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Development of a carbon footprint protocol for the UK cereals and oilseed sector.

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1. ABSTRACT

The initial aim of this project is to review existing guidance and methodologies to produce a draft protocol for calculating the carbon footprint of oilseed and cereal crops. The original objectives of the protocol were to encourage both farmer engagement and also help provide farm gate assessments for the supply chain. A second aim was to develop a carbon footprint assessment tool based on this protocol that computer literate growers would find easy to use. A third aim was to test the tool and protocol using real farm case studies to feedback and make any revisions to the protocol to improve accessibility.

Results

Most of the existing greenhouse gas (GHG) product assessment specifications are aimed at retailers and processors. The case studies showed that the initial protocol draft from the review process had some aspects that were of limited relevance or too complicated to enable a grower orientated tool to be developed. For example, obtaining typical inputs and yields from growers for multiple fields and over a number of years to counter the impact of seasonal variability made the approach too demanding. The protocol was revised during tool development, specifically to simplify these data demands.

Conclusions

- The current level of understanding of carbon footprint assessments amongst farmers is likely to be very low. Therefore, to engage farmers, it is important to focus on a simple tool to start with and seek to develop its complexity over time as the farming community's level of knowledge increases;
- A simple carbon footprint assessment protocol applied using a farmer-friendly carbon decision support tool (CDST) is possible. However, a protocol and calculator aimed at growers for competing with existing specifications for reporting retail orientated product carbon footprints would be difficult to implement;
- Even among the most progressive of the case study growers, without an initial element of face to face support the technical data demands of the carbon footprint process would have been difficult, even with the simplified tool;
- Any tool will need supporting with a training programme to help farmers understand how to measure their footprint, what the answer means and how they can seek to reduce their footprint;
- Uptake will be encouraged if areas for improvement can be identified where a focus on carbon efficiency can be aligned with financial performance improvements for the farmer.

2. SUMMARY

2.1. Introduction

2.1.1. Background

The HGCA commissioned this project to assist levy payers in understanding and estimating carbon footprints at the farm gate product level. The demand for this information and evidence for the uptake of measures to reduce farm-level greenhouse gas emissions is growing and will continue to do so. National and international standards do exist for product greenhouse gas assessment. However, these are broad-based specifications for calculating carbon footprints of products and services and are not specifically designed for agricultural products and a degree of flexibility is necessary to allow various methods and data to be used. Also, many carbon calculators and tools exist for farm level GHG reporting. This can result in quite different values being calculated whilst still claiming compliance with the same carbon assessment specifications.

2.1.2. Aims and objectives

The aim of the project was to develop a protocol for the carbon footprint of oilseed and cereal crops and a prototype carbon footprint assessment tool that translates the protocol requirements.

The prototype tool is aimed to be a user-friendly means to provide a robust and consistent carbon footprint assessment. Key scientific and commercial stakeholders in the UK cereals and oilseeds supply chain were consulted as part of the development process to gain industry understanding and acknowledgement of the protocol.

The specific objectives of the project:

1) To review existing protocols and methodologies and assess their suitability for developing a standard carbon footprint assessment protocol for UK cereals and oilseeds up to the farm gate.

2) Based on objective (1), to develop a best practice protocol with guidelines for the calculation of carbon footprints for cereal and oilseed products at the farm gate.

3) To engage with experts and key players in the UK Cereals and Oilseeds supply chain to gain feedback and endorsement of the protocol.

4) To develop a prototype tool to test and refine the standard protocol using appropriate case studies.

5) To develop an eight to twelve page growers' guide to carbon footprint assessment, including advice on mitigation methods and recommendations for best practice data management (e.g. data recording on-farm, minimum data requirements)

2.2. Materials and methods

2.2.1. Review of existing protocols and methodologies (objective 1)

Identifying and selecting existing protocols and methodologies for reviewing

The searching and selection methods used were not exhaustive – as are typical in systematic reviews of clinical or scientific evidence. There is no large body of published standards, protocols and formalised methodologies relating to greenhouse gas assessment of products, especially agricultural products, to warrant this kind of approach.

Pooled project team knowledge base

The team members already have good links to the relatively small research community concerned with GHG assessment of crops as well as awareness of the latest industry developments in research and applied consultancy in this developing field. Therefore the majority of literature and protocols reviewed were found or known of through the project team's experience in the field of carbon footprint assessment and agriculture.

Electronically published resources

In addition to the project team's extensive knowledge base, internet literature searches were conducted using key search terms in a variety of search engines to ensure other English language based protocols and methodologies relating to cereal and oilseed, or more general agricultural related greenhouse gas emissions, were included.

Selection Criteria

A basic set of selection criteria were drawn up to include the most relevant documents for review. In summary, these criteria are given to demonstrate the reasoning behind the kinds of documents that were considered, rather than to develop a detailed and strictly defined process.

Review process

A set of common requirements were defined for product carbon footprint assessments. These were based on the project team's experience and the review of methodological requirements and data needs for a typical product carbon footprint assessment framework with application to crops. Each of the selected protocols, specifications and studies were reviewed and their methodologies and approaches were reported under each of the common requirements.

2.2.2. Draft protocol development (objective 2)

Draft protocol

The review of existing protocols and methodologies informed the development of recommendations for each of the common requirements. These were summarised and discussed in a number of meetings with the project team during the protocol development process. From this process a set of recommendations were made for a draft protocol.

Expert panel review

The draft protocol was split into sections and presented to an expert panel in an electronic survey format for consultation. Experts were selected for their specialist research knowledge and/or involvement with the agricultural industry and Government regarding GHG emissions assessment. The selection was approved by HGCA.

2.2.3. Expert and industry feedback (objective 3)

Expert panel workshop

The results of the consultation were presented to the expert panel and key issues regarding the methodological elements of the protocol also presented and discussed in a workshop format. Key recommendations were noted and added to the development of the final draft of the protocol and tool development.

Industry stakeholder workshop

The tool was demonstrated at the Cereals 2012 event in Boothby Graffoe, Lincolnshire. During the presentation participants were encouraged to submit their own data to the tool in an open demonstration which revealed the key inputs, output, and sensitivities of the tool. The demonstration was accompanied with a presentation of the key issues and sources of emissions from cereal and oilseed crops, the material for which informed the growers guide.

2.2.4. Carbon footprint tool development and case study testing (objective 4)

The case studies for the trial of the tool were selected both via direct contact and intermediaries (e.g. Anglia Farmers) to represent a range of farms in terms of location, scale, ownership, type of farming system (organic and conventional), crop type (barley, wheat and oilseeds), soil type and production system (e.g. including plough based, heavy single pass samba type cultivator, minimum tillage). The farmers selected were also those who were known to be technically competent and progressive as it was felt that these would be more likely to engage in a research and development project, and be more likely to have the data needed to populate the tool.

2.2.5. Growers guide development (objective 5)

The growers guide was developed after the protocol and prototype tool was finalised and the farm case studies had been conducted. The format and structure were aligned with HGCA growers guide requirements whilst fulfilling the necessary project objectives to include mitigation methods and recommendations for best practice data management, such as minimum data requirements.

2.3. Results

2.3.1. Protocol review (objective 1)

None of the protocols and methodologies for estimating carbon footprints for cereal and oilseed crops found as part of this review were designed specifically to enable growers to use.
A very recent British Standards specification for greenhouse gas assessment of horticultural products (including open air field crops) contained requirements aimed more towards downstream assessors, such as buyers and retailers collecting data from growers (e.g. sample size protocols). These kinds of GHG assessment approaches appear to be aimed at larger organisations for regulatory (biomass energy) or voluntary (corporate) supply chain assessments where technical personnel and resources are likely to be available within the organisation to contact growers and support this process.

Allocation

Even within specifications particular to horticultural field crops, a number of methodologies could be employed for attributing growing emissions between crops and straw. The flexibility for interpreting specifications could be one reason for causing different reported emissions for crops that claim conformance to these standards. There are also contrasting views and inconsistencies in definitions and methods outlined by some of the regulatory and key guidance documents with regard to allocating a proportion of the crop emissions to straw.

Uncertainties

Reporting uncertainties is not mandatory in most of the product assessment specifications and few of the other research literature containing GHG assessments report crop specific uncertainty ranges.

Supply chain requirements and/or decision support?

Current specifications, such as PAS2050:2011, may not necessarily require grain processors, food manufacturers or retailers to require individual grower data (secondary proxy data is allowed) so protocols with a different purpose (grower decision support) may not necessarily be guided by these existing standards. The development of a suitable protocol will depend on what is driving the demand for growers to conduct assessments. This is fundamental to understanding the most appropriate approaches to be taken. Initially, the project specified that the protocol and tool would meet both consistent reporting for supply chain purposes and also be suitably farmer friendly to allow grower decision support. As the project evolved and after the expert panel workshop, the emphasis shifted more towards a simpler protocol to develop a fit-for-purpose truly farmer-friendly carbon calculator for UK cereals and oilseeds. The next section outlines how elements of the proposed protocol were refined in view of this shift of focus.

2.3.2. Protocol development (objective 2)

Elements that were formerly proposed to be excluded that are now included:

Element	Reason
Pesticides production and supply	Completeness - though pesticide production emissions are considered a relatively small contribution to cereal and oilseed crops carbon footprints, since very small quantities of the active substances are used, the indirect impact on yield was thought by some experts to warrant including. Others suggested that pesticides are only insignificant if fertiliser rate is high, and the range of application rates may not be known, so should be included in any tool. Consensus – experts suggested that excluding pesticides would be a departure from other arable foot printing approaches/tools.

Excluded elements that were formerly proposed to be included in the protocol:

Element	Reason
Slow release organic nitrogen (N) (and related nitrous oxide emissions) from intermittent manure or organic inputs that is unavailable within the year of application.	The proposal was to allocate the emissions from delayed N release to crops in a rotation in proportion to the area of these crops in the rotation at the time of application. This was considered to be too complicated for tool input data requirements to account for the different crops in the rotation and their respective area if manure was applied to any of them more than 1 year ago (e.g. the area over which organic inputs is applied is typically limited by the amount available, and thus changes annually). This makes it difficult, in general, to represent the application in rotation prior to the current year unless a complete set of data entry is provided for the whole rotation. It was felt that this effort would discourage the target user-groups at this point in time. Nitrous oxide field emissions attributed to the crop will be based on nitrogen immediately spread before or during crop growth that is readily available to the crop. Recalcitrant or slow release nitrogen is ignored because of the difficulties mentioned above regarding attribution to crops

	within the rotation, and the substantial uncertainties regarding the fate of recalcitrant N in the soil (i.e. whether it is released as N_2O or NO, volatilised, leached, or taken up by the plant). The incorporation of relatively modest effects with very high uncertainties is felt to be detrimental to the purpose of the tool.
Soil carbon sequestration	Although methods exist with which it is possible to quantify the effect of soil management practices on sequestered soil carbon, it should be noted that there are always issues surrounding the permanence of the carbon stock change, the system boundaries, and the implied reference cases. This makes the issues difficult to convey to farmers in a crop calculator and it was felt that the ability to educate users via this mechanism is limited compared to the burden of data entry for quantification.
Land use change emissions	Though the IPCC emission methodology was consistently included or mentioned in most of the key protocols reviewed and was proposed for the protocol it was excluded from the final protocol and tool. It was felt that land use change is not a common concern for UK cereal production since arable land use is typically well established. In general transitions between, say, arable and pasture are temporary and part of established farm management practices (e.g. use of ley crops). These would not be classed as land use changes. Transitions between woodland and arable cropping are better covered in a whole farm assessment since they require assurance of good calibration of the woodland component (adding to the data entry burden and beyond the scope of this project). In addition to these issues many crops are contract managed, thus the farmer may have limited availability of historic land use, tillage or production data within the 20 year period from which any land use change should be counted.
Data quality requirements	These were considered redundant for the tool - since these were only required for conformance reporting – the growers guide provides simple explanations of the secondary data used but not with respect to the quality metrics given in other protocols.
Uncertainty reporting	The prototype tool does not report uncertainty ranges in the final estimates. Informative and engaging reporting of uncertainty would need more resources and would best be included when developing the prototype into a

	mature tool. A qualitative description of uncertainty is given in the growers guide instead.

2.3.3. Expert and industry feedback (objective 3)

The results of the expert and industry feedback are too detailed to summarise within this 10 page summary section and reference to the main section of the report and the appendices is recommended. The expert panel meeting the HGCA and the project team re-evaluated the aims of the project - concluding that the most valuable output would be to provide a tool which offered a farmer decision-support focus, rather than carbon footprints for reporting to supply chains in line with existing standards and specifications.

2.3.4. Carbon footprint tool development and case study feedback (objective 4)

Selected farms

The selected case study farms covered the following counties: Lincolnshire, Humberside, Norfolk, Cambridgeshire, Northamptonshire, Oxfordshire and soil types including peat, clay, silt, loam and sandy brash. The farms ranged in size from 120 hectares (300 acres) to over 1600 hectares (4,000 acres) and included council tenants, owner occupiers and contract farmers. One of the farms was an organic contractor (although they also had some conventional production).

Dividing growing emissions between grain and straw

Most of the case study growers disagreed with the practice of allocating the emissions from crop growing between straw and grain. Basing any allocation on their relative economic value or avoiding allocation through removing emissions associated with other products which straw was considered to substitute was nonsensical for most growers. There were other reasons given by growers as to why straw may be ploughed in or exported off the farm. In the latter case it may not be associated with direct economic value to the grower. Straw may be traded for whatever quantity of manure is available at an adjacent farm but the reason for straw export may be for quick removal in order to prevent the risk that rain may hamper straw removal and delay sowing of following crops. Most case study growers preferred a straightforward approach of applying all the emissions from growing to the grain or oilseed portion of the crop. This would mean that straw at the farm gate is effectively a by-product which has a GHG neutral production.

Organic inputs

Neglecting the contributions of organic nitrogen inputs beyond the application year was considered to be inappropriate by some growers. This also impacts delayed release of nitrous oxide and how this should be shared amongst crops over time (in a rotation). Initial ideas on how this could be approached in a tool interface are presented in Figure 1. Delayed release of nutrients particularly complicates carbon footprints for crops from organic production systems in which the rotation is divided into fertility building (e.g. clover leys) and fertility exploiting (e.g. cereals) phases. For organic production, a single year approach to assessing inputs is inappropriate as it fails to take account of nutrient depletion in the production of cash crops, and an approach which is able to assess the whole rotation is needed.

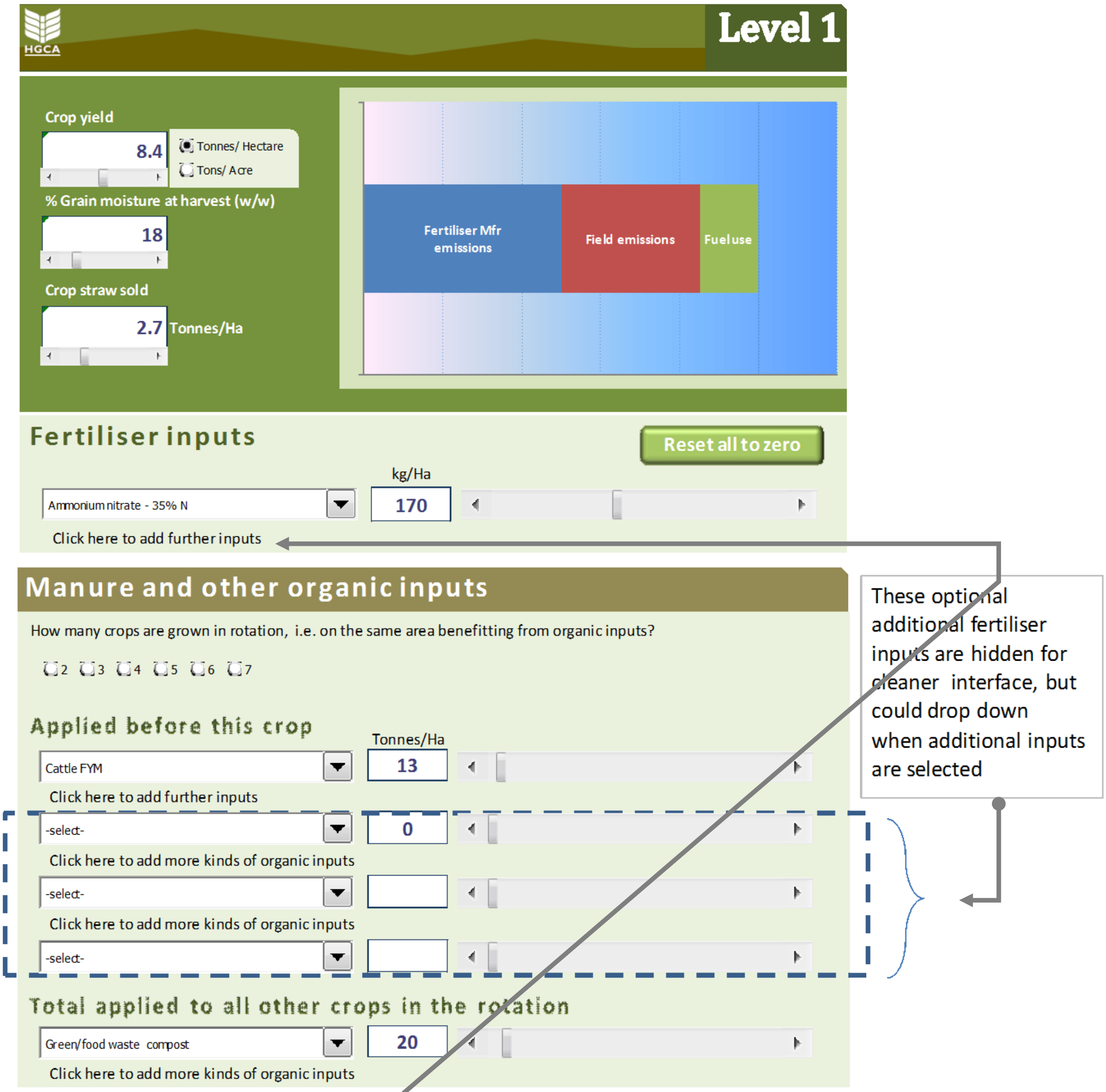


Figure 1. Ideas for user interface for allocating nitrous oxide emissions from the fraction of organic nitrogen sources that is not readily available. Under IPCC methods the same direct nitrous oxide emission factor is applied to 100% of mineral and organic nitrogen added to soils. However N in organic fertilisers that is not readily available to crops may be mineralised beyond the year of application (see main report for discussion on attributing delayed organic nitrogen emissions to crops**)** and could be shared between the crop rotation it benefits**.** This was difficult to achieve in the prototype Excel tool but could be achievable with a professional application for use online.

Due to these complications, and subsequent burden on the grower for data input, delayed nitrogen mineralisation and related GHG emissions were disregarded from the protocol and tool. Integrating these into an easy to use excel based pilot tool was challenging. However this may be possible in any further development of the tool where rotation is considered and a programming expertise can give greater flexibility to the data entry format.

2.3.5. Growers guide development (objective 5)

The purpose of the growers guide was to describe the key concepts and issues with regard to greenhouse gas emissions from cereal and oilseed crops for growers. It covers the general concepts, concise descriptions of the key issues of soil organic matter, organic farming and uncertainty. It also contains illustrative examples for typical conventionally grown winter wheat, winter oilseed, and malting barley crops and emphasises the concept of “carbon efficiency”.

2.4. Discussion/Conclusions and implications

2.4.1. A farmer-friendly product assessment protocol for the supply chain

Growers are under increasing pressure to provide carbon footprints for buyers or for supply chain assessments[1]. The protocol that was developed by this project adopted aspects from existing published standards, some of which are evolving sector specific requirements for horticultural crops. These may also attract the development of specific supplementary requirements for cereals and oilseeds in the near future. However, even the more specific set of requirements adhere to some of the more ambiguous and inconsistent aspects of the parent standard and as such are still open to flexible interpretation.

A ‘two tier’ approach

Delivering a carbon footprint protocol which has the objectives of being ‘farmer friendly’ whilst rivalling the more demanding requirements for published product greenhouse gas assessments was a difficult challenge. To resolve this problem a protocol was drafted that allowed either a simple or a more demanding approach. Subsequent expert panel workshop, tool development and testing with case studies emphasised the need for a simple approach for growers. The ‘two tier’ approach was abandoned in favour of developing a simpler ‘farmer-friendly’ protocol suitable for a prototype tool. A more detailed protocol would be a medium term goal after a simple tool has generated the required awareness and learning through the grower community. This would be dependent on a successful role out programme.

[1] The original project specification emphasised the supply chain as a key reason for the protocol stating: ‘*Buyers are also introducing carbon footprint assessment and labelling schemes which require associated farmers to undertake farm-level carbon audits. [HGCA] has received an increasing number of enquiries on carbon footprint assessment as pressure to supply this information grows. To provide levy payers with the best available advice and tools, HGCA wishes to commission a project to develop a standard protocol for farm gate, product-level carbon accounting specific to the UK Cereals and Oilseeds sector. It is likely that this work will be extended to the full supply chain at a later date.*

Compatibility with carbon footprint tools

It was clear from case study testing that a 'farmer-friendly' tool was not compatible with many of the existing formal requirements published for product GHG assessments due to the nature of the data demands but also the different objectives and assessment approach. The published standards are aimed more toward processors and retailers who have the resources to support more demanding data collection and collation and subsequent iterative refinement of estimates. Integrating a protocol through a prototype tool restricts incorporating aspects of existing standards, such as per cent threshold values for including or excluding emissions sources (which will change) or reporting and recording requirements.

Engagement and mitigation

The carbon footprint tool developed in this project was intended to engage with growers to raise their awareness of the contribution of different activities to their crop's carbon footprint. The rationale is that growers would be able to locate and target emission 'hotspots' and make decisions to manage these. An example would be using the tool to understand the GHG impact of changing fertilisers and application strategy.

The tool is developed in a farmer-friendly format. However the case studies showed the need for face to face support to encourage growers to engage with the process and understand where mitigation practices can be focussed.

2.4.2. Implications for cereals and oilseeds product carbon reporting

- A carbon footprint tool developed for successful grower engagement necessitates some kind of active initial support to explain the data required for the technical elements of product carbon footprint assessments. This helps growers interpret the answer produced beyond what can be provided in a grower's guide.

- The level of detail required for a farmer-friendly carbon footprint tool and the application of national emissions reporting methodology to a farm scale assessment limits the sensitivity to management practices to a few key factors that a grower can change. The key relationship farmers need to manage is the type and quantity of nitrogen input used against the resulting crop yield, with other aspects such as diesel use by machinery often of secondary importance.

- Development of a supply chain assessments protocol should be an explicitly separate and distinct process to the development of a (simpler) 'farmer-friendly' tool for grower awareness and engagement to help them identify how to reduce emissions.

- Concerns were raised by growers during case study testing that any minimum performance element e.g. the buyer who said the product they bought had to have a lower footprint than

X kg CO_2eq per tonne (even if unintended) could potentially unfairly discriminate against regions with less favourable soils and climate (and respective differences in inputs and associated yields).

- A key uncertainty in the mitigation argument for encouraging growers to complete carbon footprint assessments is which areas to encourage growers to focus on. Targeting nitrogen efficiency in the farming and food system to improve best practice for recycling nutrients (including composted food waste, AD digestate and biosolids), preventing losses and inhibiting N_2O through fertiliser technology makes good business and environmental sense. However, if carbon footprint assessment is to be used to drive this type of agenda, it is vital to ensure that it does actually do so and is not just an additional burden. The process should complement other crop planning advice and guidance whether driven by agronomic or financial imperatives.

Support process

The project team's experience from conducting the case studies indicates that a standalone tool may be less likely to encourage growers to engage with the process and understand where mitigation practices can be focussed without interactive and complementary support. Case studies showed that once growers were guided through the process and knew which records were required, a process taking over an hour for the first crop assessment took only a few minutes for the final crop assessment. The initial interaction and guidance with the project team member was considered essential to start the whole engagement process, although, this could be delivered to a small group rather than on a one to one basis. Indeed delivering this in small groups is probably preferable as it both reduces the resources needed per farm and leads to the development of friendly rivalry and debate on the best way in which to reduce carbon emissions.

2.4.3. Key conclusions and recommendations

1. A protocol developed for grower engagement should initially be separate to more demanding requirements of existing supply chain mediated reporting requirements[2], which are currently subject to :

    a) Ambiguity caused by an immature consensus of understanding for applying appropriate life cycle product assessment methods;

    b) Models for emissions that are not very sensitive to the impact of specific farm activities;

[2] Or at least if a single document is produced this should have two tiers to satisfy the detail required for these different purposes.

c) A farming community that needs time and support to adapt to this kind of process.

2. Since grower engagement is the main goal of the carbon footprint tool, it is strongly recommended that an active support process needs to be supported alongside the release of the tool to develop a group of committed farmer users. Defra's RDPE supported skills and knowledge framework provides an appropriate vehicle to deliver this, which could also provide much of the resource needed. If this could be coupled to industry sponsorship (by processors, grain customers etc.) for the remaining costs, it would be possible to provide the training at minimal cost to farmers, and have the advantage of attracting their participation through the active support of their customers in setting up the programme.

3. If the rationale for a farmer-friendly carbon footprint protocol is to help growers target emission reductions, more information needs to be developed on how to deliver carbon reductions and how the methods which can be used impact on farm profitability. The case studies clearly demonstrated that even the most progressive farmers did not have a detailed understanding of some notable inputs e.g. fuel use for field operations, but had a desire to learn more about these. Unless there is enough focus on how to reduce their footprint in the roll out programme, it could be argued that farmers are gaining little by way of influencing GHG mitigation which would not be achieved by promoting or adapting existing management processes (e.g. assurance, nutrient plans, improved technical efficiency etc.). Currently, simple farm GHG tools may not have the sensitivity to represent the true impact of management processes where results are functions of basic inputs such as N source, N use and crop yield for a single crop cycle. However, academics and industry are focussing on improving methods for quantified farm level GHG mitigation.

4. If supply chain assessment is also an important requirement, then buyers and downstream stakeholders who require this kind of information from growers should be involved in the roll out consortia to help support the more demanding 'tier 2' requirements. This would require more and longer term support to allow growers to become accustomed to supplying information that is consistent with existing supply chain orientated specifications.

5. A smarter approach for solving the burden of data demands for GHG assessment of crop growing is to integrate carbon foot printing tools seamlessly into farm management software. Investigating whether this is possible with farm management software that is likely to be used widely (now and in the future) by growers or via their agronomists for farm inventory record keeping, financial accounting or assurance schemes could overcome the data demand as the main obstacle to carbon footprinting.

3. TECHNICAL DETAIL

3.1. Introduction

Cereal and oilseed growers require assistance in developing carbon footprints for their produce because demand for this information and evidence for the uptake of measures to reduce farm-level greenhouse gas emissions is growing and will continue to do so.

The existing specification for calculating carbon footprints of products and services PAS2050:2011 is not specifically designed for agricultural products, and a degree of flexibility is necessary for allowing various methods and data to be used. This results in calculations being performed using different tools which claim compliance with the same carbon accounting specifications yielding different values for cereal and oilseed crops.

This project aims to develop a standard protocol, a prototype tool and growers guide that reports the carbon footprint and related uncertainties in a consistent and transparent way for the UK Cereals and Oilseeds sector.
The initial stated objectives of the project were:

1) To review existing protocols and methodologies and assess their suitability for developing a standard carbon footprint assessment protocol for UK cereals and oilseeds up to the farm gate.

2) Based on objective (1), to develop a best practice protocol with guidelines for the calculation of carbon footprints for cereal and oilseed products at the farm gate.

3) To provide recommendations for best practice data management (e.g. data recording on-farm, minimum data requirements, storage, ease of access and transparency).

4) To test and refine the standard protocol using appropriate case studies.

5) To engage with key players in the UK Cereals and Oilseeds supply chain to gain industry endorsement of the protocol.

6) To develop an eight to twelve page growers' guide to carbon footprint assessment, including advice on mitigation methods and best practice record keeping.

7) To develop a prototype tool and demonstrate its use during the project in case studies to test and refine methods and assumptions.

During the evolution of the project and to help map the objectives with the order and content of the work and this report, some of these objectives have been combined and re-ordered as follows:

1) To review existing protocols and methodologies and assess their suitability for developing a standard carbon footprint assessment protocol for UK cereals and oilseeds up to the farm gate.

2) Based on objective (1), to develop a best practice protocol with guidelines for the calculation of carbon footprints for cereal and oilseed products at the farm gate.

3) To engage with experts and key players in the UK Cereals and Oilseeds supply chain to gain feedback and endorsement of the protocol.

4) To develop a prototype tool to test and refine the standard protocol (as implemented within the tool) using appropriate case studies.

5) To develop an eight to twelve page growers' guide to carbon footprint assessment, including advice on mitigation methods and recommendations for best practice data management (e.g. data recording on-farm, minimum data requirements).

3.1.1. Overview of GHG standards, protocols, methodologies

Though there are standards applicable for greenhouse gas assessments of products, such as the EN ISO 14040 life cycle assessment series, they have only been in existence since 1997. These are frameworks with somewhat generic rules; necessary to allow considerable flexibility in how requirements are universally applied to different products and services. This also results in variations in interpretation, methodology and reported results.

Formal protocols for carbon footprint assessment or greenhouse gas assessment of agricultural practice are still in development across academic, government and business sectors. Although a concerted action by the EU was delivered on harmonising life cycle assessment methods for agricultural production more than 10 years ago (Audsley et al., 1997), the status of standard development, specifically for the GHG assessment of agricultural product groups, is relatively immature.

