table 3: Nitrogen content of crop residues

It is believed that this provides a better picture of UK practices regarding crop residues. Detail of the crop residue calculation can be found in section 4.7 of the main report and in annex 1.

10.7 Transport losses

In the conversion of emissions from units of $gCO_2e/MJ_{feedstock}$ to $gCO_2e/MJ_{biofuel}$ losses of feedstock during the transport step should be taken into account since this affects the overall efficiency of the supply chain and thus the potential for GHG emission reductions. The original report used the Biograce transport loss default values which assume that 1% of the feedstock is lost between the farm grain silo and the processing plant. This estimate was considered to be rather conservative, and not representative of the efficient loading and transport methods common to UK supply chains. Thus in this revision UK industry representatives were consulted to establish values reflecting UK practices. Average transport losses of 0.12% (Richard Whitlock Associates, R Whitlock, *pers. comm*. 2nd November) and 0.25% (SCOPA, A Bowden 2012, *pers. comm*. 30th October.) were estimated for wheat and oilseed rape respectively.

11 Impact of Updates on Cultivation Emissions

The combined impact of the updates has changed the emission results for crops in several regions, some now higher than the previous report, others lower. For crops with RED disaggregated default values (winter wheat, oilseed rape, sugar beet) in some instances the status of regions that were formerly compliant or non-compliant have changed. Here the changes to the final results are discussed for each crop, highlighting which of the above updates have caused the change.

11.1 Winter Wheat

Emissions for winter wheat have increased in most regions compared to the original report, although they have decreased in some. The increase is due in part to higher crop residue emissions as the assumed Nitrogen content of below ground residues is higher than before. Also N fertiliser inputs are slightly higher than before so the direct N_2O emissions are also higher. In addition, the regional data on the proportion of minimum tillage is lower in some regions than previously assumed, and thus machinery inputs are higher.
Only one region has changed its compliance status; Northern Ireland is now a compliant region having formerly been above the RED default. This is due to the high proportion of winter wheat (92%) for which min-tillage practices are applied in Northern Ireland, as well as the removal of the organic soil factor.

11.2 Oilseed Rape

Emissions have reduced for oilseed rape in almost every region. Yields are higher than previously, the oil content is higher, crop residue emissions are lower (due to a higher harvest index), machinery inputs are lower (due to minimum tillage assumptions), and lime fertiliser inputs are lower. The removal of the organic soils factor also contributes to the reduction.
Originally only 3 regions were compliant but the combined impact of the updates means that now 32 of the 35 NUTS2 regions are compliant (with only Northern Ireland and the two Welsh regions remaining non-compliant).

11.3 Sugar Beet

Emissions have reduced for sugar beet in all regions. This is mainly due to the removal of the organic soils factor which was quite high for sugar beet. Also the updated assumptions regarding nitrogen content of crop residues reduces their emissions contribution. Lime fertiliser inputs are also lower than previously.

Originally none of the 11 regions in which sugar beet is grown achieved compliance. The combination of the updates means that now all 11 regions achieve emissions below the RED disaggregated default and are thus compliant.

11.4 Winter Barley

Emissions for winter barley have decreased in most regions. This is due to both the removal of the organic soil factor, as well as lower N fertiliser inputs for the majority of regions.

11.5 Spring Barley

For spring barley, emissions have risen in several regions and decreased in others. While crop residue emissions are lower (due to lower ratio of below ground to above ground biomass than used previously), fertiliser and pesticide inputs are higher. The inclusion of spatially-explicit minimum tillage data has different impacts on different regions, increasing machinery emissions in some, while lowering them in others.

11.6 Oats

Emissions for oats have increased in most regions compared to the original report. Nitrogen fertiliser application rates are higher and the updated min-tillage data results in higher diesel emissions for the majority of regions.

11.7 Triticale

Emissions for triticale have increased considerably. This is primarily due to the increase in average fertiliser use which has a significant impact on emissions.

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