European biofuels policy has been a primary driver for the development and formalising greenhouse gas life cycle assessment of crops for regulatory reporting on the carbon performance of whole fuel chains. Voluntary standards or protocols for GHG assessment of agricultural activities and products are just starting to be developed; the more generic protocols or existing standards are being revised to allow refinement specifically for application to agricultural and horticultural product assessment. This is designed to remove some of the variation in how carbon footprint specifications, such as PAS2050, may be applied for specific product groups.

3.1.2. Definitions and terminology

What is a protocol?

The objective to review and develop a protocol for GHG assessment of cereal and oilseed crops depends on the definition of protocol. There are various interpretations of what constitutes a protocol for greenhouse gas assessment. Some sources determine a specification, such as PAS2050, to be a protocol (Blonk et al., 2010).Others use the term specification as a 'non-standard' standard, defining a standard by consensus of stakeholder agreement (BSI 2011[3]). Some documents contain specific rules and detailed methodologies, others just requirements to follow guiding principles with scope for interpretation. Other documents have considerable overlap, incorporating both general guidance and specific detailed methods. In general there is a weak hierarchy associated with the specificity of products to which protocols are applied (Fig 2).

For the purposes of this review, a protocol for greenhouse gas assessment of cereals and oilseeds is defined as a set of methodological requirements that aims to achieve results that are repeatable, consistent and using methods available and accepted by experts, to achieve the objectives set out in this document.

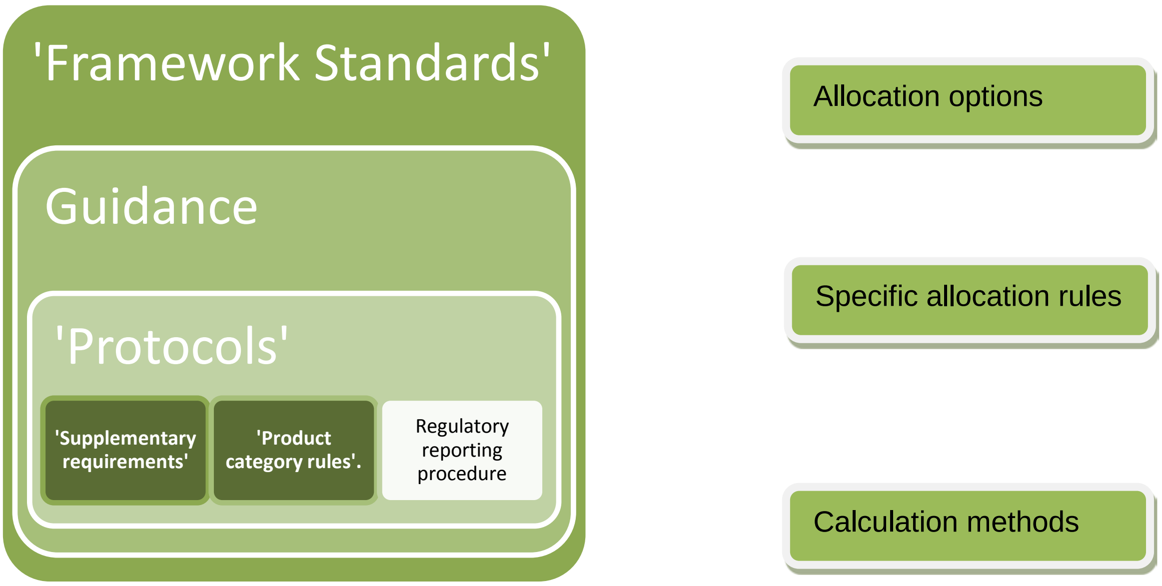


Figure 2. The terminology used to describe existing standards and protocols are not well defined. The diagram shows the loose association of these (left) to an example of how prescriptive a methodology could be for allocating emissions the closer these 'protocols' are associated to specific product groups.

[3] http://www.bsigroup.com/en/Standards-and-Publications/About-standards/Product-definitions/

Definition of carbon footprint

Carbon footprint is a popular term which is broadly taken to mean the global warming impact of important greenhouse gases (GHG's) associated with human activities, processes or products. The PAS2050 specification for the assessment of life cycle GHG emissions of goods can be used for defining the cradle to gate carbon footprint of goods from the extraction of materials used and their production. Broadly, that is the cumulative GHG impact of all activities associated with the production of a specific good, (the production of cereals and oilseeds to the farm-gate in the context of this review). Definitions of boundaries will be discussed later in this report.

The most important greenhouse gases causing global warming are considered in this review. These are often the gases set out in the reporting guidelines for nations set out in the protocol from the 1996 world meetings in Kyoto[4] and are also included in the UK GHG reporting guidelines:

- 1kg Carbon dioxide (CO_2) = 1 kg CO_2 equivalent
- 1 kg Methane (CH_4) = 25 kg CO_2 equivalents
- 1 kg Nitrous oxide (N_2O) = 298 kg CO_2 equivalents
- Hydrofluorocarbons, GWP range - group of gases (HFC's)
- Perfluorocarbons, GWP Range - group of gases (PFC's)
- 1 kg Sulphur hexafluoride SF_6 = 22,800 kg CO_2 equivalents

These gases are not equal in their potential to impact global warming for the same mass emitted. The Global Warming Potential (GWP) is a function of their different residence time in the atmosphere and also their effect on heat within the earth's atmosphere. So calculating the cumulative impact for carbon footprint assessments requires a weighting for other gases to give a 'common currency'. Carbon dioxide (the most common GHG's) is this currency, and is the standard to which other GHG's GWPs are referenced to; carbon dioxide being given a relative weighting of 1.

Methane and nitrous oxide are important GHG's from agricultural sources, and are currently understood to be 25 and 298 times more potent GHG's than carbon dioxide, respectively (IPCC assessment report four published in 2007[5]). So, 1 kg of nitrous oxide emitted to the atmosphere is reported as 298 kg carbon dioxide equivalents (kgCO_2 eq) for the purposes of carbon footprint accounting. The CO_2 equivalents bulleted above are with the latest AR4 (2007) global warming potentials covered in the Revised IPCC National Greenhouse Gas Inventories Programme (NGGIP) guidelines. These had been published for methane and nitrous oxide as 23 and 310 in previous IPCC reports. Assessment report five is due to be published in spring 2014[6].

[4] http://europa.eu/legislation_summaries/environment/tackling_climate_change/l28060_en.htm
[5] http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html
[6] http://www.ipcc.ch/pdf/press/ipcc_leaflets_2010/ipcc_ar5_leaflet.pdf

The latter three groups are unlikely to be involved in the GHG protocol for oilseed and cereals and used only, perhaps, where some refrigerants are concerned (these are used in, for example, transport/ building a/c applications and are likely to be nil or negligible in relation to farm gate crop production).

3.2. Protocol Review - Materials and Methods

3.2.1. Selection criteria for review of existing protocols and methodologies (objective 1)

The criteria for selection of documents for review are purposefully broad and inclusive. The review therefore includes a mix of documents from more generic GHG assessment framework/ protocols to specifications, rules and methodologies directly relevant to cereals and oilseed agronomy. Even though higher level standards may not be specifically relevant to oilseed and cereal production, their requirements inform detailed approaches that are relevant to agricultural product assessment.

The literature search was not exhaustive – as are typical in systematic reviews of clinical evidence - since there is no large body of published standards, protocols and formalised methodologies relating to greenhouse gas assessment of products, especially agricultural products.
Therefore the review includes key existing protocols, and guidance and research literature - pooled from the project team's experience, but also recent drafts. This would also be augmented with literature suggested by the expert panel.

Criteria for selecting literature to review included :

1) Current and past standards/protocols for assessing a product's GHG gas emissions[†];

2) Can be used or has been used for GHG assessment of agricultural products relevant to UK cereals and oilseeds;

3) Is an existing review of a protocol or methodologies for GHG assessment of products;

4) Has been published and has been approved or is in the process of being approved subject to expert peer review in some form, before dissemination;

5) Is part of a government requirement or government publication and/or has some standing/precedence[*] in the field of crop greenhouse gas assessments;

6) Are considered by consensus to be an important or fundamental publication for GHG assessment of cereals and oilseeds in some way*.

Exclusion criteria:

7) Methodologies and data sources that are over 15 years old;

8) Scientific journal publications presenting crop assessments using new, novel or non-mainstream methodologies/ or for bio energy technologies for academic deliberation are excluded from the review;

9) Evaluation of calculation methodologies of existing tools (which include protocols / methodological assumptions implicitly within their calculations) will be excluded, since the methodology may not have been documented for all the tools, and the time required for testing these manually to ascertain protocols would be impractical within the project timescales.

[†]A protocol can be informed by the broader principles set out by high level standards; they may provide consensus regarding the methodologies available and their practicality for the purposes of use. Therefore higher level more generic standards have been included as part of the review process.
* Criteria 5 and 6 are somewhat vague and open to interpretation, but literature included on these particular criteria is considered to generally be accepted by institutions/conventions as significant pieces of work.

3.2.2. Defining a set of common protocol requirements (objective 2)

Where possible, each of the selected protocols and methodologies were reviewed against a set of common requirements. The common requirements are listed below. They are derived from general experience from conducting GHG assessments of crops following common product life cycle assessment principles.

Goal and scope

- Summary of the goal and scope of the standard, protocol or methodology

Methodological requirements

- Defining functional unit/ flow
- Boundary setting - 'defining farm-gate'
- Boundary setting - included processes and inputs
- Boundary setting - excluded processes
- Boundary setting - upstream boundary & cut-off criteria (quantitative/qualitative)
- Attribution methods for emissions from inputs with co-functions
- Nitrous oxide emission methodology
- Soil carbon/ carbon storage methodology
- Land use change emissions methodology
- Allocation methods for co-products

Data needs

- Data quality requirements
- Primary data requirement
- Secondary data requirement/ default data
- Handling variability/uncertainty

Recording requirements

- Data handling and record keeping
- Reporting requirements

Data handling, record keeping and reporting requirements were subsequently excluded since the review coverage was not consistent. Most literature in the review did not have specific record keeping and reporting requirements, except for PAS2050 and the GHG protocols.

The GHG protocols are essentially quality guidelines on how to transparently report GHG emissions and how these were calculated, rather than emphasising specific assessment methodologies that should be used for carbon foot printing.

If it is within the scope of the development phase (beyond the scope of the prototype tool) to generate electronic reporting or linked databases for auditing records and verification, then a protocol for record keeping and reporting may be worth including in further tool development projects.

3.2.3. Recommendation criteria for HGCA cereals and oilseed GHG protocol (objective 2)

The general criteria for recommending the requirements of a draft protocol for cereals and oilseeds were to:

- Provide a balance that allows a tool to have ease of application
- Favour methods more applicable/suitable/relevant to crop assessment
- Report a product based value for supply chains
- Have an alignment with the consensus of existing protocols/methodologies

3.2.4. Expert and industry panel feedback (objective 3)

The recommendations for a draft protocol with background notes and justifications were sent for consultation to a panel of experts in an electronic questionnaire.

Experts were selected based on their involvement with greenhouse gas assessments and industry involvement in this field with regard to their:

- Technical understanding of the application and limitations of life cycle assessment approaches in agriculture for regulatory and voluntary reporting
- Scientific understanding of GHG emissions and other processes in agriculture
- Agronomic expertise with regard to current industry practices and GHG assessment
- Representation of key industry stakeholders with regard to GHG assessment in agriculture

A follow up workshop was conducted to allow experts to elaborate on any issues that were outlined in results and feedback obtained from the electronic questionnaire.

3.2.5. Tool testing: grower case studies (objective 4)

The 10 case study growers trialling the tool were selected both via direct contact and intermediaries (e.g. Anglia Farmers) to represent a range of farms in terms of location, scale, ownership, type of farming system (organic and conventional), crop type (barley, wheat and oilseeds), soil type and production system (e.g. including plough based, heavy single pass samba type cultivator, minimum tillage).

The farms covered the following counties: Lincolnshire, Humberside, Norfolk, Cambridgeshire, Northamptonshire, Oxfordshire and soil types including peat, clay, silt, loam and sandy brash. The farms ranged in size from 300 acres to over 4,000 acres and included council tenants, owner occupiers and contract farmers. Notably, many of the farms were engaged in contract farming or farm management contracts in addition to their core or own farm (in one case they managed 5 additional farms for local landowners). One of the farms was an organic contractor (although they also had some conventional production). Winter and spring barley (both feed and malting), winter wheat and oilseed rape were all used in the case studies and across a variety of farm and soil types.

The farmers selected were also those who were known to be technically competent and progressive as it was felt that these would be more likely to engage in a research and development project, and be more likely to have the data needed to populate the tool. In two cases the farms were linked to research or educational establishments and in these case studies lecturers or researchers were also engaged in addition to the farm managers to help understand the level of knowledge of the issues amongst those who spend their time advising others on agronomy.

3.2.6. Growers guide development (objective 5)

The content of the growers guide was informed by the development process of the tool and protocol and most importantly feedback from the case study testing. The HGCA provided guidance on the format and final versions of the Growers Guide in conjunction with their organisational protocols for these documents.

3.3. Protocol Review Results

3.3.1. Summary of the literature selected for review

The literature selected for review is listed below. The goal and scope of these are summarised in more detail in Appendix A.

1)	The International Reference Life cycle Data System (ILCD) Handbook: General Guide for Life Cycle Assessment- Detailed Guidance.
2)	Audsley et al., 1998. Harmonisation of Environmental Life Cycle Assessment for Agriculture. Final Report. EC Concerted Action AIR3-CT94-2028.
3)	Nemecek T., Kägi T. and Blaser S. (2007) Life Cycle Inventories of Agricultural Production Systems. Final report ecoinvent v2.0 No.15. Swiss Centre for Life Cycle Inventories, Dübendorf, Switzerland. Ecoinvent .
4)	The EU Renewable Energy Directive – Estimates for regional emissions from biofuel cultivation - as interpreted by AEA for the UK under article 19.2
5)	The EU Renewable Energy Directive – Biofuels reporting requirements, supplemented with further communications and standardised methodology[7]
6)	Bauen, A.,Watson,P.,Howes,J.,2008.Carbon Reporting within the Renewable Transport Fuel Obligation–Methodology. E4Tech, UK.
7)	Greenhouse Gas Protocol – Draft Agricultural Protocol For Farm-Level Inventories (WRI 2011a), (based on the working paper linked here, but a protocol draft was obtained by personal communication, this draft has since been placed on the website).
8)	WRI Product Life Cycle Accounting and Reporting Standard 2011 (WRI 2011b)

[7] e.g. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2010:160:0008:0016:EN:PDF
http://www.biograce.net/content/ghgcalculationtools/methodology

9)	PAS2050:2011 – BSI 2011
10)	PAS2050-1: 2011 Supplementary requirements for the application of PAS2050 to horticultural products.
11)	The Agri-footprint method – framework version 1.0 (2010). Holland.
12)	Williams, A.G., Audsley, E. and Sandars, D.L. (2006) Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra

3.3.2. Other standards: unavailable, in development, or supporting those selected for review

The international standard, ISO14067, for carbon footprint of products is still under development; a committee draft standard is awaiting approval before release as a draft international standard. ISO14067 provides requirements for the quantification and communication of greenhouse gases (GHGs) associated with products. Further guidance is given on calculation methods in ISO14069, this also is in development. Drafts of these documents could not be obtained for the review. Another standard of relevance that is in development by the CEN[8] TC 383 working group 2 is for the sustainably produced biomass for energy use: “Calculation for the GHG emission balance, fossil fuel balance and respective calculations, using a life cycle approach”. This is to be released after the project review (May 2012) so has not been included.

A British Standards draft is also available: Draft BS EN 16214-4. This is a draft interpretation of the RED[9] methodology and will be referred to when interpretation of the RED requires further detail along with reference to the EU biofuels data harmonisation project literature published by the Biograce project.

Other literature that is relevant to specific aspects of the protocol but do not provide coverage over enough of the crop production cycle, or are not published as protocols or standards, are not listed but these will be referenced through the various sections of the review.

[8] European Committee for Standardization (Comité Européen de Normalisation)
[9] Renewable Energy Directive of the European Union.

3.3.3. Defining the goal and scope

Key Question

What is the goal of the protocol?

Defining the goal of the protocol is crucial for subsequent methodologies such as setting the assessment boundaries. This is somewhat led by the requirements of the project objectives given by the HGCA (see Aims and objectives).

Review summary (objective 1)

Goals of the literature are outlined in more detail in the appendix. These vary, and are briefly summarised below:

- Provision of high quality life cycle assessment inventory data (Ecoinvent);
- To provide detailed guidance/rules for harmonising life cycle assessment - (EU ILCD Handbook 2010, Audsley et al., 1998)
- Product carbon footprint assessments from the cradle to gate and cradle to grave (PAS2050:2011/ WRI 2011 life cycle accounting/ reporting standard).
- Average environmental burdens of UK agricultural commodities for policy makers (Williams et al., 2006);
- Life cycle assessment of food products covering the whole food chain (Agri-footprint);
- Regulatory requirements for biofuel performance reporting (EU RED /RTFO);
- Organisational carbon accounting (GHG Protocol for agricultural activities in businesses);

Initial recommendations (objective 2)

From the review, especially in reference to the requirements outlined by the ILCD handbook for Life Cycle Assessments, the recommended goals of a life cycle assessments (and this has relevance for developing sector/product group specific protocols), should set out the following:

1. Intended application of the results/deliverables

2. Limitations due to the method, assumptions, and impact coverage

3. Reasons for carrying out the study and decision-context

4. Target audience of the results/deliverables

5. Comparative studies to be disclosed to the public

6. Commissioner of the study and other influential actors

Though some of these aspects (5 & 6) don't directly correspond with a protocol and related tool, it is helpful to address those that do. These are essentially covered by 1-3 as interpreted from the HGCA's requirements.

1) The intended application of the results

The intended application of results, understood from the original terms of reference for the project specification, was two-fold:

i) **Decision support for individual growers to reduce their crop's GHG emissions**

Calculating the greenhouse gas emissions in kgCO_2 equivalents per tonne of cereal or oilseed crop to help growers to understand the key processes and components that impact the carbon footprints of their produce.

ii) **Provision of results for supply chain assessments**.

To conduct a product level assessment of the greenhouse gas emissions associated with the typical production of cereal and oilseed crops that is independent and robust enough to enable growers to provide information for supply chains, where pressure to do so is increasing.

The protocol would serve as the basis for a compliant tool for growers to use. It is proposed that the crop GHG assessments are not intended to be communicated to consumers or the general public or for any comparative assessments. As it is unlikely that assessments will be verified by independent 3rd party assessors, the protocol would not strictly follow the documented standards required for type III product declarations[10] (BSI 2010).

2) Limitations

The protocol is only addressing the impact on global warming of the production of 1 tonne of UK cereal and oilseeds to the farm gate.

Whilst a tool can do much to remove the complexity of protocol requirements by prompting the data required, automating calculations and guiding users through the process. The greatest limitations to developing a protocol lie primarily in making a fairly complex calculation process farmer friendly. The requirement for the tool to be very accessible to growers and yet include the necessary complexity and data demands in line with existing protocols and methodologies means a balance is needed. This may limit the chances of satisfying the reasons given for the protocol.

[10] See http://ec.europa.eu/environment/ipp/pdf/epd.pdf

3) Reasons for the protocol

The reasons for developing a protocol, understood from the original terms of reference for the project specification, were:

1. For engagement of growers by providing a consistent reliable protocol for crop carbon foot print assessment, which will also raise awareness of the key GHG impacts from growing crops.

2. For growers to be able to provide the assessment to businesses such as processors, buyers and retailers, who wish to understand the carbon footprint of the growing stage of cereals and oilseeds as part of a larger supply chain assessment.

3. A secondary reason is to aim to make a protocol compatible with any future requirement for fair benchmarking – though this is not to take priority over the main reasons above.

Expert panel feedback (objective 3)

Comments were made from a member of the expert panel concerning the need to clarify the purpose of the protocol and tool more clearly. Before comments can be properly made on the proposed protocol, it was repeatedly highlighted that there is a fundamental need to substantiate what the question is that the HGCA trying to answer by looking to develop a protocol. In summary, the stated issue was that the interpretation of the HGCA purpose of the proposed protocol and carbon calculator was too vague to determine the appropriate assessment approach.

The initial specifications in the request for expression of interest and from the notes of the initial project meeting suggest that the protocol is for growers to provide customers, and processors with consistent and transparent product average carbon footprint of their crops, (feed wheat, bread wheat, malting barley etc). There was also an emphasis on engaging growers and using the protocol compliant tool to demonstrate how management decisions can reduce their crops carbon footprint.

Though it was not made explicit in the survey, it was assumed that experts would know that the protocol should not adopt approaches that are intended for larger scale policy level assessment – i.e. those evaluating the impact of changes in crop production and wider market level impacts – such as assessments that seek to understand the impacts of biofuels policy. Neither was it suggested that the protocol was for regulatory purposes – such as assessing the GHG emissions for a single crop for reporting a carbon footprint for an individual fuel batch using a ‘snap shot’ analogy.

So implicitly ruling out these inappropriate goals, one actual goal would appear to be similar to the EU guidance, BSI's PAS2050's and ISO (14025) definitions of Product Category Rules or supplementary requirements to reduce the scope for variations in the carbon footprint approach for cereals and oilseeds, as a product level assessment. Another key goal would be to provide 'micro level decision support' (ILCD 2010) for growers to enable informed management of key emissions involved in their crop husbandry practices.

Hence it was proposed that the Protocol goal was to answer to the following questions consistently:

a) 'What is the typical carbon footprint of the crop grown for a specific market from a grower?' but also from Grower's perspective a further question is:
b) 'What are the management processes I can control that affect the GHG emissions of my crop grown for this market, so I can reduce emissions?'

The second question may be limited in scope, due to current limits to scientific methods for quantifying the GHG impacts of many farm scale management actions, beyond the dominant factors of the type and quantity of nitrogen inputs, quantity of fuel used, set against simply the reported yield of crop that was attained.

It is useful to acknowledge that crop yield could be improved by many good husbandry practices that may not be captured, and therefore stimulated, by a carbon footprint tool. This is simply because many factors leading to high technical efficiencies may not directly cause substantial GHG emissions. But since these technical efficiencies lead to increased crop yield the GHG emissions per tonne of crop reported would be much lower. If more technical efficiency options are captured by a carbon calculator ,it would support the concept that carbon footprint assessment has efficacy as a decision support tool for stimulating improvements in a grower's technical efficiency.

3.3.4. Defining the reporting unit

Key question

What will the protocol requirement be for defining the unit of production to which greenhouse gas emissions are reported against?

Crops may be produced by farms for varying functions (animal feed, different kinds of foods, bread, biscuit, oils, fuel feedstock etc.) and will vary in moisture content (and therefore weight of the required material).

For reporting, it is necessary to accurately define a standard specification for crop products so that variations are accounted for by differentiating between their function[11].

Review summary (objective 1)

Due to different goals of the reviewed literature, various functional characteristics of crops can be used for reporting GHG emissions against:

- Energy content (for biofuels RED, RTFO)
- Protein content (for specific product end uses Audsley 1998)
- Mass (fresh weight)
- Mass (at 'typical' stored moisture level Williams 2006, Ecoinvent 2007)
- Organisational, but augmented with GHG intensities per mass of crop (GHG Protocol for agricultural businesses)

In the case of the biofuel carbon reporting, GHG are reported against the end function of the crop – provision of energy. The modular approach requires feed stock at the farm gate to report as kgCO_2 equivalents per MJ of fuel, as the functional unit, by using default conversion factors along the whole fuel chain.

Applying different reporting units for the many end uses of different cereal and oilseed crops is clearly inappropriate for the scope of this particular project. The standardisation between products with different end uses would add an impractical layer of complexity. For example, wheat grains for the biofuel market will be sold on their high starch to protein content. Whereas a functional requirement for grains sold for bread wheat is based on protein content. However, post farm gate processors blend different sources of flour to obtain the required protein specification, (Audsley et al., 1998). Whilst broad classifications are available from industry bodies such as nabim for

[11] Whist comparisons and benchmarking are not the primary goal of the protocol, this function may be applied in the future

wheat[12], in some cases, the end use of the grain is not known when the crop is sold. Therefore, defining a method for standardising a functional unit by end use may be problematic if the end use is not specifically known by the farmer. Conducting assessments for individual crop varieties may be too onerous for the grower due to the extent of data demanded.
In this respect, it is recommended that greenhouse gas emission estimates for cereals and oilseeds should be reported as an intermediate product, or 'reference flow' in life cycle assessment terminology, i.e. grain, by mass.

For any subsequent benchmarking it might be useful to conduct GHG assessment within general product categories for different crop types, since, for example, the crop nitrogen requirements (a significant impact on the carbon footprint of crops) for feed wheat may be different for different bread wheat, malting and feed barley etc. This would require further development of categories, but a tentative suggested grouping is given below:

- Breadwheat (nabim Group 1)
- Breadwheat and other (nabim Group 2)
- Cake and biscuit varieties (nabim Group 3)
- Wheat other (Group 4 - biofuel/feed etc.)
- Malting Barley
- Feed Barley
- Triticale
- Oats
- Rye
- OSR for industrial varieties (inc. biofuel)
- OSR for food use

For these crops, winter or spring varieties may be grown and some wheat varieties may also be autumn sown. Within the same categories mentioned above, seasonal varieties may have different yields, nitrogen demands, and resulting GHG emissions. Therefore a sub-category for winter or spring (and autumn) may be an option, yet the extra data demanded may complicate the assessment process for growers.

[12] Group 1 is for varieties best suited to bread making; Group 2 is for varieties which are suited to bread making but may not suit all millers all of the time; Group 3 varieties are best suited to cake and biscuit manufacture, while those in group 4 may be used for a range of other purposes.

Standardised moisture content.

Due to harvested crop moisture variations, the GHG emissions estimated up to the point of transfer to the dryer should be corrected in proportion to a crop weight, with specified standard dried moisture content for reporting as a functional unit for consistency. Typically this has been 15% moisture for cereals, though more recent commercial requirements such as the HGCA safe storage protocols give 14.5% for cereals.

This can be done in the background of a GHG calculator, for example, by taking reported yield and fresh weight moisture content of the yield at harvest then attributing the production GHG emissions to crop dry weight matter, and then correcting this to the crop weight at a standard moisture content for reporting (See the next section for treatment of drying emissions).
The recommended moisture contents of crops for reporting GHG emissions against are given below.

Crop	Proposed standard moisture content w/w for reporting.
All wheat	14.5%
Oats	14.5%
Barley	14.5%
Triticale	14.5%
OSR	12%

Table 1 Proposed standard mositure contents for oilseeds and cereals

Initial recommendations (objective 2)

The reference unit for crop products at the farm gate shall be 1 tonne of crop, weight corrected to standard storage moisture content for the particular product, which shall be relevant to industry specifications.
The cereal or oilseed should be allocated to a broad category of use to make any comparisons made by the grower more meaningful and allow further development of benchmarking should this arise.

Expert panel responses (objective 3)

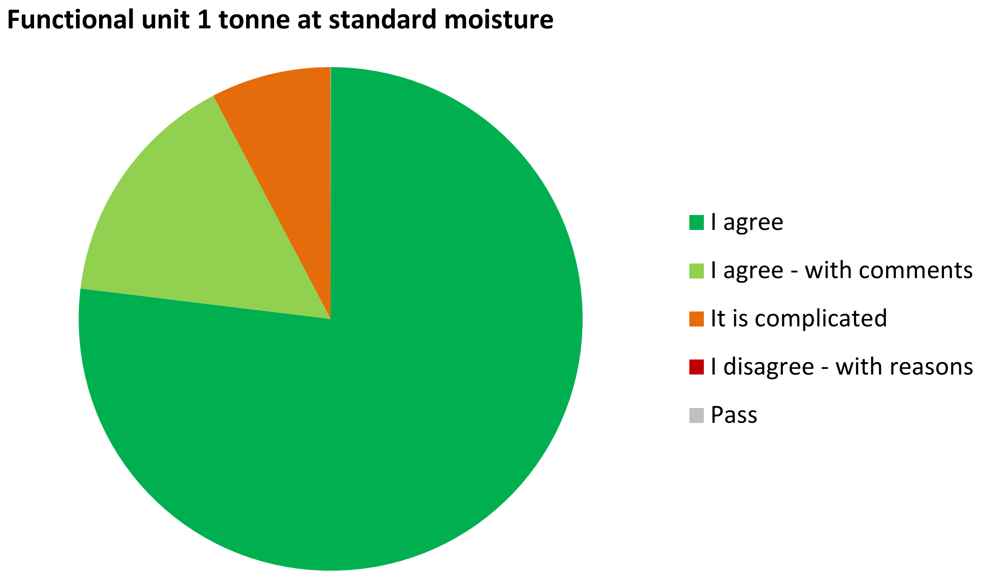


Figure 3. Expert panel's response to the proposed functional reporting unit

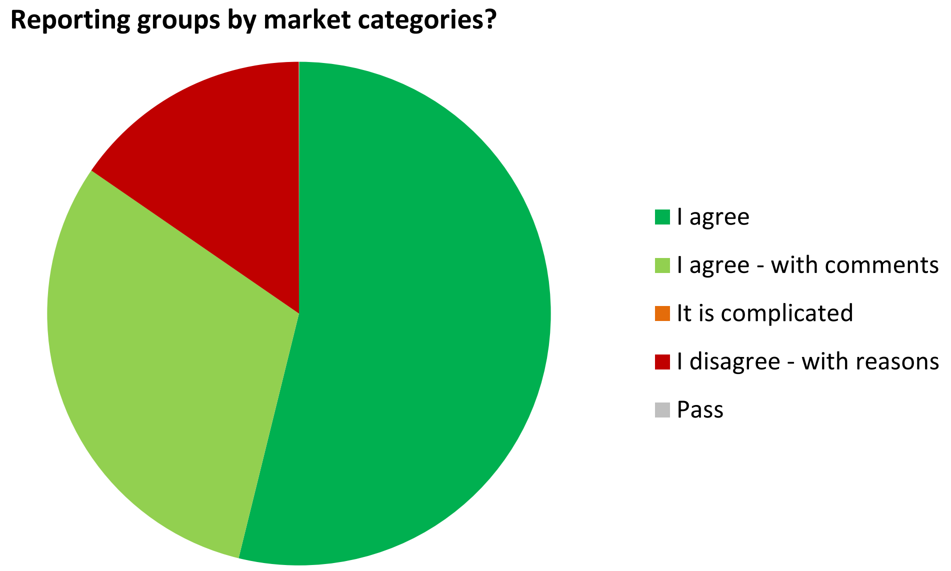


Figure 4. Expert panel's response to proposed grouping by grains market categories

Key Comments:-

- The HGCA calculator needs to be sufficiently flexible to meet any end-use. UK cereal grain is normally measured/ traded at 15%, not 14.5% moisture'.
- 'I think [an option to allow] individuals to record other information like variety for optional later use would also provide the solution to the question on reporting winter v spring'.
- 'Since the carbon footprint will be dominated by variation in N fertiliser use and crop yield, these are the things that need to be asked, rather than crop type'.

3.3.5. Defining farm gate

Key question
The protocol requirements are for greenhouse gas assessment of cereals and oilseed production to farm gate. How shall the protocol define farm gate?

Review Summary (objective 1)

The literature reviewed gives few specific criteria and examples for defining the ‘farm gate’ boundary. These are summarised below:

1. The point at which the product is transferred to a 3rd party
2. The point at which operational (physical) control is relinquished
3. The point at which financial control (ownership) is relinquished
4. Individual crop husbandry only to post harvest, not including drying or storage
5. Geographical farm gate but including crop drying and storage

The first definition is from the PAS2050 specification. This generic requirement would appear to be problematic with regard to including on or off farm grain drying. A grower may contract drying and haulage to a 3rd party yet still own the product. This could be interpreted as not leaving the business ownership, yet being transferred some degree of operational control to a 3rd party. Transfer of ownership to a 3rd party may be more of a definite boundary than just physical possession and control. However, crops grown to contract may be considered in some circumstances to be owned by the contractor. Further complications on ownership may occur for co-operatives, so there would appear to be a need to qualify this further.
The Greenhouse gas protocol for agriculture is being developed (an unfinished draft was reviewed) for whole farm business GHG reporting and is not crop specific. However the definitions for boundaries of the business are based on either financial or operational control and could prove to be useful for a crop specific protocol.

With regard to product level assessments, the physical farm gate boundary might be consistent with many farms’ operational control. However, strictly adhering to financial control/ownership criteria from a business reporting perspective could potentially lead to overly complex determination of the business status of farms in relation to the reporting boundaries. Issues of contracting and leasing arrangements and business co-operatives and farm sharing may not be as problematic for crop specific emission assessment, if these are explicitly excluded by the protocol.

It is therefore recommended to set out a more detailed physical definition of farm gate.
It follows logically by including standardised moisture content for reporting the protocol should include the crop drying process within the farm gate for completeness. Any emissions from drying and a final storage stage should be added to the GHG burden emissions from growing and transport to drying, after emissions estimated for growing and transport to storage have been corrected to the specified moisture content.

Drying

However, it should be noted that complexity may also occur at the drying stage. In reality, drying could occur in two stages, both on the farm site and at a processors, or co-operatives sites. The drying related GHG emissions may differ, therefore, due to different efficiency of technologies employed but also by end use products due to heat restrictions for preserving food grain quality (Nemecek et al., 2007).

Storage

There are a number of options to physically define if storage could be included within the (farm gate) boundary or not:
a) At the point where the grain is about to be first stored (excluding storage relate emissions). OR
b) At the point at which dried grain begins transfer from first storage to the first point of process.

Disadvantages for including storage:

Storage time may vary; distance from growing site may vary; and be subject to third party control, therefore GHG emissions could require both primary and secondary data, unless default distances and default storage time were provided. This may cause (unfair) variation in carbon footprint results when used for benchmarking purposes. For example, if a farmer uses the protocol to supply carbon footprint information for customers assessing supply chain impacts of different growers it may favour farmers who dry and store on or much nearer to their growing site.

Initial recommendation (objective 2)

The farm gate shall be physically defined: Emissions from grain drying and first storage shall be included whether stored on farm or in co-operative/merchant managed stores. Transport emissions from transfers between the farm to any offsite drying and first storage shall be included.

Qualifying details:

- GHG emissions from postharvest activities, but before grain drying, will be included in the inventory then corrected to crop mass at the standard moisture content.
- GHG emissions associated with drying crops to the standard moisture levels will be based on secondary data, but the choice of drying technology used shall be relevant to the grower’s circumstances.

- GHG emissions incurred after the point of drying within the boundary such as transport and storage shall be added to the inventory after without any correction for moisture.
- Where grain drying occurs in two phases (e.g. drying may occur on farm and then further drying at grain merchants may be implemented), a single default drying operation shall be assumed.

Expert panel responses (objective 3)

Ten out of the 12 experts consulted agreed with the proposed definition for the farm gate boundary.

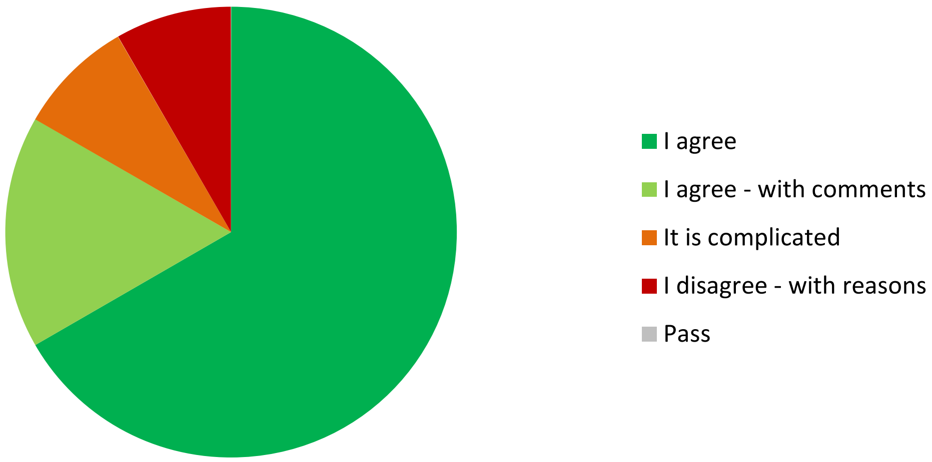


Figure 5. Expert panels response to the farm gate boundary

Key Comments:-

- 'It will be advantageous to show the emissions of all drying operations. In this way, seasonal variations in the crop moisture at harvest can be separated from drying activities that could be more or less intensive depending on sector or site preference and we may wish to use this as a driver to change practice'
- 'The answer to this question depends crucially and fundamentally on the reason(s) why a crop is being evaluated. The defined systems boundary (and subsequent calculations) is determined by the purpose of the evaluation which needs to be specified by the protocol. A "one size fits all" approach will not work when designing a protocol.'

3.3.6. Defining excluded sources of emissions

Key question

Which activities or processes should be explicitly excluded from the greenhouse assessment of crops?

Greenhouse gas emissions caused by growing cereal and oilseed crops can be the result of many contributing activities and processes, (manufacturing of inputs and fuels as well as on farm use and combustion). Some of these processes may have minor or negligible impact on the final carbon footprint, or can be uncertain and variable. Including these processes may be time consuming and unnecessary for achieving the goals of the protocol.

Review summary (objective 1)

Descriptions of processes that are explicitly excluded by the GHG assessment literature are summarised below:

- The production of machinery (inc. vehicles), buildings and equipment, PAS2050
- The production of pesticides (Agri-footprint)
- Removals and emissions of biogenic carbon dioxide (via plant photosynthesis) (RED/RTFO)
- Manure storage (Ecoinvent/ Williams et al., 2006)
- Compost storage- N leaching was excluded, though gaseous emissions were included (Williams et al., 2006)
- Industrial packaging (Agri-footprint), (only relevant for agrochemical and fertiliser supply where it is likely to be a relatively minor contribution).

Emissions from the production and supply of capital goods such as buildings, machinery and equipment are explicitly excluded from a number of the literature, rather than relying on the cut-off criteria, since these appear to be considered, in general, to make a negligible contribution to the total product emissions.

However, some protocols acknowledge studies that suggest that this may not be the case (Blonk et al., 2011– citing Nemecek 2004). One of the most comprehensive UK studies modelling the environmental burdens of agricultural commodities includes capital equipment such as buildings and machinery (Williams et al., 2006). The study's spreadsheet model for bread wheat production shows that 3% of the total GHG emissions are estimated to be due to allocations from machinery manufacture and 2% from storage (including production of building materials) (Table 4). Pesticide manufacture is estimated to be 3% of the GHG emissions. The reported boundary of this study is to the farm gate, though includes crop drying.

From a whole product life cycle perspective these percentage contributions will be relatively lower since they will include further emissions from processing, distribution and retail etc.
Therefore capital infrastructure may be close to the 1% cut-off threshold with respect to whole product assessments, if processing, distribution and retail etc. constitute two thirds of a full product footprint. Recent studies suggest this may be the case for bread retailed in the UK (Espinoza-Orias 2011). For other less intensively processed products, such as cereal animal feeds, this may not be the case.

It is likely that capital infrastructure is excluded from many assessments on the grounds of practicality, since a robust assessment of capital infrastructure along a supply chain and for farm businesses would be demanding. Audsley et al., 1998 suggest that the lifetime and application of farm machinery may vary, older tractors may be kept but put to less intensive tasks or others may be scrapped, making allocation of their related manufacturing emissions over their useful life and specifically for cropping tasks more complicated. Tailoring such an assessment to individual farms would also require more input from each farm, and it is also recommended here on grounds of practicality (and consensus) to exclude capital infrastructure such as buildings, machinery and equipment.

Initial recommendation (objective 2):
Due to practicality and following a number of the key protocols, the GHG associated with the manufacturing/construction and maintenance of capital infrastructure (machinery, buildings, equipment) and energy used in farm houses and offices etc. should be excluded from the assessment for practical reasons.

Expert panel responses (objective 3)
The main disagreements were with proposals to exclude pesticide production, on the grounds that even though the GHG impact for production may be minor– its influence on crop yield has an indirect impact, so for completeness it should be included. Excluding seed production emissions were also contested for similar reasons by a number of experts.

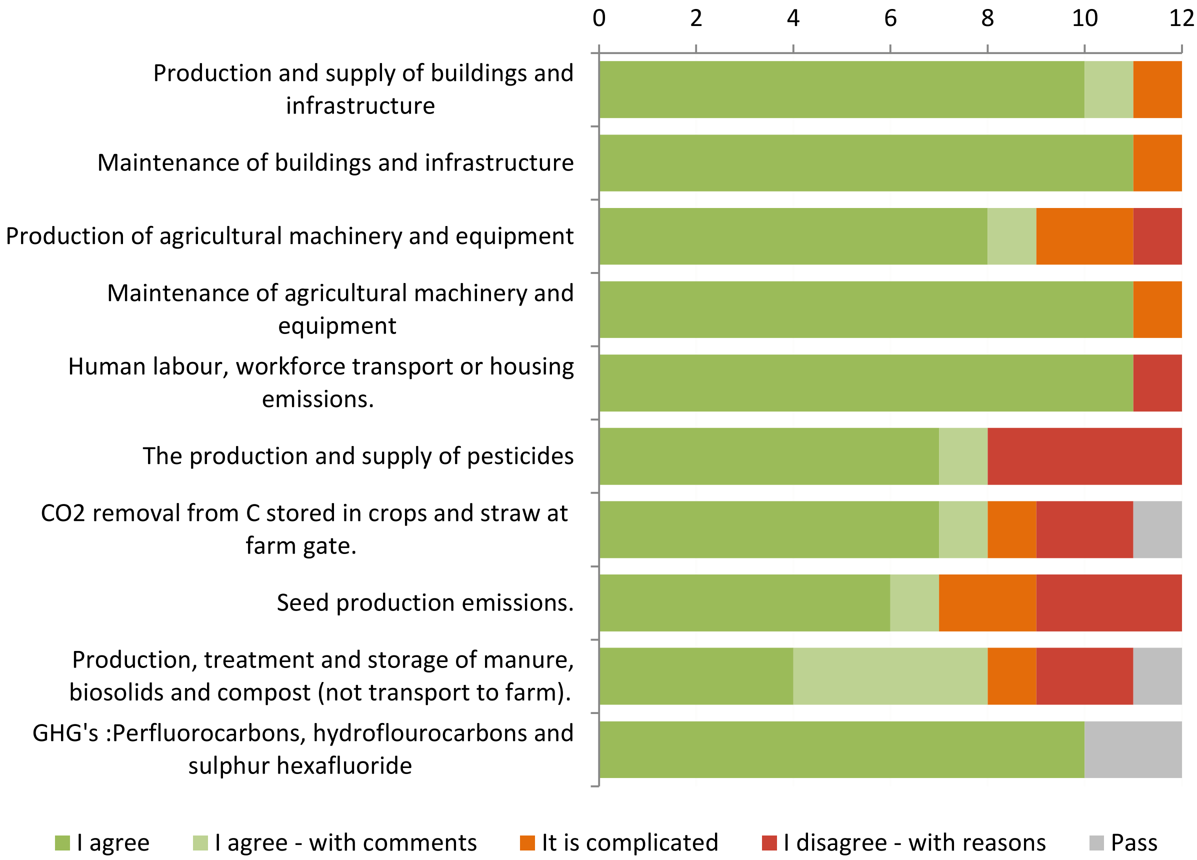


Figure 6. Expert panels response to various methodological elements

Case study feedback (objective 4) – No feedback was received regarding these aspects

3.3.7. Defining the cut off criteria for included emissions

Key question

Should quantitative criteria be used to define where minor sources of emissions can be excluded from the assessment?

Greenhouse gas emissions and removals caused by growing cereal and oilseed crops can be the result of many activities and processes with large, or many small, contributions. The calculation of smaller contributions (from on-farm activities or their supply chains, including the extraction of raw materials, their manufacture and supply into farming inputs) may be onerous. Thresholds for these contributions to the carbon footprint can be set to exclude the many smaller contributing processes from the calculations.

Review summary (objective 1)

A number of materials and sources of energy (inputs) will enter the crop production assessment boundary. Each of these inputs has a production chain involving other inputs, and so on. The application of cut off criteria is dependent on the granularity of emission sources reported for the production chain of each input and how far these extend back to raw material extraction from natural resources.

Though some programmes provide standardised datasets and threshold values in an attempt to resolve this issue, for example the Biograce programme and RED report, only percentage cut-off criteria in the literature reviewed are given by PAS2050 and the original RTFO methodology (E4Tech- Bauen et al., 2008):

- Sources of GHG emissions that are less than 1% of the products total GHG emissions (PAS2050)
- 1% of the crop biofuel fuel chain (E4Tech).

The term ‘source’ is not explicitly defined by PAS2050. However, the only other reference in the PAS2050 document and accompanying guidance with regard to definitions of sources is in the further reading section referencing CO_2 from UNECE source categories. The more detailed CORINAIR categories related to agriculture are given in Table 2. These are for reporting national air pollution inventories and may not be appropriate or consistent definitions of sources for crop GHG assessments to the farm gate. For example, emissions source from ‘use of pesticides’ may be redundant in the context of GHG emissions, although ‘combustion in manufacturing’, ‘industrial production processes’, ‘road transport’ and ‘mobile sources’ are all part of the production chain and application of pesticide.

Table 2 Emissions sources as defined by CORINAIR: IPCC reporting requirements(1996).

Agriculture	Land use change	Combustion and industrial processes
1001 Cultures with Fertilisers (except animal manure)	Managed Forests	04 Industrial Production Processes
1002 Cultures without Fertilisers	Changes in Forests etc.	01 Combustion in Energy and Transformation Industry
1003 On-Field Burning of Stubble, Straw..	Biomass Stocks	02 Non-industrial Combustion Plants
1004 Enteric Fermentation	Forest and Grassland Conversion	03 Combustion in Manufacturing Industry
1005 Manure Management	Abandonment of Managed Lands	07 Road Transport
1006 Use of Pesticides	CO_2 Emissions and Removals from Soil	08 Other Mobile Sources and Machinery

Source: http://www.ipcc-nggip.iges.or.jp/public/gl/guidelin/annex2ri.pdf

The GHG protocol for agriculture (WRI 2011) does not include a threshold on the grounds that there is no benefit for having such criteria; their rationale is that excluding processes that constitute < 1% of the GHG emissions (in this case, of an organisation footprint) would necessarily require assessment of these processes anyway, (and all other contributing processes to gauge what constitutes 100% of GHG emissions).

To prevent this procedure the Biograce[13] calculation rules stipulate a threshold of 0.1g CO_2eq MJ^{-1} of the total production chain of a biofuel, but also provide a mass or energy threshold 0.005 gMJ^{-1} biofuel, or 0.2$kJMJ^{-1}$. This threshold refers to individual 'inputs' or ,if inputs are small, then cumulatively they can be excluded if they do not add up to more than 0.1g.

Table 3. Threshold values for exclusion of inputs and processes to the RED biofuel chain calculation (www.biograce.net 2011).

Biograce threshold values	
0.005	g MJ^{-1}
0.2	kJ MJ^{-1}
10	MJ ha^{-1} $year^{-1}$
0.3	kg ha^{-1} $year^{-1}$

[13] www.biograce.net accessed Dec 2011

In the context of this protocol the total GHG assessment will be to the farm gate, not a whole fuel, feed or food chain to post consumption. Therefore some inputs could potentially be excluded, on a 1% cut-off basis, for whole product life cycle reporting, but not at a farm gate assessment boundary where there contribution is relatively greater.

Existing LCA studies could be used (with care) to make judgements on excluding inputs (pesticides, seeds etc.) and processes (transport or building and machinery construction). One of the most thorough assessments (since it models the average case for UK crops based on the best statistical sources that were available) is the DEFRA study conducted by Williams et al., (2006). The table below (Table 4) shows the results for their modelled GHG emissions estimated to farm gate. The estimates show that manufacturing emissions for machinery, pesticides and storage are above 2% of the farm gate emissions for bread wheat. It was not clear whether the 'storage' figure included building energy use, or solely construction related emissions.

Table 4. Contribution of modelled emissions for farm gate production of bread wheat, average commodity level using the model defaults. Taken from Williams et al., (2006) Agri-LCA model V3.

	Energy, MJ/ha	kg CO_2e /ha	Energy	% CO_2e per ha (small rounding/ allocation errors)
'Storage'	973	66	5%	2%
Pesticide manufacture	1,370	94	7%	3%
Fertiliser manufacture	9,906	1,053	52%	28%
Machinery manufacture	2,061	120	11%	3%
Field diesel (combustion)	4,696	335	25%	9%
'Field emissions'		2,073		55%
total	19,006	3,741	100%	100%

Preliminary or screening assessments of the GHG emissions of farm gate crop production would allow informed judgements on the GHG contribution of inputs and processes. Decisions could then be made on a level of detail that constitutes an individual 'source' and therefore what and how many 'sources' can be included or excluded from the assessment. This iterative approach is acceptable to case by case assessments but is unpractical for the development of a prototype tool.

From a realistic and practical perspective, the assessment of GHG contributions from inputs and processes will be dependent on what secondary sources of data are available for estimating GHG emissions (fertiliser production, transport emissions, operation emissions). These should be subject to data quality rules in a protocol to ensure these are the best secondary data sources for crop assessments.

Initial recommendation (objective 2)

The protocol should not include specific quantitative cut-off criteria based on GHG sources, due to ambiguity of what level of analysis could be interpreted to constitute a single ‘source’.

Much of the GHG assessment inputs (e.g. fertiliser and fuel production) will rely on secondary data and applying cut-off criteria will be subject to the granularity of the data available. This may vary. Instead, it is recommended that the required inputs and activities to the crop production process to be included in the boundary shall be based on expert judgement and practicality, shall be listed and described (in the next section of the review) and their related GHG emissions shall be subject to the most appropriate data available (defined by protocol’s data requirements for primary and secondary data). Reducing this layer of complexity from the protocol and having a simple inventory of sources that should be included in the footprint assessment should make the approach more accessible and transparent. Also more crucially, building quantitative criteria based on relative percent of the final figure into a workable tool could be unnecessarily complicated and hard to justify to growers.

Expert panel responses (objective 3)

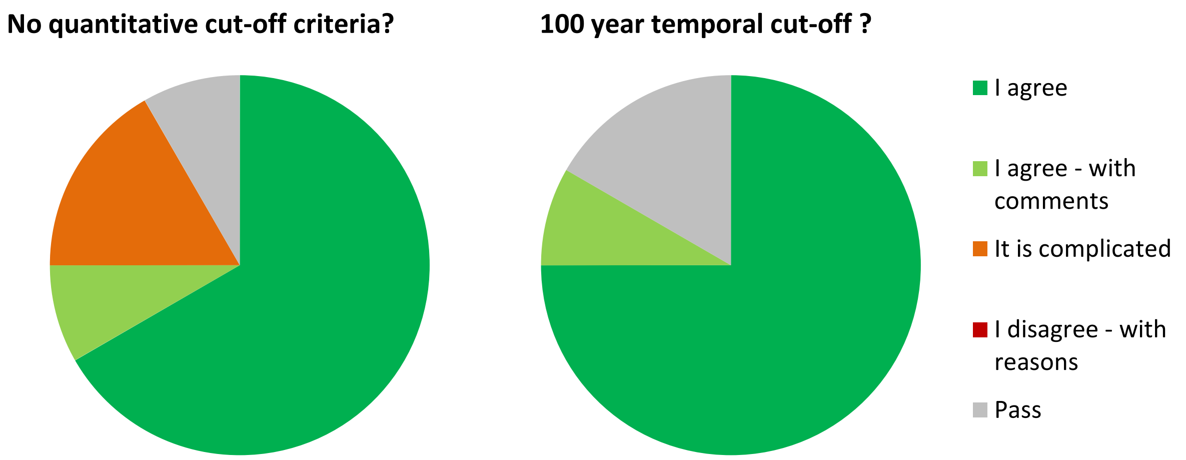


Figure 7. Expert panels response to the cut-off protocol for GHG reporting

Key Comment: ‘There are other important temporal issues (purposes affect both protocols for temporal as well as spatial systems boundaries). The most significant temporal issue concerns the allocation of soil nitrous oxide emissions between successive crops.’

Case study feedback (objective 4) – No feedback was received regarding these aspects

3.3.8. Defining crop system boundary and included inputs

Key question

Greenhouse gas emissions caused by growing cereal and oilseed crops can be the result of many contributing activities and processes, culminating in inputs to the farm (manufacturing of inputs and fuels as well as on farm use and combustion). Given that quantitative cut-off criteria are not recommended, which activities or processes should be included in the greenhouse assessment of crops?

Review summary (objective 1)

In order to determine which processes are included in the estimation of the GHG associated with growing crops, the time boundaries of the crop production system need to be defined. Many farmers do not grow individual crops in isolation but farm to optimise a production system for multiple crops. The boundary, therefore, could either be a whole crop rotation system over a number of years, or a single crop growing cycle in isolation to other crops.

Multiple crop growing system

The boundary for assessment could concern one crop as part of a sequence of other crop co-products grown in a rotation system. However this has a number of practical disadvantages:

- The data requirement from the farmer to include inputs and operations for the whole crop rotation (including cultivation of cover crops/green manure etc.) over a number of years may be too demanding
- Some form of allocation of emissions from cover crop, manure and green manure etc. to co-products is required
- The system may not be fixed; the farmer may change cropping systems subject to market prices etc.
- Other crops in a rotation may not be relevant to the oilseeds and cereals remit of the protocol

Single crop growing cycle

It is possible to attribute the benefits and related emissions of inputs and activities that help optimise and benefit the whole cropping system to individual crops, (i.e. building soil fertility over time through manure inputs). Though, in the reviewed literature, consistency in methods to handle this issue varied. Green manure or animal manure inputs not directly applied in a cropping year may be excluded from the assessment. This has a number of reporting disadvantages:

- If emissions are calculated based on the farmers data (inputs and yields) from only one growing season it will be difficult to capture the ‘lag’ or delayed cause and effect (fertility building or reduction) from the immediate GHG impacts of altering inputs on the longer term crop yields.

- Calculating the input N of a previous crop's residue (non-exported straw, stubble, roots etc.) as an input to the following crop may be complicated.

The first disadvantage may be remedied somewhat by requiring a running average for yields for the specific crop to be used. This is discussed in the section on primary (farm) data requirements.

The second issue can be resolved by allocating emissions from a crop's residues to that crop's emissions profile, not as a nitrogen input to following crops. The nitrogen from crop residues in this approach is assumed to be mineralised and cause N_2O emissions within the same growing year. Crop residue management may also be considered to impact soil carbon through 'improved soil management' (soil carbon is dealt with in 3.3.13).

The modelling approach used by Ecoinvent sets the boundary for an individual crop from the point when the previous crop has been harvested to the point of harvesting the current crop, but with post-harvest stubble cultivation allocated to the current crop. The draft standard for greenhouse gas assessment of horticultural products PAS2050-1:2012 takes a different approach and partially applies a whole cropping system boundary with respect to attributing emissions from organic inputs and green manure crop residues (these are dealt with in the next section).

The extra requirements for data collection and input for a cropping system boundary (over a number of growing seasons) limits the practicality of this approach. This may contravene one of the objectives of the protocol and tool– to encourage grower engagement. Therefore, it is suggested that the single crop approach is used. This also appears to be the consensus of other literature that was reviewed and from the project team's experience of published crop LCA studies.

Inputs to the boundary

A number of materials, sources of energy (collectively –'inputs') and operations will enter the crop production assessment boundary. These should be defined. Activities that have already been defined in the literature are outlined in Table 5.

Initial recommendation (objective 2):

a) By recommending that quantitative cut-off criteria should not be given, the activities and processes to be included in the crop production boundary will be listed and described as part of the protocol.

b) The use of data for these inputs should be subject to specified data quality requirements.

c) For the purposes of the protocol, the boundary shall be for a single crop, rather than a cropping system.

d) Emissions estimated from residues of the previous crop shall be allocated 100% to those crops.

Expert panel response (objective 3)

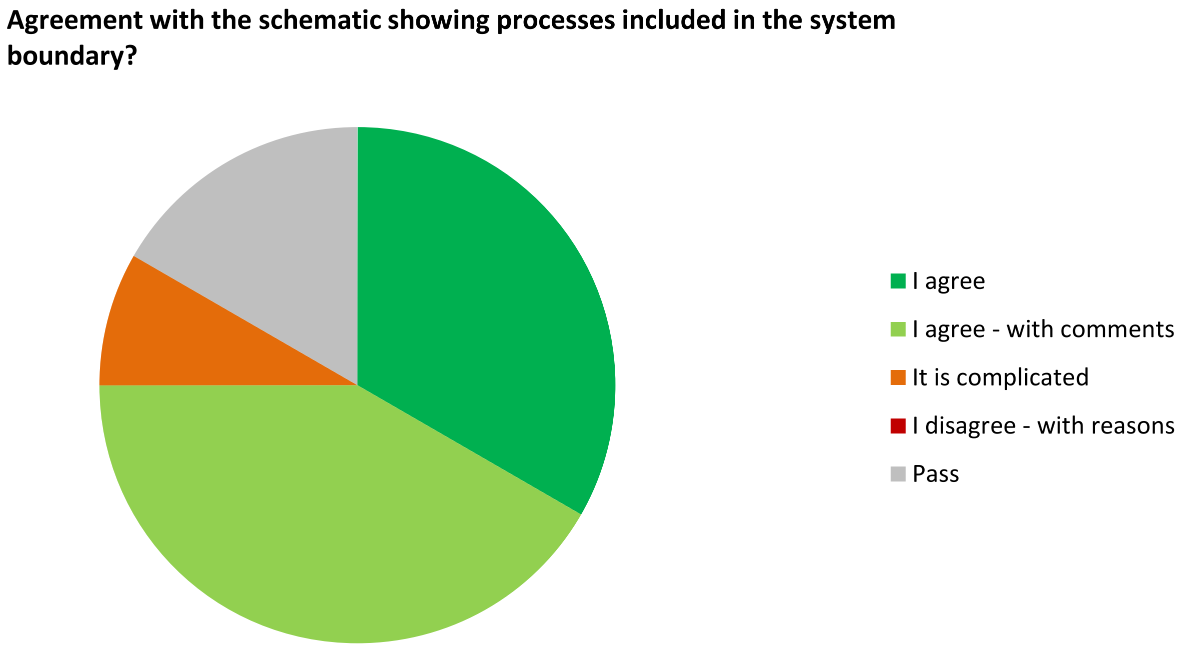


Figure 8. Expert panels response to processes included in the reporting boundary

A copy of the schematic is given in Appendix B (p198)

Table 5. Elements explicitly included/excluded in the literature reviewed. ILCD guidance, PAS2050:2011 and WRI Product protocol are excluded as being too general for agricultural systems.

	Audsley et al., 1998	Ecoinvent	AEA 2011 (RED 19.2)	EU RED	E4tech 2008 (RTFO)	WRI Agriculture Protocol	PAS2050-1: 2012	Agri-foot print	IS0205 Williams et al.	**Proposed protocol**
Seeds production	Y	Y	N	Y	N	Opt	$Y_{>1\%}$	Y	Y	Y
Fertiliser production	Y	Y	Y	Y	Y	Opt	$Y_{>1\%}$	Y	Y	Y
Pesticides production	Y	Y	Y	Y	Y	Opt	$Y_{>1\%}$	N	Y	Y
Fuel production	Y	Y	Y	Y	Y	Opt	$Y_{>1\%}$	Y	Y	Y
Lime production & emissions	?	Y	Y	Y	Y	Opt	$Y_{>1\%}$	Y	Y	Y
Compost production	?	P	N	?	N	Opt	?	?	P	N
Biosolids (sewage sludge) production and processing	?	N	N	?	N	Opt	?	?	?	N
Manure production	N	N	N	?	N	Opt	?	?	P	N
Transport of each input to regional warehouses	Y	Y	?	Y	?	Opt	$Y_{>1\%}$	Y	Y	Y
Transport of each input from regional warehouses to farm	Y	Y	?	Y	?	Opt	$Y_{>1\%}$	Y	Y	Y
Transport of crop for drying (if necessary)	?	Y	N	?	?	Opt	$Y_{>1\%}$	?	N	Y
Diesel combustion emissions from individual field operations	Y	Y	Y	Y	?	Opt	$Y_{>1\%}$	Y	Y	Y
Emissions from production of machinery	Y	Y	N	N	N	Opt	N	N	Y	N
Emissions from production of buildings	Y	Y	N	N	N	Opt	N	N	Y	N
Consumables for maintenance (including maintenance of capital equipment)	Y	Y	N	P	N	Opt	$Y_{>1\%}$	?	Y	N
Emissions from manure storage	N	N	N	N	N	?	?	N	P?	N
Diesel combustion for total operations						Y				
Electricity production and supply	Y	Y	N	Y	Y	Y	$Y_{>1\%}$	Y	Y	Y
Direct nitrous oxide emissions from soils by fertiliser (min & org) input	?	Y	Y	Y	Y	Y	$Y_{>1\%}$	Y	Y	Y
Direct nitrous oxide emissions from soils due to crop residues	?	Y	Y	Y	Y	Y	$Y_{>1\%}$	Y	Y	Y
Indirect nitrous oxide emissions from fertiliser volatilised and re-deposited	?	Y	Y	Y	Y	?	$Y_{>1\%}$	Y	Y	Y
Indirect nitrous oxide emissions from leached fertiliser	?	Y	Y	Y	Y	?	$Y_{>1\%}$	Y	Y	Y
Emissions from crop drying	Y	Y	N	?	Y	P	$Y_{>1\%}$	Y	Y	Y
Emissions from crop storage	?	?	N	Y	Y	P	$Y_{>1\%}$	Y	Y	Y
Emissions from operation of all building premises	?	N	N	N	?	P	$Y_{>1\%}$	?	N	N
Land use emissions from soil organic matter (mineral) cultivation	?	?	?	N	N	?	$Y_{>1\%}$	Y	N	N
Land use emissions from soil organic matter (peaty soils) cultivation	?	?	Y	Y	?	?	$Y_{>1\%}$	Y	N	N
Land use change emissions	Y	Y	Y	Y	Y	Y	$Y_{>1\%}$	Y	N	Y
Land use sequestration from management (organic inputs or tillage)	P	N		Opt	N	Y	N	Y	N	N

Key

Y = within assessment boundary

N = Not included or not mentioned in the assessment boundary

P = Partial – i.e. if a proportion or some aspect is allocated to the crop system boundary

Opt = Optional to include in the assessment.

$Y_{>1\%}$ = Included if processes emissions are greater than 1% of the total product GHG

? = Unclear if this is included in the assessment boundary

3.3.9. Attributing GHG emissions from crop system inputs and general farm activities to individual crops

Key questions

a) How should emissions from inputs/activities that benefit the whole cropping system, (i.e. benefits carried over a number of crops growing cycles) be allocated to the growing cycle of an individual crop?

b) Should a proportion of emissions associated with farm buildings (offices and general buildings) operational energy be allocated to individual crops?

c) Should emissions from on farm crop storage operational energy use be allocated to a crop (assuming this is within farm gate boundary, see ‘Defining farm gate’ page 20).

Crops are grown in systems where:

i) A number of inputs and operations are not exclusive to specific crops yet contribute both indirect benefits and GHG emissions; both GHG emissions and crop yields are affected by nutrients from the previous crops residues and those slowly released from manure and compost;

ii) Conversion of carbon rich land to agricultural use may still be causing gradual soil GHG emissions but also a pulse of GHG emissions during conversion (machinery but also from biomass loss as land is cleared and the more labile organic carbon fraction in soils oxidises)

iii) Data and records for materials and fuels are not collected specific to individual crop types.

How should emissions related to these inputs be allocated to individual crops?

Review Summary (objective 1)

a) Organic inputs

There are a number of different kinds of inputs to crop systems where their benefits and associated GHG emissions may not be exclusive to a particular crop growing cycle. These kinds of inputs have been identified and are summarised below:

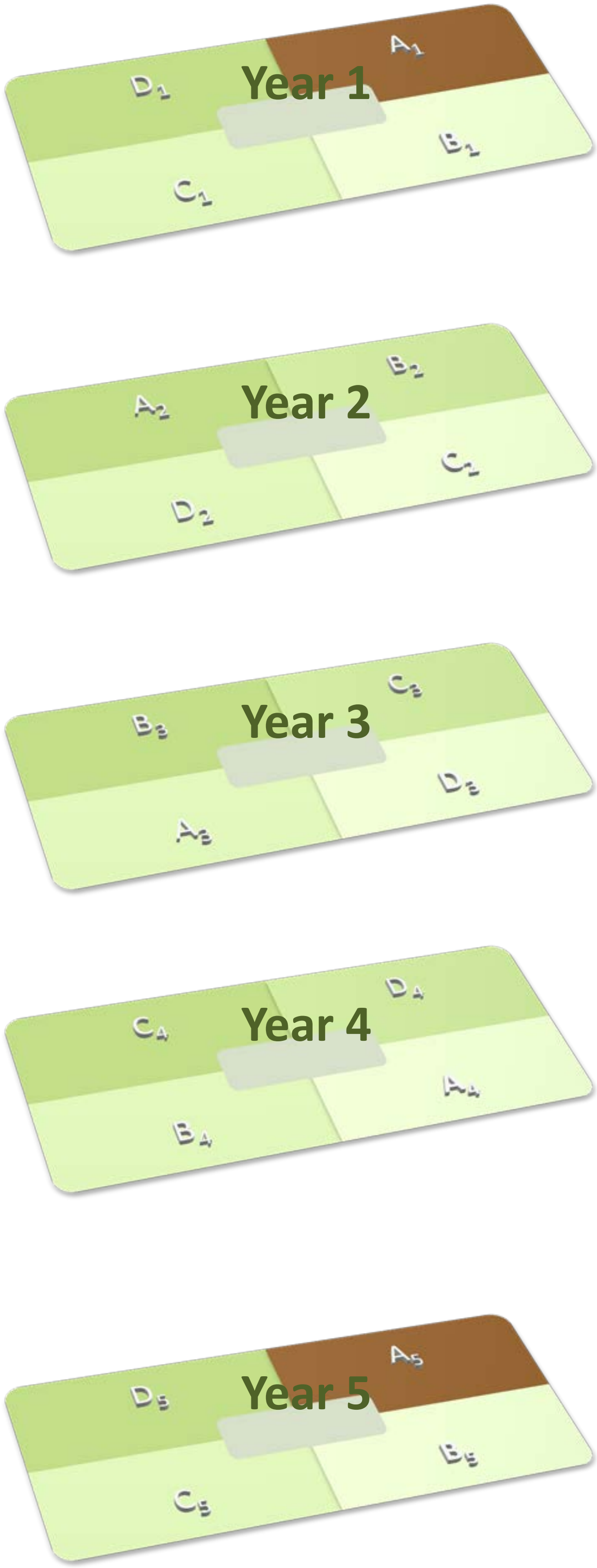
- Animal manure
- Biosolids and compost

- Green manure and cover crops
- Previous crop residues

Animal manure, compost and biosolids have GHG emissions associated with their production and storage, and if imported to the growing site, additional transport and site storage. Their addition to soils will also contribute to infield GHG emissions such as nitrous oxide emissions associated with denitrification and nitrification processes in soils. The production and storage of manure is attributed entirely to the livestock system in a number of the methodologies reviewed (Ecoinvent 2007, an option in Audsley et al., 1998). Crop residues from previous crops, green manures and cover crops also add SOM and nutrients to build fertility for following crops. Some authors suggest this should be accounted for in a separate soil quality index to complement other environmental impact indicators such as global warming impact (Audsley et al., 1998).

A protocol would require a way of attributing the GHG emissions from these kinds of inputs to the production of individual crops. Attributing the GHG emissions for the production, transport and field emission of these inputs to specific crops could take simplistic or complicated approaches. The summaries of these approaches of the various literature sources reviewed are given in Appendix A. The key methods are highlighted in Figure 9 using a simplistic crop rotation to demonstrate the approaches.

Figure 9: An example 4 year rotation



Manure, compost,biosolids and crop or green manure residues deposited just before crop A_1 in year 1 (brown) may be both a source of nutrients and field emissions over more than one growing cycle, (for simplicity in the example here 1 crop growing cycle = 1 year). This may benefit following crops B_2, C_3 and D_4 over a rotation system in reducing required fertiliser amendments, but in the case of N input, also contribute to N_2O *emissions following IPCC methodology.*

Methods found for the allocation of organic N related benefits and emissions that occur in the applied area during crop A_1 B_2,C_3 and D_4 vary:

1) Proportion by relative crop needs, from technical agronomic data.

2) By allocating any emissions in year 1 to crop A_1 and– allocating any emissions after year 1 by the proportion of area of crops A_1, B_1, C_1 and D_1 i.e. the application year, (in this example due to field symmetry, 25% of post year 1 emissions are allocated to each crop). (1& 2 from ***PAS2050-1:2012 supplementary requirements for horticultural products****).*

*3) By % 'active nitrogen content only' all to crop A_1 (**Agri-footprint methodology v1.0,**)*

*4) By assuming incrementally only 10% of the manure N is available to crops each year. So available N, (and related N_2O emissions) would appear to depend on which year the manure is applied in the rotation, if only one crop growing cycle is assessed, (**Williams et al., 2006**).*

Initial recommendations (objective 2):

- Nitrous oxide emissions from the nitrogen in organic inputs shall be attributed to the following crop on the basis of 'readily available nitrogen', not total nitrogen.

- With reference to RB209, the unavailable organic nitrogen fraction of organic inputs shall be assumed to remain after the first crop. For the purposes of applying a methodology for estimating nitrous oxide emissions it shall be assumed that 100% of the organic nitrogen fraction is mineralised.

  For intermittent or periodic spreading of organic fertiliser, nitrous oxide emissions shall be estimated as a function of the recalcitrant nitrogen fraction using either the IPCC tier 1 approach. These N_2O emissions shall be attributed to the following crops grown on the same area (and in proportion to their area not yield) over subsequent years, until the next manure application (following PAS2050-1).

  If organic fertiliser is applied before every crop, then the nitrous oxide yield will be estimated assuming mineral nitrogen equals the total nitrogen input, (readily available N + unavailable N). The estimated emissions in this case shall all be attributed to each following crop.

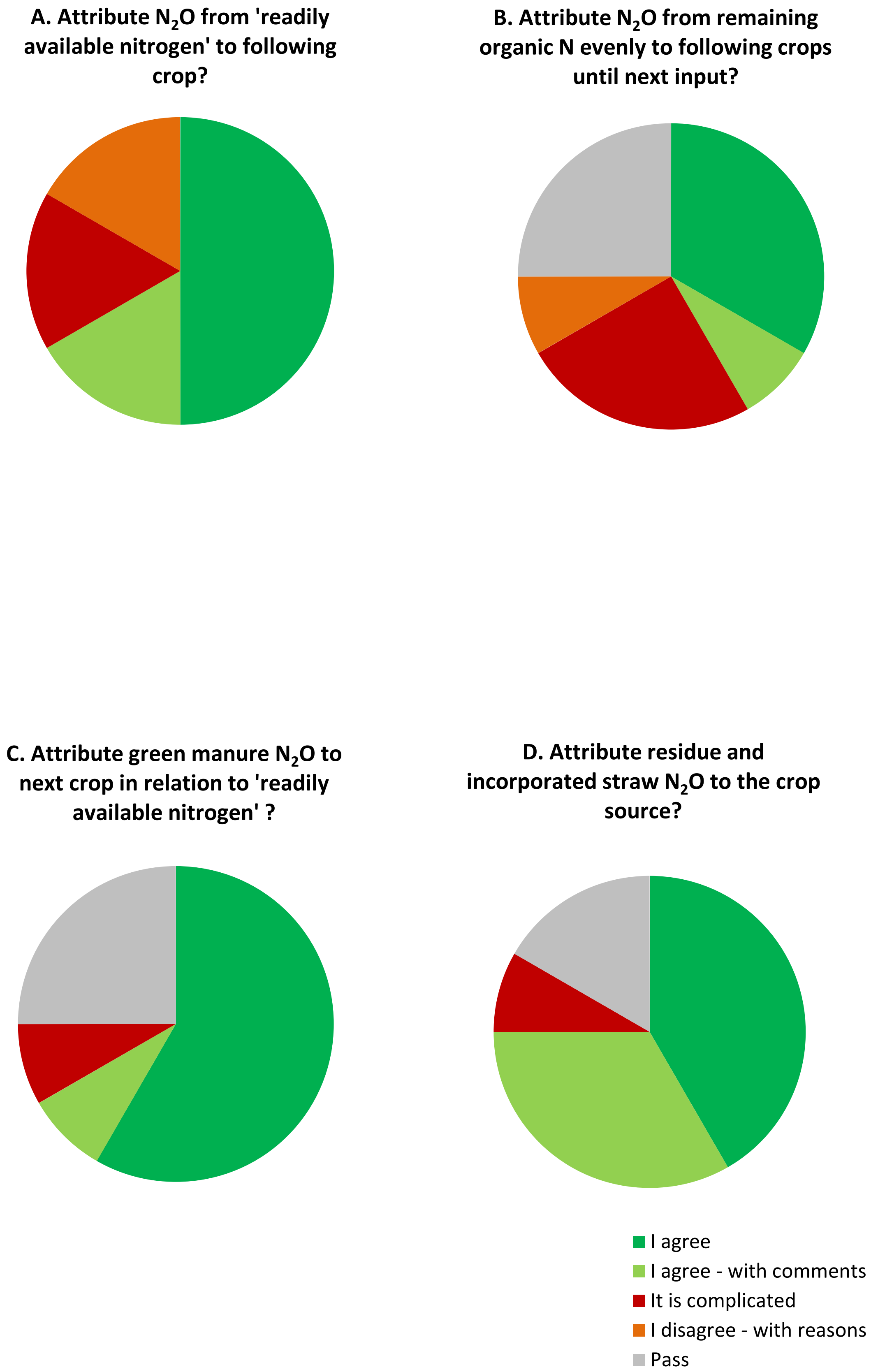
- GHG emissions from processes required for growing green manures shall be allocated to the next crop in proportion to the readily available nitrogen. The remaining production emissions shall be attributed to following crops using the same method proposed for recalcitrant nitrogen (B).

- Due to the defined assessment boundary (reporting a single crop rather than for a crop system) and for consistency with the previous crop boundary definition, emissions from a crop’s residues (including straw if incorporated) shall be attributed to that crop’s emissions profile.

  The total nitrogen in crop residues and straw shall be assumed to be mineralised for the purposes of applying IPCC (tier 1) methodology to estimate N_2O emissions.

Expert panel response summary (objective 3)

Figure 10. A to D: Expert panel's response to attribution of nitrogen related N_2O emissions to crops *(12 respondents)*



Expert panel comments (objective 3)

'This has the danger of being overly complicated, and heavily disincentivises the use of manures on-farm, which may be inappropriate from a holistic perspective. Emissions from manure are likely to happen in any case (unless used in AD or similar), and could fairly be attributed to the livestock system etc. that has produced it. It does not seem appropriate to penalise the use of manures on arable crops, if their use can support a reduction in manufactured fertiliser and increase SOM. The amount of mineralisation will also depend on current SOM status of the soil- possible that move from one equilibrium status to another so not all N would be mineralised.'

Alternatively contrasting comments regarding allocating total N to the next crop are given by other experts:

'[just] allocating the readily available nitrogen from organic inputs to a crop is neglecting the N_2O emissions from mineralisation of the organic bound N in the organic inputs. If organic material is regularly used (as it is most often practiced), most of the total N will be available in each year although originating from many different applications. I therefore opt for the IPCC approach i.e. taking the total N content as the basis'.

'Nitrous oxide emissions are related to the total N not the available crop N in the first year (available N to crop is different to available N to the environment). The inefficiency in organic N take-up in the first year should be factored in to the calculation of N loss and risk to loss as Nitrous oxide. Up to 75% N could be lost reducing likelihood of recovery to subsequent crops'.

Other shared inputs

Attributing emissions from land conversion shall be dealt with in the land use change section.

Manure production and storage

Animal manure storage and production emissions should not be included in the assessment, since these have had limited processing and are still effectively a by-product/waste of animal products.

Initial recommendation

GHG emissions from manure production and storage are attributed entirely to the livestock production systems. This is recommended for the HGCA protocol. This does not wholly penalise the use of manures as the expert had commented in the survey. The emissions for application of nitrogen from local sources of manure does not include production emissions unlike specifically manufactured fertilisers.

Compost and biosolids production emissions.

It is arguable whether some of the composting or biosolids treatment emissions should be included in the assessment. These may be a 'processed waste', and their production may be a by-product of their primary function as waste treatment. Williams et al. (2006) attribute emissions from turning and fugitive processing emissions of compost production to crops, and also from transport to the growing site. But they also apply substitution credits for these to the N equivalent of displacing the production emissions associated with inorganic fertiliser.

Initial recommendation

All emissions from compost and biosolids production/treatment operations should be considered part of a waste treatment service and not attributed to crops grown after compost or biosolids applications.

Energy used in farm operations

Another problem is how to attribute emissions associated with activities and processes such as the operation of buildings and machinery to specific crops. These are principally GHG emissions related to the direct combustion of fuels and indirect emissions related to energy used (electricity and supplied heat). Often information or records are unavailable to allow fuel and energy use to be attributed to specific crops. The following have been identified:

- Operational emissions from farm buildings (heating, lighting, grain cooling, ventilation)
- Operational (combustion) emissions from farm machinery

Initial recommendation (objective 3)

Farm building energy use should be excluded from the assessment. Most likely, this has a negligible contribution to GHG emissions per tonne of crop, when shared between the total farm produce. Also, splitting site energy between domestic use (normally excluded) and business use will require more information from farmers (even if using secondary average data for floor kWh m^{-2} net internal area). This may be unpractical for the contribution this makes to the overall GHG, so it is recommended that attributing operational energy use from farm buildings is to be excluded from the assessment.

Where current field operations/activities have no crop specific motive (hedge trimming, various agri-environment ELS, HLS scheme operations etc.) or directly attributable benefit to crops (such as nutrient inputs), these operations shall be excluded.

Energy use in crop specific operations

Most of the protocols require GHG emissions from 'energy carriers' as a reference to fuels, electricity and heat etc. to be attributed to production processes. Attributing energy carriers to growing specific crops would require either:

1. Growers recording total fuel use data for crop specific operations, or;
2. Growers estimating fuel use for their specific operations (ploughing, cultivation, discing, spraying, manure spreading, combining, grain drying etc.), or;
3. Applying proxies to estimate fuel use (e.g. operation hours per hectare, or broad soil characteristics to weight ploughing, or moisture content of fresh weight crops for drying etc), or;
4. Using fixed secondary data for average UK default emissions estimated for specific operations (per hectare and crop drying emissions based on average energy used per tonne dried crop).

It is unlikely that growers record detailed total fuel use data for crop specific operations(option 1). If they have to conduct data collation and entry for estimated fuel use for their specific operations (option-2) this could still be time consuming and a potential obstacle to users. Therefore allocating fuel use to specific crop operations would most likely rely on secondary default data, (option 3 / 4). Perhaps option 4 can be open to adjustment by farmers where necessary. Estimates of data from secondary sources should be subject to data quality requirements (section 3.3.14 and 3.3.15).

Initial recommendation (objective 2)

GHG emissions from crop production machinery, i.e. combustion of fuels used by tractors and combines to carry out cultivation and harvesting operations, - should be attributed to specific crops. This should be achieved by estimating emissions from specific crop cultivation operations required by individual crops using secondary data that is based on the most recent industry data relevant to UK conditions, where available. These should be subject to the protocol's data quality requirements and, for example, take into account farm specific factors (heavy, medium, light soils etc.).

Adjustments should be allowed by farm operators, where farm fuel use records or other data are available to do so.

Energy use for crop storage

Energy used for crop storage is assumed here to be a very small contribution to GHG emissions when shared between annual farm co-products, though few sources of data were found to substantiate this assumption. Refrigeration is not considered to be a common technology for grain cooling. HGCA recommendations cover only air cooling[14].

Initial recommendation (objective 2)

On farm storage of grain should be included in the assessment following farm gate definition (see 'Defining farm gate' page 36). The energy use emissions for on farm storage of grain is more directly related to the production process and this should be included for completeness. Since this is likely to be a relatively small contribution, it is proposed that secondary data should be used (and provided by the carbon calculator). This should be subject to data quality rules; i.e. taken from averaged seasonal energy use data for estimates representative of average industry farm storage facilities, using the estimated emissions allocated to tonne of crop stored per day.

[14] http://www.hgca.com/publications/documents/cropresearch/cooling.pdf

3.3.10. Allocating emissions between crops and any co-products

Key question

How should the GHG emissions attributed to growing the crop be shared between the harvested crop and any harvested co-products such as straw or other beneficial outputs?

Background

The carbon footprint calculated for crops will depend on how much of the GHG emissions associated with the growing stage are shared between the main crop and any co-products. Depending on its use or value, straw may be considered either a co-product for cereal crops and share a proportion of the GHG emissions, or, only a by-product with some or no benefits to crop GHG budgeting. The appropriation of different methods can have a significant impact on the final GHG result (Aylott et al., 2012, Whittaker et al., 2011). Existing product footprint specifications allow flexibility in the choice of these methods which may explain differences in results that are 'compliant' to the same specification.

Review summary (objective 1)

Interpreting the reviewed literature, crop production GHG emissions maybe allocated to crops and straw in a number of ways:

1. **No allocation is necessary**: straw is identified as a crop residue or waste and all the production emissions are attributed entirely to the crop, (**RED**).

2. **System expansion credits**: all the emissions are attributed to the crop. In addition, a GHG credit is given to the crop that is equivalent to the emissions from the manufacture and supply of products which the straw can functionally substitute (**Interpretation of substitution approach from PAS2050 and ILCD**).

3. **Allocation by energy content**: A proportion equivalent to the relative energy content of the straw and the crop, (**RED, interpreted if straw is considered a co-product**).

4. **Economic allocation**: A proportion equivalent to the mass of product and the co-product weighted by their relative economic value (**Ecoinvent, RTFO, AEA, Williams et al., 2006**)

Substitution (or 'system expansion') methods

Some of the standards require a preference to avoid allocation of process GHG's between co-products through the subdivision of the process into more detailed sub-processes (ILCD 2010). Where this is not possible (growing crops is a good example of this), the next preferred option is called system expansion. In this context, the crop production system boundary is 'expanded' to include a change in demand of the production of goods incurred through their substitution by straw, (e.g. energy, soil fertility, animal feed etc.). The greenhouse gas emissions relating to the products most likely to be substituted, e.g. in the examples above this could be natural gas, P fertiliser, feed wheat, could theoretically be credited to the crop system by their functional equivalents, net of any additional straw processing or transport emissions. The assumption is that the substituted products can be unambiguously identified and exchangeable, and directly reduce demand. This is considered for straw substituting fertiliser.

Fertiliser substitution

Straw can be considered as an input to the following crop system. Any nutrient benefit available to following crops from straw residues, theoretically, could be considered a product, displacing the need for some equivalent function provided by inorganic nitrogen fertiliser.

Following a substitution approach, the emissions from the manufacturing and supply of the avoided mineral fertiliser could then be credited back to the cropping system. But there are a number of reasons why this may be problematic:

1. Scientific evidence for quantifying the benefits between the differences in straw removal and return are uncertain, (references cited by Whittaker et al., 2011).

2. The evidence to prove how much fertiliser input is reduced by growers due to returning residues may be hard to demonstrate.

3. Other evidence cited in Whittaker et al. (2011) suggests that in some circumstances straw addition has been shown to reduce yield due to N immobilisation.

4. Any credit from the reduced demand for inorganic fertiliser due to incorporated straw is implicitly counted as part of the following crops GHG assessment so this may risk double counting

5. Notwithstanding, determining which crop or product systems should receive the GHG credit, the actual substitution of functional equivalents may be difficult to explain and convince growers.

6. GHG emissions from the fuel used for chopping wheat straw during combining, an operation specific when incorporating straw back into the soil, has been assumed to negate any of the GHG credits for P &K fertiliser (Glithero et al. (2012)), though N substitution was not considered.

Methodological arguments against substitution

Substitution is arguably more consistent with so called consequential life cycle assessment. This approach is associated with assessing the impact of changes, rather than carbon footprints, which are associated with characterising the actual situation and related (average) GHG emissions of a crops production system 'as is'.

A substitution approach would assume a reduction in production demand as a consequence of substituting another product with crop straw, and therefore account for a change in net production emissions. The change in demand could be associated with a reduction in production emissions for the average or marginal products that are substituted. There appears to be no clear published scientific consensus (Lindfors et al., 2012).

The recent guidance outlined by the ILCD LCA handbook recommends consequential assessment approaches when the impacts of decisions are likely to cause larger changes (>5%) in production capacity of other systems beyond the product system boundary.

This approach has been identified as being somewhat inconsistent with carbon footprint product assessment approaches that attribute emissions from inputs to reflect existing discrete product system boundaries in a static 'snap shot' of the average technology and activities. When applied in some circumstances, others have argued combining consequential methodology with attributional methods may incur a risk of overlap, double counting and ambiguity in identifying products that are substituted (see Brander et al., (2009)). The recommendation of substitution in PAS2050 is therefore somewhat confusing and blurs the boundaries between purely attributional approaches and consequential approaches. Recent overviews of LCA and the ILCD guidance qualify this observation, (Finnveden et al., 2009 and Lindfors et al., 2012).

Allocation by mass

Allocation of emissions by mass is only considered advisable when the co-products are functionally very similar, such as different kinds of wheat grain used for food, (ILCD 2010, GHG Draft Agriculture Protocol).

Allocation by energy content

The methods applied to biofuel reporting apply allocation by energy content (dried matter lower heating value) of the co-products. This rule is primarily applied to co-products in feedstock processing stages because the Renewable Energy Directive (RED) appears to assign zero emissions to ‘crop residues‘ at the growing stage. Others have stated that there has been some uncertainty as to whether straw is defined as a crop residue, waste or co-product by the RED (Whittaker et al., 2011).

Economic allocation method

The main advantage of applying an economic allocation is that it is probably the simplest approach. Also market value could be considered the dominant force driving production. However this method has a number of disadvantages:

1. The economic value method would need further definition at which point economic value is applied: in the field; the point directly after harvest; post drying storage; ex post to processers; a specific market value etc.

2. The price of commodities will of course fluctuate and the relative values will change over time and by location, affecting the emissions allocated to crop and straw, making the approach less objective and useful for indicative comparisons.

3. A number of the key standards and protocols advise a hierarchy of approaches where economic allocation is the least preferable option, probably due to the less than ideal situation for the goal of carbon footprint assessment if market fluctuations may be a key factor in the final results, rather than controllable operations.

It is important to define the point where allocation should occur. Since the point of separation of grain and straw for example, would likely be before drying, and therefore the emissions from any further exclusive operations (straw baling, crop dying etc.) must be attributed to each co-product separately.

Summary

Straw from crops may either be exported from the arable system for a variety of uses, or chopped and incorporated back into the soil. There does not appear to be an ideal solution for allocating growing emissions between crops and exported straw. The review highlights a number of ways in which the emissions associated with growing are shared between crops and straw, if exported from the arable system. The advantages and disadvantages are summarised in the following tables.

Option 1.

All GHG emissions from crop growing are allocated 100% to the crop, essentially straw is considered to be a by-product or waste residue from crop production, not a co-product.

Advantages	Disadvantages
• Avoids allocation (preference of ISO14040 etc.). • Consistent in time. • Consistent with attribution of organic inputs. • Crop growing is arguably the primary driver. • There is no large swing in a crop's emission profile if a grower decides to export straw or not. • Simple/transparent, easy for a grower to understand • Consistent with EU RED.	• Does not adequately reflect that straw has a value in the UK. • Straw sales may support the primary activity of crop growing, so should be acknowledged. • Effectively allows user of straw to claim a GHG neutral product, except for straw specific operations such as chopping, baling and transport.

Option 2.

100% of the production related GHG emissions are attributed to the crop, but the system is expanded so that substitution credits can be removed from this burden, equivalent to the GHG emissions associated with products that are displaced by straw.

Advantages	Disadvantages
• Avoids allocation (preference of ISO14040 etc.). • Follows PAS and original RTFO C&S reporting.	• This is arguably more appropriate for assessment of changes in GHG emission relating to markets impacts for policy assessment, not attributional product assessment. • Unambiguously identifying products that are substituted may be problematic, (average of the market spread of substituted products, or a identifying the single marginal one?).

Option 3.

GHG emissions from growing are allocated in proportion to energy content between crops and straw (if crops and straw are used for energy and straw is considered of value as a co-product, not a by-product or waste).

Advantages	Disadvantages
• Consistent in time. • Consensus with the RED.	• Doesn't satisfactorily reflect the primary product as the cause of emissions. • Doesn't reflect the function of the products. Energy is not the exclusive function of both crop and straw production.

Although, the original RTFO methodology set a minimum threshold of >10% of the total market value as a condition before applying energy allocation based on a 3 year average market value.

Option 4.

GHG emissions from growing are allocated simply in proportion to the mass split between the crop and straw.

Advantages	Disadvantages
• Consistent in time. • Simple/transparent.	• Doesn't satisfactorily reflect the primary product as the cause of emissions. • Doesn't reflect the function of the products.

Option 5.

GHG emissions from growing are allocated between crop and straw in proportion to their economic value (perhaps based on a 3 year average as suggested in the RTFO).

Advantages	Disadvantages
• Reflects that straw has value and, in some proportion, may influence the overall reason for production - economic benefit. • Allows allocation for crops and co-products with very different end functions with one method.	• This is market based and variable, in time and regionally. • Changing GHG emission results based purely on external market conditions may not be conducive to grower engagement for aiding GHG mitigation. • If only applied to exported straw, then this may exhibit a swing the in crop's GHG profile. • Organic straw may have a different value, complicating crop GHG results.

Initial Recommendations (objective 2):

The proposed method is Option 1. This is consistent with the proposed approach to attributing 100% of the emissions from organic fertiliser production and incorporated straw to its primary product or primary reason for its existence. The carbon calculator could report results from both options 1 and 5 to demonstrate to growers that there is no definitive method.

Expert panel response (objective 3)

There was no consensus from the expert panel apart from the key advice that any method should be chosen with the proviso that the risk of perverse outcomes are minimised. One expert, with arguably the most experience in GHG assessments of biomass and crops, advocated economic allocation for exported straw above all other methods. This was qualified by the project team for the need to account for the costs of harvesting, grain drying, straw baling and carting on site from the sale price to provide the value of straw and grain in the field at the point of separation. This would have to be based on averaged default costs otherwise this would complicate data requirements especially where different costs occur regionally and at different times of the year due to changes in straw demand for bedding and feed.

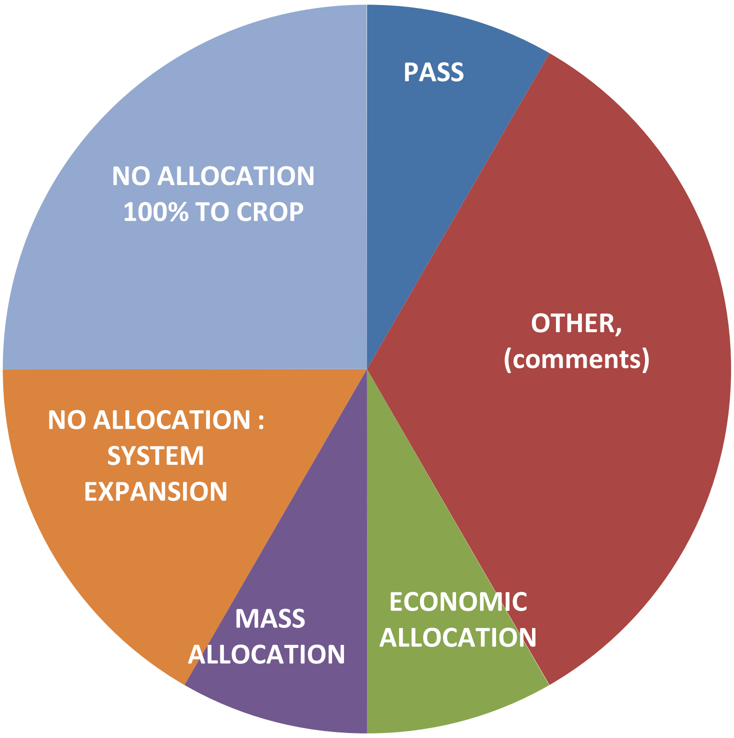


Figure 11. Expert panels response to the question of allocation of husbandry emissions to crop by-products

Case study feedback (objective 4)

Co-product allocations (i.e. to straw) were highly contentious and not recognised or acceptable amongst the growers that were part of the case studies. There would appear to be a risk that any method for allocation of GHG emissions to straw may destroy the validity of the carbon footprinting approach from the perspective of the growers.

3.3.11. Nitrous oxide emission methodology

Key question

Should the protocol use ‘tier 1’ IPPC methodology for nitrous oxide (N_2O) emission estimates for crop assessment?

The consensus of most of the literature reviewed is to use Intergovernmental Panel for Climate Change (IPCC) methodology for estimating nitrous oxide emission from agricultural crops and soils. ‘Tier 1’ methodology is commonly used to farm and crop assessments since detailed ‘tier 2’ and 3 methods are not currently endorsed in UK national inventory (and therefore PAS2050). However this does not necessarily mean that more soil and climate specific methods shouldn’t be used, such as the method adopted from Stehfest and Bouwman (2006), and used, in part, for the UK RED submission for regional cultivation estimates as a sensitivity analysis along with results from ‘tier 1’ (AEA 2010).

Review summary (objective 1)

The majority of the assessment literature found relies on IPCC methods for calculating nitrous oxide emissions from agricultural soils. These have been developed by the Intergovernmental Panel for Climate Change for national greenhouse gas inventory reporting as part of the Kyoto agreement on climate change.

The UK and Dutch national inventory interpretation of various revisions of IPCC ‘tier 1’ methods have been used by a number of the sources. The ‘tier 2’ (more detailed) category of method was used by AEA for the UK’s regional assessment of biofuel cultivation for article 19(2) of the EU Renewable Energy Directive, (RED) for biofuel carbon intensity reporting. This is because the RED requires the regional estimates for biofuel crop cultivation to account for variation in climate and soils. According the authors of the submission:

‘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......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’.

The 'tier 1' methodology is a much simpler approach for national inventory reporting. The method essentially provides blanket emission factors for the percentage of the total nitrogen inputs that are converted to nitrogen that is lost as nitrous oxide. The emission factor of 1% total nitrogen applied to soil is emitted as nitrogen in nitrous oxide, both directly and indirectly from re-deposition to soils after losses to the atmosphere during initial spreading. Also another emission factor is applied to nitrogen lost to groundwater. A default 30% of the total nitrogen input is assumed to have leached to groundwater.

N_2O emissions from cultivating organic soils

A blanket emission factor of 8 N_2O-N kg/ha for cultivating organic (peat derived) soils or histosols is given by the IPCC. The IPCC definition of organic soils follows an FAO (1998) definition[15] and may not accurately reflect the UK industry's understanding of organic soil. For example, the Agricultural Land Classification of England and Wales (1988) defined the texture class of organic mineral soils as having greater than 6% organic matter and 10% of organic matter if clay content is >50% whereas the FAO definition is 35 % organic matter for a mineral soil (~20% organic carbon).

Uncertainty

The uncertainty range for IPCC tier method for direct N_2O emissions are substantial (the IPCC 'tier 1' emission factor (EF) for direct N_2O emissions of 1.0% of N_2O-N yielded from N input is considered to be between 0.3 and 3.0%. The IPCC appears to suggest the emission factor is between a third and three times the estimated value for nitrogen lost as direct nitrous oxide emissions (N_2O-N) from nitrogen inputs to soils. As AEA (2010), citing Stehfest and Bouwman (2006) model for N_2O from N inputs to soils, report that the model's 95% confidence interval, a range between -51% to +107% of the estimated emission, is comparable to IPCC 'tier 1' uncertainty range. That is to say there is a 5% chance that the estimated result will not fall within the stated uncertainty range of half the estimate as a lower bound and over double the estimated emission as an upper bound.

Initial recommendation (objective 2)

The protocol or tool should allow an option for a simple 'tier 1' approach for assessment using IPCC (2006) defaults. Perhaps using primary data and similar UK sources for estimating nitrogen input from crop residues from the RED 19(2) (see Appendices) instead

[15] *'Soils are organic if they satisfy the requirements 1 and 2, or 1 and 3 below (FAO, 1998): 1. Thickness of 10 cm or more. A horizon less than 20 cm thick must have 12 percent or more organic carbon when mixed to a depth of 20 cm; 2. If the soil is never saturated with water for more than a few days, and contains more than 20 percent (by weight) organic carbon (about 35 percent organic matter); 3. If the soil is subject to water saturation episodes and has either: (i) at least 12 percent (by weight) organic carbon (about 20 percent organic matter) if it has no clay; or (ii) at least 18 percent (by weight) organic carbon (about 30 percent organic matter) if it has 60 percent or more clay; or (iii) an intermediate, proportional amount of organic carbon for intermediate amounts of clay (FAO, 1998)'.*

Source 11.6 footnote 4 ： http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_11_Ch11_N2O&CO2.pdf

of IPCC Table 11.2[16] for below ground residues, above ground biomass, dry matter nitrogen content etc.

Balancing reported improvements in accuracy with the practicalities of the extra data selection from farmers on categories of soil texture, pH, organic carbon content etc. it may be debateable as to whether a 'tier 2' methodology should be recommended.

Expert panel responses (objective 3)

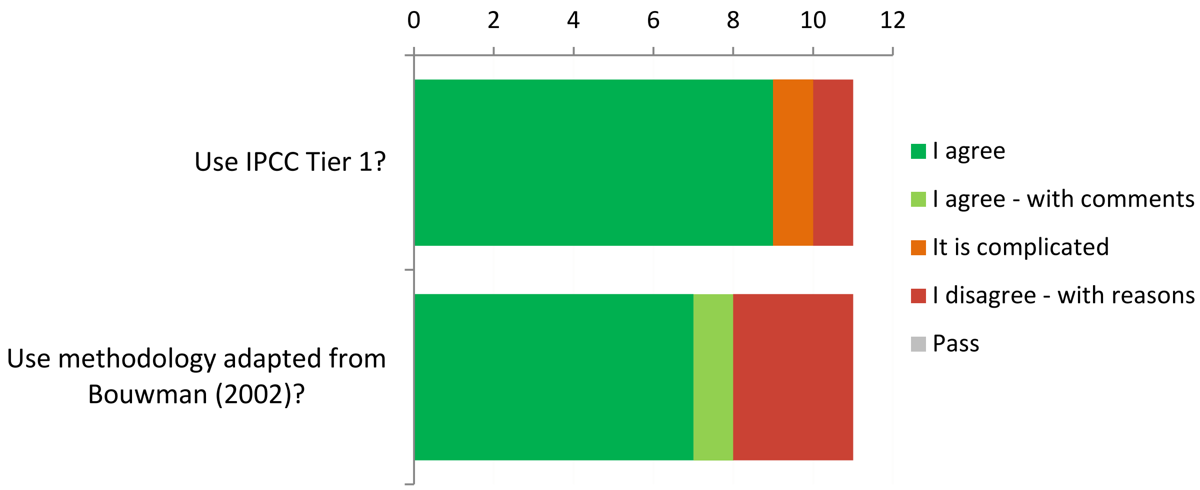


Figure 12. Expert panels response N_2O emissions methodology

A number of the expert panel did not agree with using the more detailed approach developed by Bouwman et al. (2002) for estimating nitrous oxide emissions from soils. For many reasons this was considered inappropriate by a key expert, though these reasons were not outlined. The AEA conclusions regarding the Bouwman and Stehfest (2006) model having no clear advantages over the favoured 'tier 1' IPCC method was also cited by another expert.

Case study feedback (objective 4)

Awareness of nitrous oxide as an important GHG in farming was very low amongst the case study growers. Most growers were unaware of different GHG's, and therefore their different global warming impact potential, though some knew that methane was worse than carbon dioxide and only one of the ten could explain where nitrous oxide comes from in the growing process.

[16] IPCC Table 11.2, published in http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_11_Ch11_N2O&CO2.pdf

One grower was very concerned about being penalised for the poorer soils which he and his colleague's farm. His concern related to the lower yields compared to growers who farm regions with more fertile soils and favourable climate and the bias that any supply chain benchmarking could disadvantage his crops and potentially be used to negotiate discounts. Also less fertile soils would possibly require greater nitrogen inputs resulting in more nitrous oxide emission following the proposed methodologies.

Given these concerns excluding a second 'tier 2' approach would be a suitable recommendation.

3.3.12. Accounting for land use change emissions

Key Questions

a) Should the protocol estimate and attribute land use change emissions for cropland that was formerly grassland or other land use?

b) If yes, should the protocol follow the consensus IPPC basic default carbon stock change method, and should the emissions be spread over ~20 years evenly, or incrementally amortised?

c) If the date of the land use change is not accurately known, how is this dealt with?

Review summary (objective 1)

Given CAP reforms, this aspect is only likely to apply to permanent grassland converted to arable land if this has been done within 20 years prior to the present. However, comments from the project team were made regarding grubbing of orchards and replanting justified for business productivity. An annual LUC emission per hectare is applied within the 20 year period post conversion.

Apart from the Agri-footprint method 1.0, the consensus appears to be using the IPCC defaults, or similar, for land use stocks and dividing these over a 20 year period either incrementally reducing from the transformation or evenly, (see summary 4.1.10 in Appendix A).

Initial recommendations (objective 2):

a) Only direct land use change emissions should be accounted for when changes in permanent land use occurs (5 year grass leys would not be considered permanent grassland), and the IPCC methodology and defaults should be adopted following consensus.

b) The IPCC default emissions from land use change should be allocated over 20 years evenly for simplicity. Therefore only GHG emissions from land use change should be accounted for in the crop inventory if the growing year overlaps with this 20 year window (post LUC).

c) Given a constant emission over 20 years following b) (rather than following an incremental reduction in emissions per year) an uncertain date would not give variations in attributed emissions with a 20 year period. The uncertain date should follow the method outlined by PAS2050-1:2012 for horticultural products.

Expert panel response (objective 3)

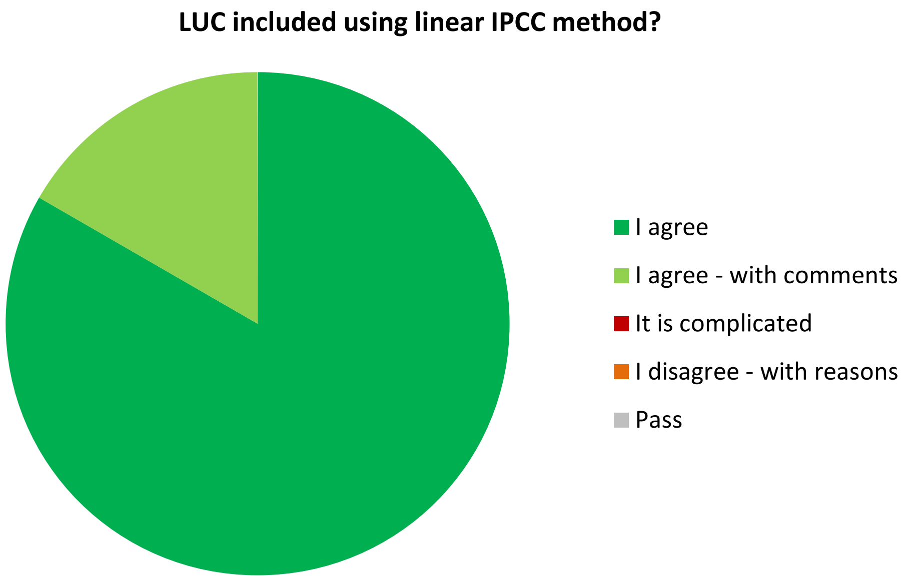


Figure 13. Expert panels response to the proposal for including the IPCC land use change emissions method

Case study feedback (objective 4) – no case study feedback was given.

3.3.13. Carbon uptake in crops and soil

Key questions

a) Following PAS2050 and WRI GHG protocol, should GHG removals (as well as emissions) be estimated and reported as part of the HGCA protocol?

b) Should temporary carbon storage in crops and straw (if a co-product) be reported at the farm gate, or should this biogenic carbon be ignored by the inventory?

c) Can increases in soil carbon storage be estimated due to management improvements (as outlined in the management factors given in the IPCC methods, and suggested in the RED)?

Review summary (objective 1)

Carbon storage in crops

The ILCD detailed guidance gives options for the inclusion of temporary carbon storage and the equivalent delayed emissions:
'If this is within the first 100 years from the time of the assessment it shall not be considered quantitatively'. However, the ILCD also states that "temporary carbon storage" shall only be considered if explicitly required to meet the specific goal of a study.

If it is an explicit requirement, then the ILCD provisions require that 'flows shall carry a GWP_{100} year impact factor of -0.01 kg CO_2 eq kg CO_2 $^{-1}$ year^{-1} of storage/delayed emission'. Essentially a 1 per cent credit for every year carbon is stored.

Biogenic carbon in the straw and crop is excluded from a number of the protocols where these are used for food or feed. Except for feed and food, recent changes to PAS2050 require removals (carbon taken up by photosynthesis) even if temporary, to be reported. So potentially straw exported for purposes other than food or feed may still require carbon removal to be reported separately at the farm gate following PAS2050:2011.

In conclusion, storage may only be appropriate where straw is used for further bio-based products that are not combusted or degraded over many years, but it is considered inappropriate for crops and a farm gate boundary where these are largely produced for food and feed.

Increased carbon storage in soil

The Renewable Energy Directive makes provision for emission savings from soil carbon sequestration via ‘improved agricultural management’. Management factors are also documented in the IPCC reporting methodology (IPPC 2006).

However, the PAS2050 specification and related horticultural supplementary requirements exclude soil carbon from the inventories due to the uncertainty associated with calculating additional sequestration. The issue is that permanence of additional soil carbon, i.e. an increase in stocks built up through altering tillage practices or increasing organic inputs, is hard to guarantee over 100 years. A change in management practice to deep ploughing in the future may release soil organic carbon relatively rapidly compared to the sequestration rate potentially undoing carbon uptake that has been claimed as sequestration. An analogy would be sequestering carbon by planting trees and assuming the afforested area will mature, permanently storing a set amount of carbon for over a 100 years, (a time period typically applied in GHG assessments to qualify genuine carbon sequestration). But if the land is cleared for agriculture before forest maturity the actual GHG benefits of carbon storage would be largely negated since the wood is likely to be burnt or decomposed and ultimately returned to the atmosphere within the 100 year period.

Additionality

A final complication is that it is difficult to ascertain net carbon sequestration. An additional change in carbon stored depends on knowing the baseline carbon stock of the soil– i.e. having a good assessment of the soil organic carbon content at equilibrium prior to management changes. Also, additionality from another location would occur anyway. It would be complicated to explain and demonstrate to growers that organic inputs could ordinarily be returned to the soil anyway, irrespective of local storage. From a global perspective, this would not result in any increase in net carbon storage, ruling out claims of additional or genuine carbon sequestration.

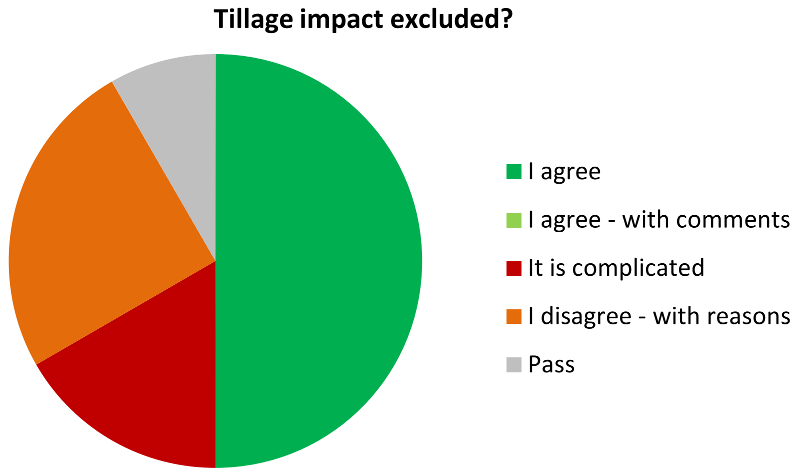
Initial recommendations (objective 2)

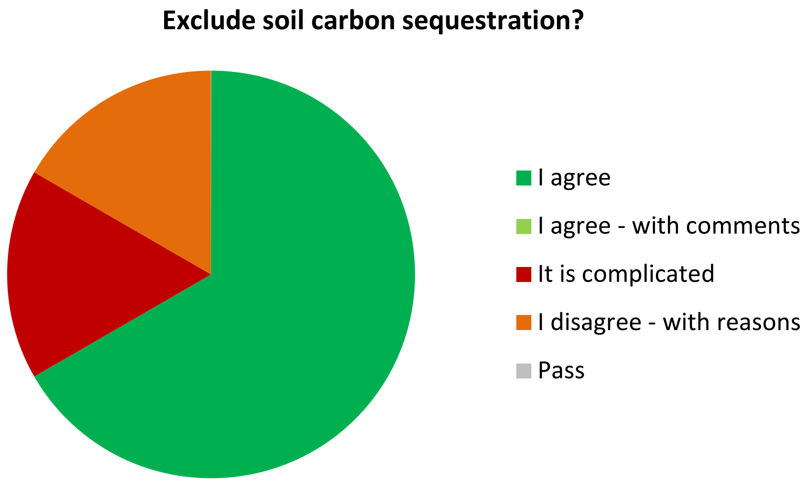
For these reasons, the proposal is to exclude from the protocol GHG impacts of soil carbon changes that are not associated with land use changes.
Also carbon sequestered within crops is proposed to be excluded from the protocol for carbon footprint assessment of oilseed and cereal crops.

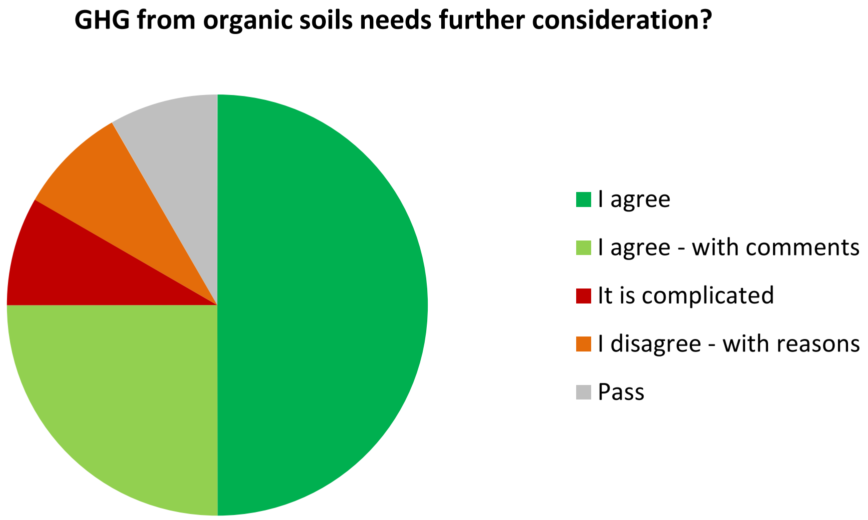
Expert panel response (objective 3)

This subject area is complex and a number of the experts had different views on what would be important to include or the complications of excluding.

Figure 14. Expert panel response to the excluding various elements and further consideration for organic soils







3.3.14. Primary data requirements

Key question Should the protocol provide rules for growers for minimum requirements for input data? The primary goal communicated by the HGCA is grower engagement. However, a goal of the protocol and related calculator is also to produce a GHG assessment that is a representative estimate of the emissions of a grower's typical crop to satisfy pressure from supply chain requirements for grower reporting. This has implications for requirements on how data is selected to prevent bias.

Review summary (objective 1)

Temporal data requirements

Assessments that are based on a single growing year may not be representative of the typical crop due to differences in climate between growing years. For this reason, it is recommended that a running average is used (following ILCD Guidance 2010 and RTFO). However this may be burdensome in practical application. Users would be required calculate averages from historical records of fertiliser inputs, yield, moisture and operational fuel specific to each crop. This may not be feasible for many growers.

Since the primary goal of the HGCA calculator/protocol is to encourage uptake by as many growers as possible, it is recommended that a two tier assessment providing both a single year assessment and an optional rolling average where historical data is available to the grower.

For example:

- A simple, less demanding option for providing data for a single year should be mandatory.
- Adding historical data from the past 4 years could be encouraged but left optional.

Saving annual entries to a user account could be implemented when a more sophisticated web based tool is developed.

Spatial data sampling

Husbandry of the same crop in different fields may vary and therefore inputs and operations and related emissions may vary in a single harvest year. The supplementary requirements to PAS2050-1:2012 for field horticulture crops includes a sampling regime that requires 100% of field data(yields, inputs etc.) to be collected from single growers. Capturing all of this variation through 100% sampling regime for farm input data may be onerous and unrealistic.

PAS2050-1:2012 offers a sampling rule which is aimed at assessment by buyers, processers and retailers who procure produce from multiple growers of horticultural products. These sampling requirements are not applicable to arable crops from individual growers.

Initial recommendations (objective 2)

Growers may operate farms with ten's to hundreds of fields extending over different soil types and growing combinable crops in varying systems. Ensuring primary data is representative of the growers' fields would require a sampling procedure that is not onerous but still be broadly representative of the typical crop supplied by the grower. Measures should prevent selective bias, such as growers selecting their best performing fields not their overall growing average.

The following recommendations for the protocol are made:

A) Primary data shall reflect GHG emissions for the average farm production of crops, reported within each broad crop group outlined previously.

B) A scientifically robust sampling procedure to represent a typical crop from many fields over a number of seasons could be onerous, and potentially reduce practical engagement by growers with the protocol and calculator.

To strike a balance between the use of representative data and practicality mandatory requirements for calculating area weighted arithmetic mean averages of yield and inputs and selection of a statistically robust sample size of growers' fields are not given. The growers guide should be consulted which provides advice on the best practice approach for primary data.

For example, for the purposes of supply chain reporting, advice could be given in the growers guide to provide estimates for fields that exhibit middle range values in terms of yield and inputs where such fields make a dominant contribution to the total output of the crop within the respective crop categories. This would encourage growers to report a fair and representative GHG assessment to interested parties.

C) For a simpler 'tier 1' assessment the grower shall use an estimated typical yield per hectare and inputs for the harvested crop in the most common soil type and husbandry used to grow the crop .

D) For more detailed 'tier 2' assessments the grower shall provide yield and fertiliser input data based on a minimum of 3 seasons growing records to obtain an average assessment, representative of the grower.

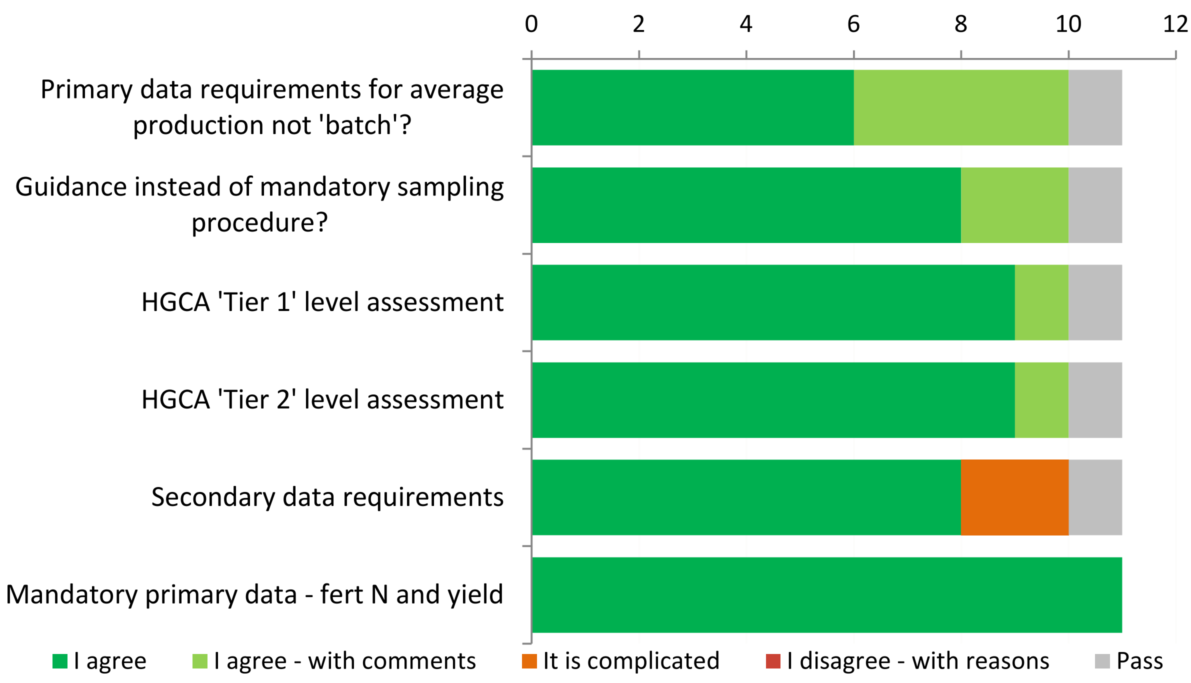
E) For processes such as grain drying and machinery fuel use where secondary data is considered more accurate or accessible than primary data, though perhaps is older or geographically less appropriate etc., this data shall be used in preference.

Implemented in a carbon calculator for example, a 'tier 1' assessments fuel use data (litres per Ha) for field operations and grain drying may be fixed defaults taken from secondary sources. For ‘tier 2’ assessments, fuel use for each operation shall be the same defaults but could be open for modification by the grower.

F) Primary data on the quantity of nitrogen applied and the type of fertiliser shall be mandatory, as shall primary data on crop yields.

Expert panel response (objective 3)

Figure 15. Expert panel response to proposed primary and secondary data requirements and associated methodologies



Case study feedback (objective 4)

Only C, E & F were implemented in the tool.

The proposed 2 tier approach to allow single year and 3 year average data was not implemented in the tool in favour of keeping a simpler single year approach. Many farms have data field by field and will not usually have 3 year averages readily available for yield, fertiliser and especially fuel use for individual operations.

Most growers were thought to have yield data at an aggregate level for each year, but input data was not aggregated. So there was a concern that growers, rather than be able to get a feel for the average fertiliser used per hectare for crops over the dominant soil type farmed, would have to calculate weighted averages for inputs from complex data records, maybe 50+ fields over 3 years. This applies more so for fuel used for individual field operations.

There are significant gaps in knowledge on key costs and returns which can affect the grower's carbon footprint- notably diesel use for field operations. Interestingly all the case study farmers knew they both needed and wanted to know more about whether their field operations (and their machinery) were efficient, but none were routinely recording data on this. This is an area where a focus on carbon could be united with a clear commercial driver given the rapid increase in fuel prices.

The case study feedback highlighted the issue of seasonal impacts on yields. Several farmers were not keen to do the assessments based on their 2011 crop data given the very low yields achieved due to drought. For single year assessments most of the emissions will be incurred before crop yield is known, so assessments must be conducted retrospectively which favours guiding growers to use an average approach. It may be that a 'tier 2' approach should still be implemented but requiring 3 year averages for yield and nitrogen fertiliser inputs, and allowing operational fuel use to rely on the tool default data.

The 'tier 1' approach should still be possible by encouraging a best estimate for the grower's average crop yield and nitrogen fertiliser application for a single year's crop growing cycle on the dominant soil type over the farmed land. Guidance for 'tier 1' data requirements should be given in the growers guide and the tool.

3.3.15. Secondary data quality requirements

Key Question

For purposes of transparency, should secondary data quality requirements be included in the protocol?

A number of the protocols and guidance documents provide criteria for the selection and use of suitable published data for estimating the greenhouse gas emissions from the manufacture of inputs to the farm such as fertiliser, or the production and combustion emissions associated with fuels. Some protocols and guidance documents require some form of assessment of the data quality used to be reported.

Review summary (objective 1)

Given the scope of the project is to provide a protocol that will be implemented through a carbon calculator, these secondary data quality requirements given in a protocol will not be directly relevant to the grower. Rather these should be used to select the most appropriate data for use in the tool. Realistically, data availability is likely to be the key determinants of selected data, since the availability of directly appropriate data is often limited.

Where provisions for secondary data requirements are given in the reviewed literature, it is mainly with regard to preferences for certain sources of data, such as peer reviewed literature, international and government reports and guidelines, but also to data quality criteria such as those given in PAS2050 and the GHG protocol.

Initial recommendations (objective 2)

Data quality requirements for secondary data shall follow the requirements of PAS2050 (7.2), interpreted with respect to crop production as below:

Accuracy preference:

The secondary data used for defaults or replacing primary data shall be justified, i.e. that it is likely to be more accurate or realistic than collecting primary data from growers.

Technology preference:

The data shall be based on technology that reflects the machinery and inputs (fertiliser etc.) used in the UK, as far as is practical.

Age preference:
The most recent secondary data sources shall be preferred. This refers mainly with regard to emission factors and models (IPCC or otherwise).

Geographical preference:
The choice of data sources shall give preference to UK climate, energy mix. Sources of data shall prefer UK government publications and accepted international sources (IPCC) shall be considered within the context of UK farm scale GHG assessment.

Contravention:
If data sources contravene these general requirements, these shall be clearly communicated, and justification given.
It is proposed for transparency purposes that the Growers Guide shall explain the data sources used in the calculator, and where these contravene the data quality requirements above, justifications shall be clearly given.

Expert panel response (objective 3)

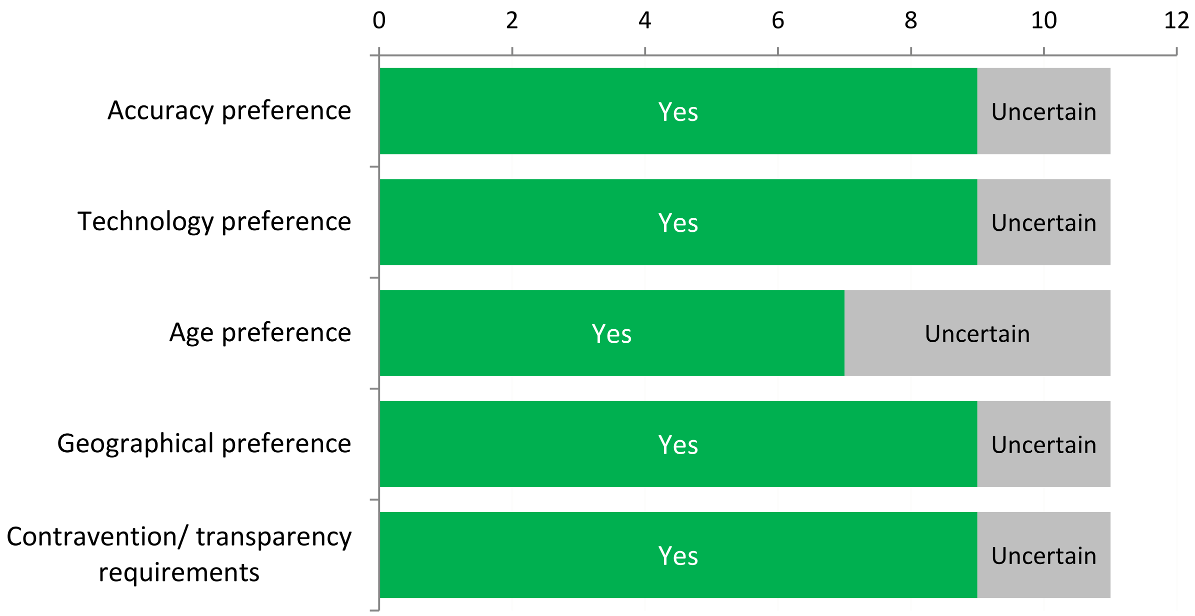


Figure 16. Expert panels response to data quality requirements of the protocol

Case study feedback and finalised protocol (objective 4)
The secondary data quality requirements were considered redundant for the carbon calculator development. These were then excluded from the final protocol. Instead, it is

recommended that descriptions of the secondary data are provided in the Growers Guide to provide transparency in how the carbon footprint estimates are made.

3.3.16. Uncertainty

> Key Question
> Should uncertainty be communicated in the final results of the protocol, and if so how?
>
> The original project specification outlined the need to for transparency in reporting uncertainty:
> 'Uncertainty in product-level carbon footprint assessment calculations can never be totally removed but by developing a standard protocol, the HGCA aims to provide a tool that manages and reports uncertainties in a consistent and transparent way for the UK Cereals and Oilseeds sector'.

Review summary (objective 1)

Only three protocols had formal requirements to report the uncertainty, ISO14040 as interpreted through ILCD requires quantitative expression of the lack of precision. The WRI protocol for product life cycle assessment requires a qualitative statement on uncertainty in the data inventory used. Much of the Ecoinvent data has uncertainty ranges within each unit process; these can be used in LCA software using Montecarlo analysis. The Dutch Agri-footprint method 1.0 also advocates this approach for full life cycle assessment of agricultural products using mean averages and standard deviations of input data.

A section on conducting an uncertainty assessment was a part of the original PAS2050:2008 but was not a requirement. This has since been removed from the revised PAS2050:2011 though it is likely that ISO14067 will require a quantitative and qualitative uncertainty assessment (BSI 2011).

N_2O emitted from nitrogen inputs has a substantial contribution to the carbon footprint of arable crops. Fairly large uncertainties are given for the IPCC tier 1 methods for the assessment of nitrous oxide emissions from nitrogen inputs to soils, (see section 3.3.11 p68). It is arguable that incorporating these log-normal ranges into the results of the tool could dominate most other GHG sources and therefore may not be conducive to helping farmers engage with the issue of greenhouse gas mitigation. Though, if transparency is required in reporting uncertainty, this may be necessary. An alternative is to describe the issue of uncertainty in the Growers Guide.

Variability of data and results is also handled by PAS2050 which requires averages to be used for data, but requires re-assessment if circumstances are likely to alter product carbon results by 5% over a 3 month period. 5% is likely to be within the uncertainty range and reporting tolerance for primary data for most crop estimates. Therefore these re-assessment rules appear to be inappropriate for the proposed protocol.

Initial recommendation (objective 2)

It is recommended that uncertainty in the assessment is described qualitatively in the Growers Guide by way of an overview. Explaining the scientific details behind the uncertainty ranges in the models for N_2O emissions may complicate the basic goal to engage farmers with the carbon footprint process.

3.3.17. Initial proposed protocol

1. Defining the crop emissions reporting unit

The report estimated growing GHG emissions against one metric tonne of crop produced: The growing emissions will be corrected to 1 metric tonne at commercially appropriate stored moisture content:

• Cereal grain 14.5%

• Oilseeds 9 %

2. Product reporting group

A. For the purposes of future benchmarking and fair comparisons - the GHG emissions shall be reported for within the following broad crop group categories:

• nabim Group 1 - wheat for bread making

• nabim Group 2 - wheat primarily for bread making but with other uses

• nabim Group 3 - wheat for biscuit or non-bread baking etc.

• Group 4 - wheat for other uses - animal feed, biofuel etc.

• Malting barley

• Feed barley

• Oilseed rape - food grade

• Oilseed rape - industrial (including biofuels etc.)

• Linseed

• Food oats

• Feed oats
• Rye
• Triticale

B. The reporting groups shall further distinguish between winter and spring varieties.

3. Defining the farm gate

Emissions from grain drying and first storage shall be included whether stored on farm or in co-operative/merchant managed stores*.

Transport emissions from transfers between the farm to any offsite drying and first storage shall be included.

4. Defining the cut-off criteria

The HGCA protocol shall not require specific quantitative cut-off criteria to define the detail of upstream sources of GHG's to exclude. The included processes shall be outlined in this protocol and has been subject to expert consultation and the protocols data quality requirements.

4b. Temporal cut off.

For consistency with other protocols:

1. The assessment of global warming impact for crop growing to the farm gate shall be within a 100 year time period from production at the farm gate.
2. The global warming potentials of greenhouse gases shall be within a 100 year period from being emitted.

(Please note: though these temporal boundary issues are combined here, it is acknowledged that there are different reasons for 1 and 2 within an assessment protocol).

5(i). Excluded Processes

A. Production and supply of buildings and infrastructure.
B. Maintenance of buildings and infrastructure
C. Production of agricultural machinery and equipment
D. Maintenance of agricultural machinery and equipment
E. Carbon dioxide removals, (sequestration), from the atmosphere and storage of carbon in crops and straw.

F. The production, treatment and storage of manure, biosolids and compost within the control of a third party, (but not transport to site), that are used as organic fertilisers.
G. Perfluorocarbons, Hydrofluorocarbons and sulphur hexafluoride.
H. Human labour and related workforce transport or housing emissions.

5(ii) - Included processes.

Activities	**Proposed Initially**	**Key** **Y** = within assessment boundary **N** = Not included or not mentioned in the assessment boundary
Seeds production	Y	
Fertiliser production	Y	
Pesticides production	Y	
Fuel production	Y	
Lime production & emissions	Y	
Compost production from wastes	N	
Biosolids (sewage sludge) production and processing	N	
Manure production	N	
Transport of each input to regional warehouses	Y	
Transport of each input from regional warehouses to farm	Y	
Transport of crop for drying (if necessary)	Y	
Diesel combustion emissions from individual field operations	Y	
Emissions from production of machinery	N	
Emissions from production of buildings	N	

Consumables for maintenance (including maintenance of capital equipment)	N	
Emissions from manure storage	N	
Electricity production and supply	Y	
Direct nitrous oxide emissions from soils by fertiliser (min & org) input	Y	
Direct nitrous oxide emissions from soils due to crop residues	Y	
Indirect nitrous oxide emissions from fertiliser volatilised and re-deposited	Y	
Indirect nitrous oxide emissions from leached fertiliser	Y	
Emissions from crop drying	Y	
Emissions from crop storage	Y	
Emissions from operation of all building premises	N	
Land use emissions from soil organic matter (peaty soils) cultivation	Y	
Land use change emissions	Y	
Land use sequestration from management (organic inputs or tillage)	N	

6. Attribution of GHG's from organic inputs

A. Nitrous oxide emissions from the nitrogen in organic inputs shall be attributed to the following crop on the basis of 'readily available nitrogen', not total nitrogen.

B. With reference to RB209, the unavailable organic nitrogen fraction of organic inputs shall be assumed to remain after the first crop.

Notes: For the purposes of applying a methodology for estimating nitrous oxide emissions it shall be assumed that 100% of the organic nitrogen fraction is mineralised.

For intermittent or periodic spreading of organic fertiliser nitrous oxide emissions shall be estimated as a function of the recalcitrant nitrogen fraction using either a ‘tier 1’ or ‘tier 2’ approach. These N_2O emissions shall be attributed to the following crops grown evenly (in proportion to their area not yield) over subsequent years, until the next manure application. If organic fertiliser is applied before each crop, then the nitrous oxide yield will be estimated assuming mineral nitrogen equals the total nitrogen input, (readily available N + unavailable N). The estimated emissions in this case shall all be attributed to each following crop.

C. GHG emissions from processes required for growing green manures shall be allocated to the next crop in proportion to the readily available nitrogen. The remaining production emissions shall be attributed to following crops using the same method proposed for recalcitrant nitrogen (B).

D. Due to the defined assessment boundary, (reporting a single crop rather than for a crop system), and for consistency with the previous approaches emissions from a crop’s residues (including straw if incorporated) shall be attributed to that crop’s emissions profile.

The total nitrogen in crop residues and straw shall be assumed to be mineralised for the purposes of applying (‘tier 1’ or ‘tier 2’) methodology to estimate N_2O emissions.

7. Allocation between crops and straw

100% of the GHG emissions from crop growing shall be attributed to the grain. Straw is not attributed any of the crop growing emissions.

8. Soil carbon and land use change emissions

A. GHG emissions from direct land use changes shall be included in the crop inventory. LUC shall be estimated in a fairly simple manner based on the IPCC's methodology, where emissions from LUC shall be linearly annualised over a 20 year period to allow attribution to an annual crop growing cycle.

(PAS2050:2011 follows this approach and has default estimates for annual CO_2 emissions from ‘grassland’ or ‘forestry’ to ‘arable’ that could be used).

B. Soil carbon sequestration - a long term increase in soil carbon storage - through low and no till practices shall be excluded from the GHG crop inventory.
Notes: Permanence is hard to guarantee over the 100 year assessment period. Built up soil organic carbon could be lost relatively rapidly with a change in regime to deep ploughing for example.

C. Soil carbon sequestration from inputs - shall be excluded in GHG crop inventory by the protocol.
Notes: Though the IPCC provides a simple management factor for manure inputs, more data intensive modelling approaches would be required at the farm level. These are beyond the practical goals of the HGCA protocol and calculator.
There are also considerable uncertainties attached to estimating whether sequestration from inputs may actually be an additional removal of carbon dioxide, or just shifting the carbon storage location.

D. Carbon dioxide emissions from the draining of peat and cultivation of organic or peaty soils can be estimated using IPCC land use and land use change ‘tier 1’ methodologies.

9. Primary data requirements
A. Primary data shall reflect GHG emissions for the average farm production of crops, reported within each broad crop group outlined previously.
Notes: This would allow growers to report a fair and representative GHG assessment to interested parties.

B. A scientifically robust sampling procedure to represent a typical crop from many fields over a number of seasons could be onerous, and potentially reduce practical engagement by growers with the protocol and calculator.
Notes: To strike a balance between the use of representative data and practicality mandatory requirements for calculating area weighted arithmetic mean averages of yield and inputs and selection of a statistically robust sample size of growers’ fields are not given. The Growers Guide should be consulted which provides advice on the best practice approach for primary data.

C. For a simpler 'tier 1' assessment, the grower shall use an estimated typical yield per hectare and inputs for the harvested crop in the most common soil type and husbandry used to grow the crop.

D. For more detailed 'tier 2' assessments, the grower shall provide yield and fertiliser input data based on a minimum of 3 seasons growing records to obtain an average assessment, representative of the grower.

E. For processes such as grain drying and machinery fuel use where secondary data is considered more accurate or accessible than primary data, though perhaps is older or geographically less appropriate etc., this data shall be used in preference.

Notes: Implemented in a carbon calculator for example, a 'tier 1' assessment's fuel use data (litres per Ha) for field operations and grain drying may be fixed defaults taken from secondary sources. For 'tier 2' assessments, fuel use for each operation shall be the same defaults but could be open for modification by the grower.

F. Primary data on the quantity of nitrogen applied and the type of fertiliser shall be mandatory, as shall primary data on crop yields.

10. Secondary data quality requirements

Data quality shall follow the requirements of PAS2050 (7.2) - interpreted with respect to crop production as below:

Accuracy preference:

The secondary data used for defaults or replacing primary data shall be justified, i.e. that it is likely to be more accurate or realistic than collecting primary data from growers.

Technology preference:

The data shall be based on technology that reflects the machinery and inputs (fertiliser etc.) used in the UK, as far as is practical.

Age preference:

The most recent secondary data sources shall be preferred. This refers mainly with regard to emission factors and models (IPCC or otherwise).

Geographical preference:

The choice of data sources shall give preference to UK climate, energy mix. Sources of data shall prefer UK government publications and accepted international sources (IPCC) shall be considered within the context of UK farm scale GHG assessment.

Contravention:
If data sources contravene these general requirements, these shall be clearly communicated, and justification given.

Notes: The Growers Guide shall explain the data sources used in the calculator, and where these contravene the data quality requirements above, justifications shall be clearly given.

11. Nitrous oxide emissions
A. The IPCC ‘tier 1’ methodology for nitrous oxide emissions shall be used to conduct a HGCA level 1 crop assessment.
This was proposed with the prospect of including direct as well as indirect nitrous oxide emissions resulting from nitrogen application on crop land, (i.e. from atmospheric redeposition and also N_2O from N that has been leached from soils to groundwater beyond the farm geographical boundary).

B. Where this allows GHG mitigation through better management decision, making a more detailed (tier 2) methodology shall be used for level 2 assessments of nitrous oxide emissions from crop production. This shall require specific reference to the crops growing conditions with regard to:
• Fertiliser type
• Fertiliser application rate
• Crop type
• Categories of simple soil parameters (texture, organic carbon, drainage etc.) Note: This is based on empirical modelling by Bouwman et al. (2002).

3.4. Carbon Calculator Review Materials and Methods

3.4.1. Introduction

Central to this project is that the calculator should be

1. Usable by farmers without the support of consultants, advisory services, LCA practitioners, etc.
2. Provide decision support functionality with robust and credible outputs
3. Have an educational purpose in order to empower farmers

An assessment of existing calculators was conducted for applicability in this context.

3.4.2. Review source

The assessment consisted firstly of collating a list of existing tools from review articles of Driver et al. (2010) and Sheane et al. (2010) followed in large part the recent review by Whittaker et al. (2013). Driver et al. (2010) is a review of global scope which categorises more than 60 agriculture relevant GHG calculators or models. Sheane et al. (2010) is a review of farm-based GHG accounting tools conducted for the Scottish Government. A partial list of the tools reviewed is provided later in this report.

3.4.3. Exclusion criteria

Many of the tools or models were excluded from further analysis simply because UK cereals and oilseeds were not within their scope. In addition, process-based models were excluded since the requirement for expert involvement in their initialisation, application, and interpretation currently makes them unsuitable as user-friendly decision-support tools within the given context. Models which were described only in journal articles were excluded as not meeting the constraint of being immediately usable by farmers.

3.4.4. Scoring

Most of the calculators found were recently evaluated by Whittaker et al. (2013) with equally weighted scores of 0 to 3 (as percentages of actual to maximum) given for categories of user-friendliness, information, comprehensiveness and transparency (Table 6). The SAC GHG calculator and the CEUKF wheat GHG tool were augmented to the list of tools evaluated by Whittaker et al. (2013). Since the criteria assessed in Whittaker et al. (2013) directly relate to the key properties identified above, this was adopted here, but with the scores re-classified as follows; “very high” (81-100%), “high” (61-80%), “medium” (41-60%), “low” (21-40%) and “very low” (0-20%).

Though this provides a relative assessment of the different tools available, it is acknowledged that the user-friendliness scoring is somewhat subjective and the reviewers who have made scoring choices are not representative of farmers.

Table 6 showing the scoring methodology taken from Whittaker et al. (submitted for review)

	Score			
Criteria	**3**	**2**	**1**	**0**
User Friendliness				
Is the tool readily available?	Yes- online or ready to download	Yes - but requires installation	Yes- but requires permission /password	Not available
Is support available?	Yes- a support telephone number	Yes - a support email address	Less obvious	None
Are manuals provided?	Yes - detailed with data collection guidance	Yes - detailed manual	Basic instructions	None
Target User	Any	Some knowledge required	Trained user	Expert
Quality of Tool design and architecture	Very easy to use	Some navigation required	Limited but functional	Not user friendly
Are alternative units are provided?	Yes - to many inputs	Yes - to some	A few key inputs	No
Rating				
Informative				
What format are results provided in?	Graphical and tabular	Tabular	A single number and a graph	A single number
Does the tool provide a breakdown of where emissions occur?	Yes - clear demonstration of where results occur	Emissions are grouped into categories but separate emissions can be calculated	Emissions are grouped into categories	No breakdown
Rating				
Transparency				
Upfront level of transparency of emission factor data	Full & detailed disclosure of data	Limited disclosure of data	Can be estimated by manipulation of input data	No details given
Is it clear whether or not direct and indirect emissions are included for N2O emissions?	They are measured separately/this is stated in the supporting material	From the resources used it is clear whether or not this is included	Not referenced, but from the results it is clear whether this is included	Not evident
Is it clear whether emissions from crop residue incorporation are included?	They are measured separately/this is stated in the supporting material	From the resources used it is clear whether or not this is included	Not referenced, but from the results it is clear whether or not this is included	Not evident
Are global warming potentials stated?	Yes GWP's are stated and referenced	Separate GHG's are listed but as CO2 equivalents	All results are provided as CO2 equivalents.	CO2 only given

	Score			
Criteria	**3**	**2**	**1**	**0**
Rating				
Comprehensiveness				
Does the tool include emissions from fertiliser application?	N, P and K are included separately	Only N is included	Fertilisers' are grouped into one category	Not included
Does the tool differentiate between N fertiliser types?	Yes a few types of N fertiliser	Yes- between organic and non-organic	N fertiliser is only measured as 'kg N'	No/Not included
Does the tool include emissions from fertiliser manufacture?	Yes - with references provided for specific fertiliser	Yes but for generic 'N fertiliser' emission factor	Yes but not referenced	Not clear/no
Does the tool include direct N2O emissions from fertiliser application?	IPCC - higher tier applied	IPCC Tier 1	Another method used	Not clear/no
Does the tool include indirect N2O emissions from fertiliser?	IPCC - higher tier applied	IPCC Tier 1	Another method used	Not clear/no
Are soil parameters required for N2O emissions?	Yes - the N2O results depend on it	Can be otherwise defaults are used	Yes but is not apparently used	Not clear/no
Does the tool include N2O emissions from crop residue incorporation?	IPCC method used and results are based the defined fate of straw	IPCC - but not linked to any information specified by user	Some other method	Not clear/no
Does the tool include N2O emissions from manure application?	IPCC - higher tier applied	IPCC Tier 1	Another method used	Not clear/no
Is uncertainty addressed?	Yes- for inputs and emission factors including N2O emissions	N2O emissions uncertainty included	Uncertainty in inputs and emission factors included	No uncertainty addressed
Does the tool include land use change?	Yes - from specific land conversion scenarios - with references	Yes- from specific changes in soil SOC	Yes in some way but it is not referenced	Not included

3.5. Carbon Calculator Review – Results

3.5.1. List of calculators

Table 7 List of calculators - those which were not excluded are marked "OK".

Tool	Applicability/description	Reviewer
CALM	OK	Sheane et al.
C-PLAN	OK	Sheane et al.
SAC	OK	Sheane et al.
Dairy & livestock tool	Dairy, closed source	Sheane et al.
GHG emissions in dairy farming	Discontinued	Sheane et al.
Greenhouse in Agriculture	Non-UK	Sheane et al.
Int'l Wine Carbon Calculator	Non-UK; 'too niche'	Sheane et al.
DairyCrest Carbon Calculator	Dairy	Sheane et al.
COMET-VR	Non-UK	Sheane et al.
Farming Enterprise GHG Calculator	Non-UK	Sheane et al.
FarmGas	Non-UK	Sheane et al.
HGCA Biofuel GHG Calculator	OK	Sheane et al.
CFF Organic Farmer Carbon Calculator	OK	Sheane et al.
DeNitrification-DeComposition	Process based model	Sheane et al.
Lincoln Farm Carbon Calculator	Non-UK	Sheane et al.
ACR Fertilizer Management	Non-UK	Driver et al.
ACR Forest Carbon	Forest	Driver et al.
ACR Livestock Manure Management	Livestock	Driver et al.
AOS Beef Feeding (Edible Oils)	Beef	Driver et al.
AOS Beef Feeding (Reducing Days-on-Feed)	Beef	Driver et al.
AOS Beef Life cycle	Beef	Driver et al.
AOS Biogas	Manure only	Driver et al.
AOS Dairy Cattle	Dairy	Driver et al.
AOS Energy Efficiency	Energy only	Driver et al.
Nitrous Oxide Emission Reduction Protocol (NERP)	Non-UK	Driver et al.

AOS Pork	Pork only	Driver et al.
AOS Tillage	Non-UK	Driver et al.
APEX - Agricultural Policy Environmental eXtender	Process-based model	Driver et al.
Australian Farm GAS Calculator	Non-UK	Driver et al.
Beauchemin et al 2010	Non-UK	Driver et al.
CAR - Forest Project Protocol	Forest	Driver et al.
CAR - Livestock Project	Livestock	Driver et al.
Carbon Trust	Expensive	Driver et al.
CASA Express or CASA CQUEST	Process based model	Driver et al.
CCX - Agricultural Best Management Practices	No N2O	Driver et al.
CCX - Agricultural Methane	o N2O	Driver et al.
CCX - Forestry Carbon Sequestration	No N2O	Driver et al.
CCX - Sustainably Managed Rangeland	No N2O	Driver et al.
CDM -- ACM0010	Livestock	Driver et al.
CDM (small-scale) -- IIIA Nitrogen Fertilizer Offset	Too niche	Driver et al.
COMET-VR/ -FARM	Process based model	Driver et al.
Cool Farm Tool	OK	Driver et al.
DAYCENT/ CENTURY	Process based model	Driver et al.
DMI 2007	Milk only	Driver et al.
FAO 2010 Dairy	Dairy	Driver et al.
FAO EX-ACT (EX-ante Appraisal Carbon Balance Tool)	Landscape tool	Driver et al.
Field to Market	Non-UK	Driver et al.
GHGS	Livestock	Driver et al.
HOLOS	Non-UK	Driver et al.
Peters et al 2010	Non-UK	Driver et al.
RGGI - Manure Management	Manure only	Driver et al.
RGGI -Afforestation	Forest	Driver et al.
RothC	Process based model	Driver et al.
VCS ALM Grassland Management	Grass only	Driver et al.

VCS MSU – EPRI	Non-UK	Driver et al.
VCS –SALM	SOC only	Driver et al.
VCS - Afforestation/ Reforestation	Forest	Driver et al.
Biograce calculator	OK	Other
Muntons barley calculator	OK	Other
RFA-RTFO	OK	Other
CEUKF wheat GHG assessment tool	OK	Other

3.5.2. Evaluation of applicable tools

In general, it is apparent, from the selected list below, that the differing scope of biofuels (RFA-RTFO, BEAT, RSB, HGCA Biofuel Calculator) and farmer focused tools leads to different performance with respect to the above criteria. Given that biofuels tools are often designed with the LCA practitioner in mind this implies that key criteria were comprehensiveness and transparency not usability by the farmer. Whereas, in general, the farmer focused tools achieve user-friendliness at the expense of comprehensiveness.

Table 8 Selected calculators for evaluation.

Calculator	**Format**	**Reporting unit**	**Available**	**User-friendliness**	**Informativity**	**Transparency**	**Comprehensiveness**
CALM	Online	Whole farm	Y	H	VH	H	M
C-Plan	Online	Whole farm	Y	H	M	L	L
SAC farm assessment tool	Spreadsheet	Whole farm	?	M	H	H*	M
Ccalc	Spreadsheet	User-defined	Y	H	M	M	L
Cool Farm Tool	Spreadsheet	Whole farm/unit of land/unit of crop	Y	H	VH	VH	VH
Climate Friendly Food	Online	Whole farm	Y	H	VH	M	L
Munton's Barley calculator	Spreadsheet	1 tonne of crop	Y	M	VL	VL	L
CEUKF wheat GHG assessment tool		?	?	M	H	VH	VH
RFA-RTFO calculator	Download standalone	1 hectare of crop	Y	H	H	M	M
BEAT	Download standalone	1 hectare of crop	Y	L	VH	VH	L

RSB	Online	1 hectare of crop	Y	H	VH	VH	VH
HGCA Biofuel GHG calculator	Online	1 tonne/litre bioethanol	Y	H	H	M	L

* Since the tool is Excel-based transparency is assumed, although this hasn't been verified.

The tools with the highest score with respect to the above key criteria were the Cool Farm Tool, the CEUKF wheat GHG assessment tool, and the RFA-RTFO calculator. There is considerable commonality in these tools (indeed in most of the above) in terms of the algorithms and emissions factors used. However, none of these achieved the maximum in terms of user-friendliness often due to imperfect matching with respect to language, format and scope.

It was thus concluded to build a new tool for the purpose of this project. However, as described in the above section on protocol development, this would not mean any innovation in terms of the algorithms employed but only the user interface - which should be novel, designed entirely with the farmer in mind, and be subjected to iterative user-review throughout the project.

3.6. Case study tool testing

The case studies selected for the trial of the tool were selected both via direct contact and intermediaries (e.g. Anglia Farmers) to represent a range of farms in terms of location, scale, ownership, type of farming system (organic and conventional), crop type (barley, wheat and oilseeds), soil type and production system (e.g. including plough based, heavy single pass samba type cultivator, min-till).

The farms covered the following counties: Lincolnshire, Humberside, Norfolk, Cambridgeshire, Northamptonshire, Oxfordshire and soil types including peat, clay, silt, loam and sandy brash. The farms ranged in size from 300 acres to over 4,000 acres and included council tenants, owner occupiers and contract farmers. Notably, many of the farms were engaged in contract farming or farm management contracts in addition to their core or own farm (in one case they managed 5 additional farms for local landowners). One of the farms was an organic contractor (although they also had some conventional production). Winter and spring barley (both feed and malting), winter wheat and oilseed rape were all used in the case studies and across a variety of farm and soil types.

The farmers selected were also those who were known to be technically competent and progressive as it was felt that these would be more likely to engage in a research and development project, and be more likely to have the data needed to populate the tool. In two cases the farms were linked to research or educational establishments and, in these case studies, lecturers or researchers were also engaged in addition to the farm managers to help understand the level of knowledge of the issues amongst those who spend their time advising others on agronomy.

3.7. Results of case study testing

3.7.1. Assessment results

A summary of results from the case studies is shown below in order to provide a context for further assessments by individuals. The crops represented were winter wheat (4), malting barley(3), oilseed rape(2), spring barley(1).

Whilst the results may be taken in the absence of more complete survey data to represent reasonable figures for emissions from UK cereal and oilseed production, it is important to note that the case studies represent emissions from a single year and for particular site conditions. More robust estimates of emissions would require multiple years and a more comprehensive coverage of sites and management options.

3.7.2. General observations

The following general observations were made from the case study assessments and farmer interviews:

Context

The language of carbon footprinting, e.g. CO_2 or CO_2–equivalents lacks value for the farmers. These measures were seen as intangible and thus lack meaning in absolute terms. For farmers to engage and begin to assess practical mitigation observations it is necessary to provide context to the figures through benchmarking or other more innovative reporting methods. The collated results of the case studies at the start of this section, in conjunction with the Growers Guide were developed with this purpose.

Nitrogen issues

kg CO_2 equivalents per tonne	Malting Barley	Spring barley	Oilseed rape	Winter wheat	Winter wheat	Winter wheat	Oilseed rape	Malting barley	Winter wheat	Malting barley
Mineral N applied	0	85	241	235	205	149	177	147	213	130
Fuels used	85	61	52	66	64	52	51	80	99	54
Yield (dried weight)	5	8	4	8	8	9	5	4	9	7
Fertiliser production	0	43	217	121	102	102	211	98	100	74
Fertiliser induced field emissions	111	114	453	220	213	101	215	209	167	124
Agrochemicals	0	25	53	26	25	27	49	45	28	11
Crop residue management	0	0	29	0	0	10	27	8	3	5
Field energy use	41	20	36	22	21	15	27	46	30	20
Grain drying	4	7	0	9	0	2	4	6	6	9
Transport off site	3	14	0	0	0	0	5	0	0	0
Totals	158	225	788	398	361	257	538	412	334	243

The focus on "carbon" can be misleading in the context of cereals and oilseeds, since the major source of GHG emissions for conventionally grown crops is related to nitrogen supply. Since the relationship between N supply and grain yields is clearly established for such crops, the most obvious mitigation options relate quite simply to good agronomy – optimising outputs against inputs. Since N fertiliser production and field N_2O emissions are acknowledged hotspots, they also represent potentially very effective mitigation opportunities. Both the fertiliser manufacturing sector and the academic community are investing substantial effort in identifying options to mitigate the emissions in this regard whilst maintaining production. A calculator should have the flexibility to adapt its emission factors accordingly as improvements are made.

Organic methods

The concept of an annual or single crop carbon footprint does not adapt itself easily to organic farming methods. In organic cereal production systems a 5 or 6 year rotation is employed within which there is a 2-year “fertility building” phase involving the use of leguminous clovers. The uncertainty about the quantity of N fixed and the fate of that N (plant uptake, direct N_2O emission, or indirect loss through e.g. volatilisation or leaching) is greater than for conventional systems, which means that quantification is less certain. In addition, yields tend to be higher in crops grown immediately after the fertility building period in relation to those grown later in the rotation, which in turn affects the emission per unit produced. Although proposed solutions may involve allocation to individual crops or assessment of a rotation as a whole, the complications in relation to benchmarking are clear. A reasonable conclusion at this stage is that it is more tractable and relevant to focus on improving understanding of conventional cropping systems since these account for the major part of crop production in the UK and consequently GHG emissions. It is anticipated that improved quantification of these systems will inform methods to analyse organic farming systems.

Supply chain sensitivity

There is concern about how the outputs of carbon footprinting assessments will be used in the supply chain. Some regions are less favourable than others for cereal and oilseed production. This is already reflected in differing productivity performance. Any programme which may provoke the supply chain to employ carbon thresholds with regard to sourcing is undesirable without a more considered analysis of environmental, social, and economic consequences.

Allocation

The concept of allocation to co-products lacks meaning for most farmers since it produces artefacts, such as the straw price, affecting the emissions per unit of grain produced, even though management and production may be fixed. The loss of credibility with farmers in proposing such methods makes it inappropriate to use in a scalable educational format currently.

Levels of detail

A method offering a combination of Level 1 and Level 2 input data appeared more likely to confuse than enlighten at this point in time. The key messages surrounding the importance of optimising inputs and outputs emerge with the Level 1 method.

Pesticides

Emissions from pesticides were included in the final tool although emissions from infrastructure, seed, etc. were not. This is because the use of agro-chemicals is considered to be a controllable input for farmers whereas embedded emissions, in e.g. machinery, buildings and seed, are not.

3.7.3. Revised final protocol after expert workshop and case study testing

In view of the findings from meetings with the HGCA after the expert workshop and subsequently from feedback received by the farm case studies outlined in the previous section, a simpler protocol is proposed below.

1. Defining the crop emissions reporting unit

Report estimated growing GHG emissions against one metric tonne of crop produced:

The growing emissions will be corrected to 1 metric tonne at commercially appropriate stored moisture content:

• Cereal grain 14.5%

• Oilseeds 9 %

2. Product reporting group

A. For the purposes of future benchmarking and fair comparisons - the GHG emissions shall be reported for within the following broad crop group categories:

- nabim Group 1 - wheat for bread making
- nabim Group 2 - wheat primarily for bread making but with other uses
- nabim Group 3 - wheat for biscuit or non-bread baking etc
- nabim Group 4 - wheat for other uses - animal feed, biofuel etc.
- Malting barley
- Feed barley
- Oilseed rape - food grade plus biofuels
- Oilseed rape - industrial and speciality
- Linseed

- Food oats.
- Feed oats
- Rye
- Triticale

B. The reporting groups shall further distinguish between winter and spring varieties.

3. Defining the farm gate

Emissions from grain drying and first storage shall be included whether stored on farm or in co-operative/merchant managed stores*.

Transport emissions from transfers between the farm to any offsite drying and first storage shall be included.

4. Defining the cut-off criteria

The HGCA protocol shall not require specific quantitative cut-off criteria to define the detail of upstream sources of GHG's to exclude. The included processes shall be outlined in this protocol and have been subject to expert consultation and the protocols data quality requirements.

B. Temporal cut off.

For consistency with other protocols:

1. The assessment of global warming impact for crop growing to the farm gate shall be within a 100 year time period from production at the farm gate.

2. The global warming potentials of greenhouse gases shall be within a 100 year period from being emitted.

(Please note: though these temporal boundary issues are combined here, it is acknowledged that there are different reasons for 1 and 2 within an assessment protocol)

5(i). Excluded Processes

A. Production and supply of buildings and infrastructure.

B. Maintenance of buildings and infrastructure

C. Production of agricultural machinery and equipment

D. Maintenance of agricultural machinery and equipment

E. Carbon dioxide removals, (sequestration), from the atmosphere and storage of carbon in crops and straw.

F. The production, treatment and storage of manure, biosolids and compost within the control of a third party (but not transport to site) that are used as organic fertilisers.

G. Perfluorocarbons, hydroflourocarbons and sulphur hexafluoride.

H. Human labour and related workforce transport or housing emissions.

J. Non crop growing general farm activities such as drainage, ditching, hedging and conservation schemes etc.

5(ii) – Included processes

	Proposed Initially	Revised protocol	**Key** **Y** = Within assessment boundary **N** = Not included or not mentioned in the assessment boundary
Seeds production	Y	Y	
Fertiliser production	Y	Y	
Pesticides production	Y	Y	
Fuel production	Y	Y	
Lime production & emissions	Y	Y	
Compost production from wastes	N	N	
Biosolids (sewage sludge) production and processing	N	N	
Manure production	N	N	
Transport of each input to regional warehouses	Y	Y	
Transport of each input from regional warehouses to farm	Y	Y	
Transport of crop for drying (if necessary)	Y	Y	
Diesel combustion emissions from individual field operations	Y	Y	
Emissions from production of machinery	N	N	
Emissions from production of buildings	N	N	
Consumables for maintenance (including maintenance of capital equipment)	N	N	
Emissions from manure storage	N	N	
Electricity production and supply	Y	Y	
Direct nitrous oxide emissions from soils by fertiliser (min & org) input	Y	Y	
Direct nitrous oxide emissions from soils due to crop residues	Y	Y	
Indirect nitrous oxide emissions from fertiliser volatilised and re-deposited	Y	Y	
Indirect nitrous oxide emissions from leached fertiliser	Y	Y	
Emissions from crop drying	Y	Y	
Emissions from crop storage	Y	Y	
Emissions from operation of all building premises	N	N	

Land use emissions from soil organic matter (peaty soils) cultivation	Y	N	
Land use change emissions	Y	N	
Land use sequestration from management (organic inputs or tillage)	N	N	

6. Attribution of GHG's from organic inputs

A. Nitrous oxide emissions from the nitrogen in organic inputs shall be attributed to the following crop on the basis of 'readily available nitrogen', not total nitrogen.

B. The available organic nitrogen fraction is calculated with reference to RB209 and the IPCC tier 1 emission factors shall be applied to this as if this were total nitrogen to estimate nitrous oxide emissions attributable to the following crop. The unavailable organic nitrogen fraction of organic inputs remaining after the first crop shall be excluded from the assessment boundary.

C. GHG emissions from processes required for growing green manures shall be allocated to the next crop in proportion to the readily available nitrogen where this data is available.

D. Due to the defined assessment boundary (reporting a single crop rather than for a crop system) and for consistency with the previous approaches, emissions from a crop's residues (including straw if incorporated) shall be attributed to that crop's emissions profile.

E. The total nitrogen in crop residues and straw shall be assumed to be mineralised for the purposes of applying (IPCC tier 1) methodology to estimate N_2O emissions.

7. Allocation between crops and straw

All of the GHG emissions from crop growing shall be attributed to the grain. Straw is not attributed any of the crop growing emissions.

8. Soil carbon and land use change emissions

All soil GHG emissions from land use changes are not considered by this protocol.

Notes: Land use change is not a common concern since arable land is typically well established in the UK. In general transitions between, say, arable and pasture are temporary and part of established farm management practices (e.g. use of ley crops). These would not be classed as land use changes.

Transitions between woodland and arable cropping are better covered in a whole farm assessment since they require assurance of good calibration of the woodland component (adding to the data entry burden and beyond the scope of this project). In addition to these issues, many crops are contract managed, thus the farmer may have limited availability of historic land use, tillage or production data within the 20 year period from which any land use change should be counted.

Carbon sequestration from land management and organic inputs are not considered by this protocol.

Notes: A change to deep ploughing may rapidly release any soil carbon that has been sequestered through inputs and management. So it is difficult to guarantee permanence of any practices that have sequestered soil carbon over the 100 year assessment period. Also assessing whether soil carbon storage is currently in a state of equilibrium with management practices is very difficult without direct measurement and more complicated modelling.

9. Primary data requirements

Notes:

A scientifically robust sampling procedure to represent a typical crop from many fields over a number of seasons could be onerous, and potentially reduce practical engagement by growers with the protocol and calculator.

To strike a balance between the use of representative data and practicality mandatory requirements for calculating area weighted arithmetic mean averages of yield and inputs and selection of a statistically robust sample size of growers' fields are not given. The growers guide should be consulted which provides advice on the best practice approach for primary data collation.

A. The grower shall use an estimated typical yield per hectare and inputs for the harvested crop in the most common soil type and husbandry used to grow the crop.

B. For processes such as grain drying and machinery fuel use where secondary data is considered more accurate or accessible than primary data, though perhaps is older or geographically less appropriate etc., this data shall be used in preference.

C. Primary data on the quantity of nitrogen applied and the type of fertiliser shall be mandatory as shall primary data on crop yields.

11. Nitrous oxide emissions

The IPCC tier 1 methodology for nitrous oxide emissions shall be used to conduct a crop GHG assessment.

This shall include direct as well as indirect nitrous oxide emissions resulting from nitrogen application on crop land, (i.e. from atmospheric redeposition and also nitrous oxide from nitrogen that has been leached from soils to groundwater beyond the farm geographical boundary).

3.8. Discussion

3.8.1. Existing product protocols for the supply chain

Specifications already exist for product assessments which are applicable for supply chain requirements. These are evolving towards sector specific requirements. The key specification for greenhouse gas assessment of products, PAS2050 (BSI 2011), may attract the development of supplementary requirements for cereals and oilseeds, just as the horticulture sector has developed the first supplementary requirements PAS2050-1:2012 (co-sponsored by the Dutch Product Board for Horticulture and the Dutch Ministry of Economic Affairs, Agriculture and Innovations). Given the move to formalise product carbon footprint assessments for horticultural products and the forthcoming ISO14067 product carbon footprint standard, which is similarly aligned to include equivalents to supplementary requirements, these specifications are the most likely candidates for buyers and retailers supply chain requirements for the arable sector.

3.8.2. Is a 'farmer-friendly' supply chain protocol possible?

Product assessment oriented protocol for supply chains

The criteria for developing a protocol for growers was based on the consensus of existing methodologies and specifications, therefore the first draft protocol necessarily adopts similar requirements of supply chain orientated carbon footprint assessments. Supply chain influence was a factor that was highlighted by the HGCA in commissioning this project. The HGCA considers levy payers to be under increasing pressure to provide carbon footprints for buyers or for supply chain assessments[17] therefore it was sensible to follow published supply chain oriented methodologies.

[17] The original project specification emphasised the supply chain as a key reason for the protocol stating: '*Buyers are also introducing carbon footprint assessment and labelling schemes which require associated farmers to undertake farm-level carbon audits. [HGCA] has received an increasing number of enquiries on carbon footprint assessment as pressure to supply this information grows. To provide levy payers with the best*

Are reporting standards drivers for crop footprinting?

The key UK product carbon footprint standard (PAS2050:2011 Clause 7.3) appears, however, to only require processors or manufacturers using grains to obtain actual primary data from crop growers if their own processes contribute less than 10% to the supply chain and processing carbon footprint. Though this clause is a little ambiguous and clearly interpreting the boundary for calculating the 10% threshold is difficult. This begs the question as to whether a misinterpretation of standards is driving the demand for carbon footprint information from growers when an off the shelf average using secondary sources could conform to the requirements. If this is not the case, then the requirements and motives of the organisations requiring famers to supply this information need to be clearly understood in developing any protocol.

Initial two tier approach

Delivering a carbon footprint protocol which has the objectives of being 'farmer-friendly' whilst rivalling the more demanding requirements for published product greenhouse gas assessments was a difficult challenge. The protocol required a balance to be struck between these competing objectives. The risk of compromising both objectives to the point that neither is achievable or effective was a distinct tension in the initial development of the protocol.

In an attempt to resolve this problem a two tier option was initially proposed. This was designed to allow growers that wished to conduct a more detailed assessment for suppliers to add more information('tier 2'), whilst growers only able to supply basic inputs, such as fertiliser input and crop yield, could conduct simple ('tier 1') assessments. During the tool development, certain elements of the detailed 'tier 2' approach were disregarded and the protocol evolved into a simpler tool aimed more at grower engagement with some options to override default fuel use for different farming operations.

Separate protocols for separate objectives

To develop a supply chain assessments protocol, an explicitly separate and distinct process to the development of a (simpler) 'farmer-friendly' tool or other medium for grower awareness and engagement, is needed. It may be appropriate for the HGCA to lead the development of any BSI or ISO supplementary requirements for cereal and oilseed crops greenhouse gas assessments, just as the Dutch Horticulture board have for horticultural products. Supplementary requirements may override much of the general requirements of

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available advice and tools, HGCA wishes to commission a project to develop a standard protocol for farm gate, product-level carbon accounting specific to the UK Cereals and Oilseeds sector. It is likely that this work will be extended to the full supply chain at a later date.

PAS2050 so the process may allow an independent and trusted representation to be made whilst reducing confusion within industry if different specifications and protocols arose.

3.8.3. Qualifying the objective of carbon footprint assessment

If the objective is ultimately to encourage more GHG efficient farming practices, is it necessary for a grower to quantify their own crops' carbon footprints?

With or without carbon footprint assessments further resources will be required to promote GHG efficient farming practices. The key question is whether quantifying crop GHG emissions will encourage growers to tackle additional GHG mitigation activities or whether this is an extra layer of complexity. A secondary question is whether existing scientific methodologies available for the carbon footprint process are sensitive or appropriate for farm level management practices.

3.8.4. GHG assessments and crop assurance

Two of the growers that were involved in the case study testing reported that they felt this area of work was where farm assurance was 15 years ago, with competing standards and systems, and they wanted HGCA to take a lead so that a common standard can be achieved and delivered.

Crop assurance schemes differ, however, from carbon footprint assessments. Rather than an audit against largely qualitative criteria such as management procedures[18], carbon footprints aim to quantify greenhouse gas emissions from complex interactive systems which are highly variable. Quantifying greenhouse gas emissions per tonne of crop or per hectare also brings in the notion of good and bad performance. Concerns were raised by growers during case study testing that any performance element, even if unintended, could potentially unfairly discriminate regions with less favourable soils and climate (and respective differences in inputs and associated yields).

3.8.5. Uncertainty reporting

Another aspect that limits GHG emissions as a crop performance measure is the uncertainty associated with assessments. Many published carbon footprint estimates for crops, methodologies or the tools that have been developed rarely include uncertainty ranges in

[18] Schemes such as the UK Red tractor combinable crop assurance for cereals and sugar beet (AFS 2012) are largely based on auditing against documented procedural and management practices rather than quantitative assessments, see www.redtractorassurance.org.uk.

their final reported results. Yet some of the underlying uncertainties in the methodologies used can be quite large relative to the final reported result, even when aggregated. This is especially so for GHG emissions from managing soils. An argument for purposely omitting uncertainty margins, is that this may risk engaging growers by requiring burdensome explanations and scientific discourse on estimating global N_2O yields from fertiliser use. Providing growers with final results indicating that there is a 95% chance that results are within ±60% of the reported average value[19], for example, could also give the impression that carbon footprint assessments are not a very useful way of benchmarking performance for decision making and GHG mitigation.

Sensitivity

The level of detail required for a farmer-friendly carbon footprint tool and the emissions methodology available means that the sensitivity to improving certain management practices is limited. The majority of the GHG emissions predicted by the tool for conventional cereal and oilseed crops are effectively a simple function of nitrogen use and crop yield. This is because nitrous oxide from nitrogen spread to land and emissions from nitrogenous fertiliser manufacture are the dominant contributors to a conventional cereal or oilseed crop's carbon footprint relative to the tonne of crop yielded (Hillier et al, 2009). Secondary data on emissions from mineral fertiliser manufacture is typically the second largest contribution to conventional husbandry. The other key factor, fuel use, is likely to rely heavily on secondary data and defaults for farm operations since most growers in the case studies did not record fuel use for specific field operations.

[19] Williams et al., 2006 quote an estimate for coefficient of variation of 30% (ratio of standard deviation to mean) for aggregated uncertainty for emissions agricultural products modelled to the farm gate. Assuming a normal uncertainty distribution for the uncertainty distribution of the results (this may not be the case), , 95 % of the results could lie within 2 standard deviations from the mean i.e. ±60% of the emission. The IPCC uncertainty range for the estimating of nitrous oxide emissions from nitrogen use in soils is log normal, between a 33% and 300% of than the estimated value.

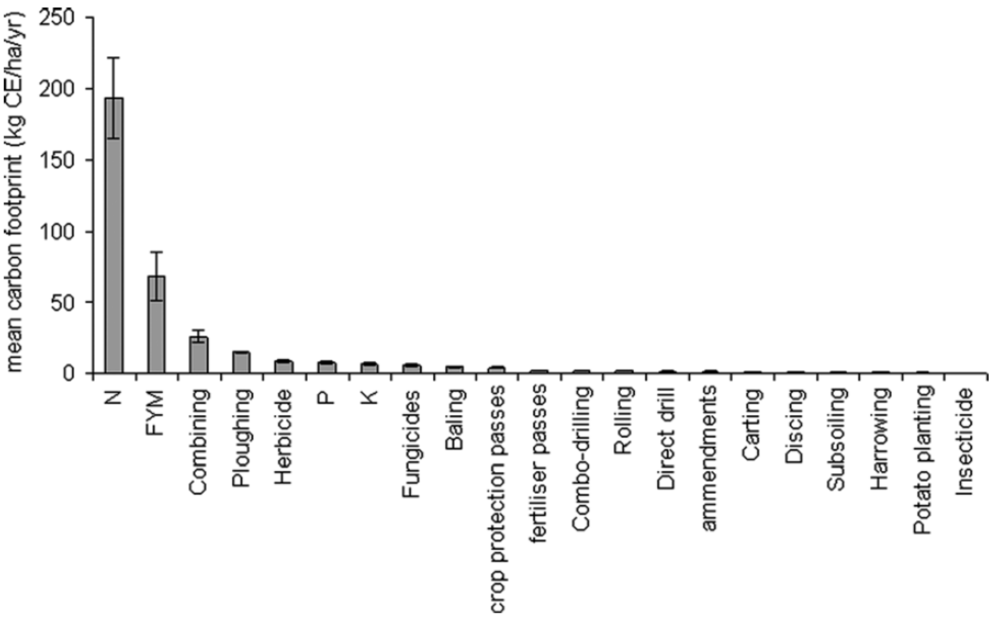

Figure 17. The average source of GHG emissions (as carbon equivalents, not CO_2 equivalents) per Ha for arable crops (chiefly cereals, oilseeds, potatoes and break crops) from a survey of 54 Scottish farms. The error bars represent the standard error of the survey results and do not include the uncertainty in the methodology used for estimating emissions. (Taken from Hillier et al. 2009)

3.8.6. Efficacy of a carbon footprint decision support tool for engagement and stimulating crop level GHG mitigation

Support process

The awareness of key sources of greenhouse gases was generally poor amongst the case study growers. This emphasised that a carbon footprint tool for grower engagement necessitates some kind of initial support to explain the data required for the technical elements of product carbon footprint assessments beyond just a grower's guide.

Case studies showed that once growers were guided through the process and knew what records were required, the process time for the first crop assessment could be cut to 10 minutes for the final crop assessment. Again, the initial interaction and guidance with the project team member was considered key to this learning process.

Evidence

The efficacy of carbon assessments stimulating net GHG mitigation by growers would be very useful evidence to support the carbon footprint agenda. Anecdotal evidence from the project teams experience suggests that informed farmers do know (and like) the message that carbon footprints per tonne are closely linked to technical performance, with healthy crops which use resources well (especially nitrogen) scoring well on both carbon footprints and financial success. This has been backed to some degree by a study on farm technical efficiency being correlated with environmental performance using data from farm business surveys (Wilson et al., 2001).

The counter argument is that targeting nitrogen efficiency in the whole farming and wider food system through direct support towards improving best practice for recycling nutrients (including composted food waste, AD digestate and biosolids), preventing losses and inhibiting N_2O through fertiliser technology may be just as beneficial with or without having to burden farmers with putting numbers on their crops. However this is a complex area with seemingly few studies comparing these different approaches in a robust way, and though an interesting and valuable avenue to explore it is sadly beyond the scope and remits of this project.

3.8.7. Key conclusions and recommendations

1. A protocol developed for simple grower engagement should initially be separate to more demanding requirements of existing supply chain mediated reporting requirements[20], which are currently subject to a number of issues such as:

   a) An immature development, understanding and acceptance of appropriate, specific and clear life cycle product assessment methods and data requirements;

   b) Models for emissions that are not very sensitive to specific farm management activities;

   c) A farming community that needs time and support to adapt to this kind of process.

2. If grower engagement is the main goal of a carbon footprint tool then it is strongly recommended that an active engagement process also needs to be supported alongside any tool. Larger groups of growers hosted by regional training centres exploiting existing farming networks would be a suggested approach. Ideally this kind of enterprise would be jointly sponsored through industry (cooperatives, buyers and retailers,) and also public sector bodies who have a similar policy agenda, giving growers the impetus to attend.

[20] Or at least if a single document is produced this should have two tiers to satisfy the detail required for these different purposes.

3. If the rationale for a farmer-friendly carbon footprint protocol is to help growers target emission reductions, it may be useful to find evidence to support this. Otherwise there could be a counter argument that supporting GHG mitigation by promoting key low carbon management practices, such as improving nitrogen efficiency[21] without the perceived additional complexity of encouraging quantitative carbon footprint assessments is as effective, are making grower carbon footprint assessments less relevant or even burdensome.

4. If crop assessment for supply chain reporting is also an important objective then currently more buyers and downstream stakeholders who require this kind of information from growers should be involved in the consortia to help support this process. This would require more and longer term support to allow growers to become accustomed to supply information that is consistent with existing specifications.

5. Following 3, it may be useful to consider developing a PAS2050 (or ISO14067 equivalent) supplementary requirement for cereal and oilseed crops in parallel but separate and distinct from grower engagement activity. This would help to improve acceptance of carbon footprinting within the industry and help to reduce any uncertainty and confusion by not publishing different competing approaches. Given time, the grower engagement process could be designed to converge with the technical requirements of a supply chain product assessment protocol.

6. One approach for solving the data demands is to investigate whether there is potential to integrate carbon footprinting tools seamlessly into existing or developing farm management software that is likely to be used widely (now and in the future) by growers or via their agronomists for farm inventory record keeping and assurance.

[21] The red tractor combinable crop assurance scheme already includes requirements for nutrient plans and nutrient efficiency to have been conducted.

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WRI 2011b. Product Life Cycle Accounting and Reporting Standard. World Resources Institute.

4. APPENDICES

4.1. Appendix A – Summary of the reviewed literature

4.1.1. Goals and scope

Source	GOAL AND SCOPE
The International Reference Life Cycle Data System (ILCD) Handbook: General Guide for Life Cycle Assessment- Detailed Guidance.	The (ILCD) Handbook provides detailed technical guidance to ISO14040 and 14044:2006 standards on life cycle assessment. It provides detailed method provisions for LCA studies. As such, this document represents the application of ISO14040 and 14044 standards and so replaces a review of these separately. It is a general guidance document and does not provide product group guidance, but proposes to act as a parent document for specific guidance documents and therefore has some relevance to developing a GHG protocol for cereals. The guidance defines situations with relevant provisions aligned to the assessment for these. The most appropriate situation for carbon footprint calculations for cereal and oilseed crops is defined in the handbook as situation A: a partial attributional life cycle assessment for micro-level decision support. Provisions are made in the ILCD guide specifically for agro systems (7.4.4.1).
Audsley et al., 1998	The report is a concerted action from the EU to harmonise methods for environmental Life Cycle Assessment (LCA) for agriculture. It is a methodological study using three cases studies for growing wheat, one in the UK and two in Switzerland. The scope of the study is to use these case studies to address issues related to LCA for environmental impacts and resource use (not limited to GHG emissions).
Life Cycle Inventories of Agricultural Production Systems. Data v2.0. Ecoinvent report No.15	The goal of the Swiss Centre for Life Cycle Inventories is to offer a set of unified and generic life cycle inventory data of high quality. The aim of the Ecoinvent report No.15 is to provide datasets for agricultural production, including crop production systems that are typical of Switzerland, Europe and the US, (Methods and data for the US production systems are not considered below). The inventory includes elemental flows

Source	GOAL AND SCOPE
(2007)	(emissions from and elements taken) by individual unit processes; these can be combined into systems to give inventories for agricultural production. The environmental impact of these flows on natural systems can be characterised by various methods. Estimating the global warming potential of the greenhouse gases emitted in the elemental flows based on the latest IPCC equivalents is one such method, along with many other methods of accounting for different potential (environmental) impacts.
The EU Renewable Energy Directive - as interpreted by AEA for the UK under article 19.2	Article 19(2) of the EU Renewable Energy Directive (Directive 2009/28/EC) requires Member States to submit a report, by 31 March 2010, including a list of areas in their territory where typical average GHG emissions from crop cultivation can be expected to be at, or below, default figures set out in Annex V, part D. Therefore a methodology for calculating regional estimates of the carbon intensity (GHG) for cultivation of biofuel feedstocks is required. The UK methodology to estimate regional emissions for biofuel cultivation is presented by AEA as an interpretation of RED methodology for estimating default regional emissions for biofuel cultivation, on behalf of the UK Government's Department for Transport. This methodology has since been updated (15/12/2010) and this version is included in the review summaries. The methodology uses national data to estimate greenhouse gas emissions (defined in the RED) as co_2eq per MJ fuel for cultivation. The feedstocks considered are winter feed wheat; winter barley; spring barley; oats; triticale; oilseed rape (OSR)and sugarbeet.
The EU Renewable Energy Directive	Article 17.2 of The EU Renewable Energy Directive requires member states to require economic operators to show that the biofuels and bioliquids concerned comply with the sustainability criteria including greenhouse gas savings. The Directive contains

Source	GOAL AND SCOPE
	rules for calculating greenhouse gas savings, (Annex V part C, augmented by various communications; 2010/C 160/02 etc.). This necessitates the calculation of greenhouse gas emissions for biofuel crop feedstocks. The RED has been deemed unpractical for regulation due to the lack of details for calculations to be made without differences in interpretation, (Whittaker et al,, 2011). However a draft standard, BS EN16214-4, interpreting the RED GHG calculation methodology has been released for public comment and interested parties by British Standards. Where detail is lacking in the Directive literature, for the purposes of the review, this draft and Biograce[22] literature has been used for interpretation.
UK Renewable transport fuels obligation methodology (Bauen et al., 2008)	To provide a methodology to fairly differentiate between the carbon intensity of biofuels on a well to wheels basis. A second goal, though reported as a lesser priority, is to provide assessment of the impact of the policy on GHG emissions. The scope is for default emissions along the fuel chains of each biofuel pathway to be provided for the calculation of biofuel emissions per MJ fuel delivered.
Greenhouse Gas Protocol – Draft Agricultural Protocol (unfinished) for farm-level inventories	Guidance for incorporating GHG accounting and reporting of agricultural production into inventories of producers and their customers to: Increase consistency and transparency in accounting; standardise approaches and principles; meet decision making needs of internal management and external stakeholders; and provide more effective management of emissions along the agri-supply chain. The protocol is for organisation based accounting not product level accounting. The protocol is not aligned with the WRI's Product GHG reporting protocol, but rather the Corporate Level

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Source	GOAL AND SCOPE
	Standards. As such, the agricultural guidance is not a standalone protocol but is to be used in conjunction with the GHG Protocol Corporate Standard (WRI 2004) and/or 'Scope 3 standard' for supply chain partners who wish to include agricultural emissions in their organisation inventory. However there is one section in this protocol (6.3) that refers to 'ratio indicators', where the definition of intensity ratio is applicable for reporting GHG emissions per crop with the suggested function of comparing across businesses. However the protocol sets these as optional and are reported along with the required absolute GHG emissions (ch 9).
WRI Product life cycle accounting and reporting standard 2011	The product life cycle accounting and reporting standard is for performance tracking of products' GHG emissions reductions over time. It is not a prescriptive standard for making product comparisons or business decisions making, though guidance is given on additional specifications needed (allocation choices and data sources etc.). The objectives of the standard focus on transparent reporting more than specific methodology.
PAS2050:2011	Primary objective to provide a common basis for GHG emissions quantification to inform GHG reduction programmes. The British standards specification for greenhouse gas life cycle assessment requirements is generically applicable to a wide range of goods and services.

Source	GOAL AND SCOPE
PAS2050-1 Supplementary requirements for the application of PAS2050 to horticultural products	The supplementary requirements, when approved, are to be used in conjunction with PAS2050:2011 to provide a common basis for GHG emissions quantification from the cultivation stages of the horticultural sector. (SR in the text below denotes where supplementary requirements are specified, specific to this horticultural sector protocol). The objective is to provide product GHG emissions to downstream businesses or to inform GHG reduction programmes.
The Agri-footprint method – framework version 1.0	To give a framework and progress the assessment of the environmental impact of agricultural products that are produced and consumed in the Netherlands. The method is for calculation of primary fossil energy use, land occupations, and ReCiPe end scores as well as global warming potential (kgCO_2eq) for averages of product categories using commodity statistics. It is a whole food chain, not producer, focused assessment. The method excludes impacts for the consumer phase.
DEFRA Project IS0205, Williams et al., 2006	The research aim of DEFRA project IS0205 was to build detailed models of the environmental burdens and resource use involved in producing agricultural and horticultural commodities, rather than product assessments using actual farm level primary data. The burdens were based on a number of environmental impact characterisation methods commonly reported in life cycle assessment (not exclusively GWP). The review here only covers their approach reported for estimating the GWP of cereals and oilseed rape. Feed cereal burdens are also calculated for livestock commodity estimates.

4.1.2. Defining the functional unit

Source	Defining Functional unit/ flow
The International Reference Life Cycle Data System (ILCD) Handbook : General Guide for Life Cycle Assessment- Detailed Guidance.	The ILCD guidance requires the functional or declared unit to be well defined and specified. The guidance suggests the production of cereals is a multifunctional process since straw and grains are both produced, so both should be defined. If different products from one crop may be produced, and the final product is not known at the point of removal from the 'farm gate', then this is defined as a reference flow. A reference flow is also required to be clearly identified quantitatively and qualitatively as the detailed name of the product 'plus further information that identifies its relevant characteristics and the location-type.'
Audsley et al., 1998	The functional unit of bread wheat in this study is defined by the protein content (102 kg protein produced), or standardised to 1 tonne of 12% protein-corrected wheat for bread making at 15% moisture content. The authors point out that post farm gate processing may blend wheat flour of different protein content (with likely different production GHG burdens) to obtain a required % protein, at this point the burdens of those systems would need to be apportioned to the product.
Life cycle Inventories of Agricultural Production Systems. Data v2.0. Ecoinvent report No.15 (2007)	1 kg of fresh matter ('humidity' at harvest – and at storage is given in the data set for each cereal product and OSR) the humidity value is the same for all the cereal products – 15% moisture w/w.
The EU Renewable Energy Directive - as interpreted for the UK by AEA under article	The functional unit reported is for 1 MJ of biofuel (lower heating value)(Emissions reported as g CO_2-eq/MJ of biofuel). Conversion steps to provide the resulting post cultivation emission per MJ of fuel were taken from RED defaults and

Source	Defining Functional unit/ flow
19.2	methodology in JRC CONCAWE well to wheels study (JRC 2007). The details of the exact calculation processes and data used are not given in the AEA report.
The EU Renewable Energy Directive	The functional unit is MJ of energy (lower heating value). (Default emissions are reported as g CO_2-eq/MJ for feedstocks and fuel).
UK Renewable fuels transport obligation methodology (Bauen et al,, 2008)	MJ of biofuel supplied (carbon reporting as kgCO2 e /MJ fuel, assumed to be at the lower heating value, but not defined in the report).
Greenhouse Gas Protocol – Draft Agricultural Protocol (unfinished) for farm-level inventories	The protocol is not a product or service based assessment, but rather an entity /organisation based, however in section 6.3 intensity ratios relating to GHG/mass are introduced as a voluntary reporting metric.
WRI Product life cycle accounting and reporting standard 2011	WRI Product life cycle accounting and reporting standard defines the product unit rather generally - as follows: 'For all final products, companies shall define the unit of analysis as a functional unit' 'Companies shall define the product, unit of analysis, and reference flow' But where the final products are unknown (perhaps in the case of cereals/OSR at farm gate) the unit of analysis shall be the reference flow (e.g. 1 metric tonne of wheat, rather than a 500g loaf of bread).
PAS2050:2011	PAS2050 is not specific (mass, volume or time depending on the key functional characteristics) but with supplementary requirements, (Section 5.9).

Source	Defining Functional unit/ flow
PAS2050-1 Supplementary requirements for the application of PAS2050 to horticultural products	No specific function unit is given due to the diversity of horticultural products. However, guidance in the supplementary requirement suggests the need for precision and defining physical properties necessary to achieve consistency – such as product grading or dry matter content.
The Agri-footprint method – framework version 1.0	The functional unit is defined as 1 kg of product sold to the consumer, (no allowances are made for partial or farm gate boundary in this method).
DEFRA Project IS0205, Williams et al., 2006	The reported unit is 1 tonne of wheat/OSR /feed cereals (at typical dried stored moisture content by % weight .i.e. wheat is assumed to be 86% DM, so 14% moisture w/w).

4.1.3. Defining the farm gate

Source	Boundary ('defining farm gate')
The International Reference Life Cycle Data System (ILCD) Handbook: General Guide for Life Cycle Assessment- Detailed Guidance.	General requirements are given to identify the system boundary and included processes – including a schematic diagram: ‘The qualitative definition of the system boundaries shall identify those parts of the life cycle that are to be included to provide the required data...’ Also see ILCD excerpt in the summary of the cut-off criteria.
Audsley et al., 1998	Audsley et al. define the boundary as the physical farm gate for identical products – but with an important requirement to include off farm drying if given cereal crops may not be identical (i.e. the same moisture) at this point:

Source	Boundary ('defining farm gate')
	'The agricultural boundary ideally stops when identical products pass out of the farm gate. Where the products passing the farm gate are not identical it may be necessary to include further industrial processes, for example off-farm drying'.
Life cycle Inventories of Agricultural Production Systems. Data v2.0. Ecoinvent report No.15 (2007)	Postharvest treatments such as stubble cultivation were included in the harvested crop inventory. Drying is not included (Ecoinvent has a separate module for crop drying, the impacts are assumed to be proportional to the litres of water removed).
The EU Renewable Energy Directive - as interpreted for the UK by AEA under article 19.2	The RED GHG calculation methodology includes crop drying as a 'conversion' step and this process is not included in reporting regional emissions from biofuels cultivation. Default values for GHG emissions for crop growing can only be used where the GHG emissions from crop growing in regional areas have been shown not to typically exceed those defaults. If these are exceeded, then regional averages or actual values are required to be reported.
The EU Renewable Energy Directive.	The RED boundary for reporting carbon intensity fuels is from field to wheel. However the requirement for regional emissions from biofuels cultivation does not include crop drying. Instead the RED GHG calculation methodology includes crop drying as a 'conversion' step.
UK Renewable transport fuels obligation methodology (Bauen et al., 2008)	The boundary is from raw materials extraction and inputs to specific crops (not crop systems) to the supply of biofuel for use (classified as the fuel chain). However, the modular approach suggested in the methodology provides for reporting emissions from crop production, a module for drying and storage, and a module for feedstock transport. Waste material collection (a module for emissions relating to removal of straw residues) is not included in the methodology

Source	Boundary ('defining farm gate')
	boundary.
Greenhouse Gas Protocol – Draft Agricultural Protocol (unfinished) for farm-level inventories	The protocol gives the option for reporting GHG inventories for the organisation that have a boundary defined by either direct organisational control (either as financial or operational) or by equity share. Selection of an approach (equity share, operational control or financial control) should be applied consistently.
WRI Product life cycle accounting and reporting standard 2011	Cradle-to-gate inventory is defined by the WRI standard as – 'A partial life cycle of an intermediate product, from material acquisition through to when the product leaves the reporting company's gate' (e.g., immediately following the product's production). Further clarification is provided: 'The boundary of a cradle-to-gate partial life cycle inventory shall not include product use or end-of-life processes in the inventory results'.
PAS2050:2011	Defining the boundary PAS2050:2011 determines this to be to the point where the product leaves the organisation undertaking the assessment and is received by another party. This could be interpreted as a physical transfer from one organisation's control to another.
PAS2050-1 Supplementary requirements for the application of PAS2050 to horticultural products	PAS2050-1 qualifies the general PAS2050 requirements with mention of activities associated with horticultural products to be included 'from initial preparation for cultivation through to the point of its transfer from the grower to another party that is not the consumer' (PAS2050-1 section 3.3).

Source	Boundary ('defining farm gate')
The Agri-footprint method – framework version 1.0	The method is for assessment to end of life (post-consumer waste disposal). Unlike PAS2050, the goal is to provide a consistent methodology for estimating the environmental impact of food products for consumption, and is not explicit about definitions of farm gate.
DEFRA Project IS0205, Williams et al., 2006	The 'farm gate' was defined as the assessment boundary but this term was not qualified in detail, except that emissions from the crop drying process were included within this boundary.

4.1.4. Excluded processes

Source	Excluded processes
The International Reference Life Cycle Data System (ILCD) Handbook : General Guide for Life Cycle Assessment- Detailed Guidance.	No specific processes are universally excluded by ISO14040/44 (see section regarding cut off criteria). But requirements to justify that excluded processes, stages or inputs and outputs do not change the overall conclusions of a LCA given (subject to the goal of the assessment).
Audsley et al., 1998	The following were excluded: Human labour, general atmospheric nitrogen deposition, (on the cropland rather than atmospheric N deposition related to the fertiliser used by the assessed crop); interactions between other crops in a rotation; and livestock emissions associated with manure production, transport and storage.

Source	Excluded processes
Life cycle Inventories of Agricultural Production Systems. Data v2.0. Ecoinvent report No.15 (2007)	Emissions from the production and storage of any manure used for crop production are all allocated to animal husbandry.
The EU Renewable Energy Directive - as interpreted for the UK by AEA under article 19.2	Biogenic carbon dioxide is not taken into account for biofuels in the RED (considered neutral assuming a net zero emission, short carbon cycle, between sequestration and combustion). Methodology for the handling of manure emissions does not feature in the assessment. Emissions associated with the production of capital infrastructure are absent.
The EU Renewable Energy Directive	Biogenic carbon dioxide combustion emissions are not taken into account for biofuels in the RED (considered neutral as a short carbon cycle between sequestration and combustion). Emissions from the manufacture of equipment and machinery are excluded (Annex V, 1).
UK Renewable transport fuels obligation methodology (Bauen et al., 2008)	Bauen et al. exclude: • Emissions from the production of seed • Manufacture and maintenance of machinery and equipment • Emissions from perfluorocarbons, hydroflourocarbons and sulphur hexafluoride. • Emissions associated with the production of chemicals (in fuel conversion plants) that contribute < 1% of the fuel chain emissions
Greenhouse Gas Protocol – Draft Agricultural Protocol (unfinished) for farm-level inventories	Protocol draft requires that intensity ratios (GHG/tonne) should exclude woodland that is not directly connected to the production system.

Source	Excluded processes
WRI Product life cycle accounting and reporting standard 2011	Under the general principle of 'completeness', a requirement is stated to 'disclose and justify any significant GHG emissions and removals that have been excluded'.
PAS2050:2011	PAS2050:2011 (6.4.4) excludes GHG emissions and removals from the production of machinery, buildings and other capital equipment, unless supplementary requirements have been developed which includes these (none have as yet). Biogenic CO_2 removals (as carbon) in food and feed are also excluded from PAS2050:2011.
PAS2050-1 Supplementary requirements for the application of PAS2050 to horticultural products	PAS2050-1 Supplementary requirements exclude GHG emissions and removals from the production and maintenance of: equipment/materials for climate control (i.e. greenhouses); tractors and cultivation machinery; irrigation equipment; buildings and roads; and other infrastructure in the cropped area. Biogenic CO_2 removals (as carbon) in food and feed are excluded from PAS2050:2011.
The Agri-footprint method – framework version 1.0	• Capital goods, following PAS2050. • Pesticides production (considered negligible contribution) • Refrigerants and industrial packaging (considered negligible contribution) • Consumer related emissions, (transport, cooking, storage refrigeration etc.).

Source	Excluded processes
DEFRA Project IS0205, Williams et al., 2006	Manure production/storage emissions are not allocated to the crops. All emissions from compost heaps are assumed to be gaseous, but indirect emissions from N losses from leaching are excluded. It is not clear whether seed production emissions are included in the crop inventories in the model, though a proportion of the crop yield in their spreadsheet model (V3) ‘harvested outputs’ for winter bread wheat which is labelled as ‘grain mass used as seed t/ha’ (the default value is 0.185 for conventional wheat and 0.2 to 0.25 for organic wheat (winter, spring)). This may be included by removing seeds from the final yield (as appears to be reported in the model as net yield t/ha). This would assume seeds are taken directly and are not bred separately and imported onto the farm.

4.1.5. Cut-off criteria

Source	Cut-off criteria (quantitative/qualitative)
The International Reference Life Cycle Data System (ILCD) Handbook: General Guide for Life Cycle Assessment- Detailed Guidance.	The guidance gives provisions (6.6) for defining the quantitative cut-off criteria subject to the goal and scope of the assessment. ILCD requires LCA's to: 'Define the cut-off % value to be applied for [crop production], waste and elementary flows [GHG emissions] that cross the system boundary, but that are not quantitatively included in the inventory'. Interpreting the statement in section 6.3 (p 107) that: 'The cut-off % value shall generally relate to the quantitative degree of coverage of the approximated overall environmental impact of the system'. This would seem to mean: defining a % threshold for GHG emissions from processes will depend on how much of the emissions are to be expected to be estimated for a crop (through iterative means or using approximations/rough calculations of the final result).
Audsley et al., 1998	No physical cut–off criteria are apparent in the study. Included processes and input flows to the crop assessment boundaries are considered on a case by case basis, with no reference to a per cent contribution cut off threshold.
Life cycle Inventories of Agricultural Production Systems. Data v2.0. Ecoinvent report No.15 (2007)	No strict quantitative cut-off rule is followed in the Ecoinvent protocol. It is reported that discretion is used by the practitioners involved in compiling LCI data as to whether or not the production of a certain input or the release of a certain pollutant is included.
The EU Renewable Energy Directive- as interpreted for the UK by AEA under article	No formal cut off criteria is given, though seed production emissions are excluded on grounds of lack of data but assuming a likelihood of a <1% material contribution (based on OSR and wheat seed production emissions, taken from RED default

Source	Cut-off criteria (quantitative/qualitative)
19.2	values).
The EU Renewable Energy Directive	Methodology for the calculation of the original defaults was not found. However later communications (OJ C160 p8, 11) state ‘It would not seem necessary to include in the calculation inputs which have little or no effect on the result, such as chemicals used in low amounts in processing’. The draft BS EN 16214-4 recommends that the GHG contribution of inputs be ignored if their combined value is unlikely to affect GHG savings of the finished biofuel rounded to the nearest percentage point.
UK Renewable transport fuels obligation methodology (Bauen et al., 2008)	Individual ‘sources’ contributing less than 1% to the fuel chain emission.
Greenhouse Gas Protocol – Draft Agricultural Protocol (unfinished) for farm-level inventories	Cut off criteria are purposefully omitted: ‘the practical implementation of [a materiality threshold] is not compatible with the completeness principle of the Agricultural Protocol. In order to use a materiality threshold, the emissions from a particular source or activity would have to be quantified to ensure they were under the threshold. However, once emissions are quantified, most of the benefit of having a threshold is lost.’

Source	Cut-off criteria (quantitative/qualitative)
WRI Product life cycle accounting and reporting standard 2011	Need to establish a definition of ‘insignificance’. There is no quantified threshold by the protocol, though an example of ‘1% of the mass, energy, or volume and estimated GHG significance over a process, life cycle stage or total inventory is included. Also, it is suggested that ‘to determine insignificance, a company should estimate the process’s emissions using data with upper limit assumptions to determine [insignificance], in the most conservative case’.
PAS2050:2011	PAS2050:2011 requires any one ‘source’ of GHG emissions, which contributes more than 1% of the ‘anticipated’ total GHG of the product being assessed, to be included (3.31).’ Also, a further requirement is given that all sources contributing to the total GHG of the product should account for 95% or greater than the ‘anticipated’ life cycle GHG emissions. The anticipated emissions are to be gauged by preliminary or other published assessments.
PAS2050-1 Supplementary requirements for the application of PAS2050 to horticultural products	Follows the same PAS2050:2011 1% contribution threshold requirement; no other supplementary requirements are given for cut-off criteria.
The Agri-footprint method – framework version 1.0	All elementary flows (sources of GHG emissions) that are >1% of the total product emissions (full life cycle) are included, following PAS2050.
DEFRA Project IS0205, Williams et al., 2006	No cut off criteria is given in the study.

4.1.6. Defining crop system boundary and included inputs

Source	Boundary depth/Scope
The International Reference Life Cycle Data System (ILCD) Handbook : General Guide for Life Cycle Assessment- Detailed Guidance.	The ILCD has provisions (5.4) for developing 'product category rules' (PCR's) which are stricter and more detailed in the definition of boundaries and other requirements than the ILCD general requirements. These are to provide enough detail to allow assessment to be reproducible along with documented methodologies and data sources. These may overrule ILCD requirements if the PCRs are developed and approved in an ILCD compliant review process. There are product category rules already published for 'groats, meal and pellets of wheat and other cereal products' [23]and also bread products. It is doubtful whether the former has been approved to conform to the ILCD requirements for PCR.
Audsley et al., 1998	The following are included in this study: Machinery and building production (based on component material manufacture and allocation based on time/use); machinery repair; fertiliser and pesticide production; seed production; and transport of all inputs.
Life cycle Inventories of Agricultural Production Systems. Data v2.0. Ecoinvent report No.15 (2007)	Buildings and machinery production are included. Emissions from production and transport to regional storehouses are included for seeds, fertilisers, pesticides, energy carriers, along with field operations (fertilising, spraying, soil cultivation, harvest and transport).

[23] http://www.environdec.com/en/Product-Category-Rules/Detail/?Pcr=5940

Source	Boundary depth/Scope
Renewable Energy Directive - as interpreted for the UK by AEA under article 19.2	RED requires 'the inputs/variables that affect emissions from cultivation will typically include seeds, fuel, fertiliser, pesticide, yield, and N_2O emissions from the field' (2010/C 160/02). The use of lime is also given in the RED default value calculations for OSR. Emissions related to seed inputs for UK cultivation of barley, triticale and oats were omitted from the UK regional assessments since the OSR and wheat seed production emissions (taken from RED default values) are reported to be <1% of the GHG emissions per MJ fuel, with the rational that their impact is negligible.
Renewable Energy Directive	'The inputs/variables that affect emissions from cultivation will typically include seeds, fuel, fertiliser, pesticide, yield, and N_2O emissions from the field' (2010/C 160/02). The default data for cultivation given in Annex V is based on JRC's original well to wheels calculations and a related spreadsheet (2008) which also includes emissions from 'handling and storage', though the references were unavailable to substantiate what this included.
UK Renewable transport fuels obligation methodology (Bauen et al., 2008)	'All direct or indirect emissions, or avoided emissions that are a result of the production of a biofuel'. This is an inclusive requirement but the methodology lists defaults for individual inputs/activities etc. for the feedstock production stages in report's 3rd Annex including fertiliser, lime and pesticide production emissions as well as drying and storage emissions. Transport is only referenced for feedstock from farm gate to processors.
WRI Greenhouse Gas Protocol – Draft Agricultural Protocol (unfinished) for farm-level inventories	Much of the protocol rules are associated with determining what GHG emitting processes or activities fall within the organisation's reporting boundaries defined as Scope 1, 2 and 3. Reporting emissions in the scope 3 category is optional. Kyoto protocol GHGs are included in the assessment, (i.e.

Source	Boundary depth/Scope
	perfluorocarbons, hydroflourocarbons, sulphur hexafluoride and methane, carbon dioxide and nitrous oxide). Scope 1 emissions are from sources from property owned or under operational control of the organisation, (organisation's facilities and vehicles). Scope 2 emissions are those from organisational electricity use, where emission sources are external to organisational control, from combustion used to generate electricity. Scope 3 emissions from all other indirect emission sources controlled by 3rd parties, but are influenced by the organisation (e.g. through demand/use/activities). Within the context of farm gate, this may alter emissions where grain dryers are owned or operated and used by one business (scope 1 and 2) and not another where only scope 1 and 2 emissions are reported.
WRI Product life cycle accounting and reporting standard 2011	A generic requirement is that 'The boundary of the product GHG inventory shall include all attributable processes'. Under the general principle of 'completeness' it is stated: 'Ensure that the inventory report covers all product life cycle GHG emissions and removals within the specified boundaries.'
PAS2050:2011	PAS2050:2011 requires including all direct emissions and those from the production of inputs to the crop production process associated with: • Energy (including extraction, supply and processing) • Operation of premises (farm offices) • Storage of products • Manufacturing/processing • Transport (allocated by mass, if mass limited, volume if volume

Source	Boundary depth/Scope
	limited).
PAS2050-1 Supplementary requirements for the application of PAS2050 to horticultural products	In addition to the general requirements of PAS2050:2011, a list of specific materials relevant to horticultural sector are specified to be included (pesticides, fertilisers, energy carriers, production materials, packaging and consumables). These are give further explanation in an Annex (D) of the supplementary requirements. Supplementary requirements 8.2.3.3 also specifies CO_2 emissions from fossil sources in lime fertilisers and mushroom compost shall be fully accounted for using full oxidation of the fossil carbon content to CO_2.
The Agri-footprint method – framework version 1.0	Electricity and fuel production and supply. Fertiliser production and transport, seed is included in the crop growing. Lime emissions are included so it is assumed that the production emissions are as well. Production transport and disposal of food packaging is included.
DEFRA Project IS0205, Williams et al., 2006	The following were listed in the project report: • Field diesel use for detailed models of cultivation • Chemical and manure applications and harvesting • Machinery manufacture • Producing fertiliser (including composts) and pesticides • Drying and cooling direct energy • Direct soil-crop emissions to air and water (nitrate, nitrous oxide and ammonia) • Construction of buildings

4.1.7. Attributing GHG emissions from inputs and activities to crop growing

Source	Allocation methods for inputs
The International Reference Life Cycle Data System (ILCD) Handbook: General Guide for Life Cycle Assessment- Detailed Guidance.	Under 1 c) of the provisions, any residual nutrients, such as N from crop residues, are considered a co-product and an input to the production of the next crop. These are to be treated with system expansion (i.e. gain a credit for substituting inorganic N manufacture), or allocation with the ILCD documented provisions required for cases of multi-functionality, (7.2.4.6 and 7.9) (see co-product allocation principles for ILCD).
Audsley et al., 1998	See allocation for co-products – the same approaches are used by Audsley et al. N related impacts/benefits from organic inputs were allocated entirely to the crop being assessed, since no data on the other crops in the rotation were available. However, a soil quality index was proposed by the study group to account for carry-over of nutrients and soil organic matter which were quantified from the assessed cropping practices. For livestock manure inputs into a Swiss organic wheat production system, a physical causality approach was used which attributes the GHG emissions associated with the production of clover (a green manure), equivalent to the nitrogen input from livestock manure, to the assessment. Presumably this assumes clover is grown to replace a marginal demand for livestock manure in organic systems. Emissions from machinery manufacture were allocated top crops in proportion to crop production hours to total machinery lifetime.
Life Cycle Inventories of Agricultural Production Systems. Data v2.0. Ecoinvent report No.15 (2007)	Since crops are treated individually, the N fertiliser effects from residues of preceding crops in the rotation were allocated to those crops. Since this is a modelled (not actual) inventory, the Ecoinvent methodology assumes a reduction in the N requirement for the current crop from residue input, essentially

Source	Allocation methods for inputs
	crediting the system. Machinery manufacturing emission for capital inputs were calculated on the basis of weight. This weight is allocated to cropping as a proportion of total weight, based on the ratio of lifetime and working time utilised for the specific cropping operations.
Renewable Energy Directive - as interpreted for the UK by AEA under article 19.2	No methodology or requirements are apparent for the allocation of emissions from multifunction inputs (e.g. manure/biosolids) that may benefit crops over time in sequence or rotation. All N inputs appear to be allocated to the crop on which they are applied directly (i.e. immediately prior to preparing soils for the current crop).
Renewable Energy Directive	As above.
UK Renewable transport fuels obligation methodology (Bauen et al., 2008)	No distinction is made for allocating emissions from slow release inputs (manure) that benefit a number of crops. The methodology assumes a reference system - leaving straw in the field is GHG neutral, which assumes: • No nutrient benefit to rotational crops systems and; • No net impact on GHG emissions.
Greenhouse Gas Protocol – Draft Agricultural Protocol (unfinished) for farm-level inventories	Limited information for the product ratio reporting metric (GHG/tonne) – the protocol focus is for organisational based reporting, i.e. GHG per farm business, based on everything that can be directly and (optionally) indirectly controlled by the business.

Source	Allocation methods for inputs
WRI Product life cycle accounting and reporting standard 2011	Only generic guidance on allocation, given in the next section of the review.
PAS2050:2011	GHG burdens associated with inputs that are utilized by more than the product in assessment – (slow release N into the system taken up by different crops in succession or rotation).
PAS2050-1 Supplementary requirements for the application of PAS2050 to horticultural products	Where inputs provide a function or resource for more than one crop, i.e. crops in rotation, but are not attributable to any one crop, the PAS2050-1 allocates production emissions based on(ordered in preference): a) The proportion based on relative crop needs in the rotation. b) Emissions/benefits delayed beyond 1 year are allocated to crops in a rotation in proportion to their area coverage in the year the input is applied. (8.2.1.c) PAS2050-1:2012) Examples given are slow release organic fertilisers and soil improvers, such as manure, green manure, compost and biosolids. These are allocated as b) also. Any delayed emissions are to be totalled and averaged over a three year period of crop production (8.2.2.1).

Source	Allocation methods for inputs
The Agri-footprint method – framework version 1.0	The authors state that as manure is in surplus in many countries, it is therefore considered as a waste rather than useful product. However manure use emissions (N_2O, diesel for transport, storage and spreading) are still allocated in the Agri-footprint method to the cropping system by active nitrogen content, (defined as the efficiency of the uptake of the crop relevant to mineral fertilizer uptake). This is given as 60% N in liquid manure, 55% in solid poultry manure, and 40% in solid manure from all other animals.
DEFRA Project IS0205, Williams et al., 2006	Manure benefits are credited 'upstream' to livestock as substitution for emissions related to inorganic fertilizer production. The study assumes manure becomes available to the crop as N fertiliser at incrementally 10% per year, (after storage and spreading losses) and the target crop appears every 4 years in rotation. Compost imported to cereals production is credited emissions equivalent to the substitution of inorganic fertiliser by N content, minus their process emissions (turning and gaseous losses) and transport to the farm.

4.1.8. Allocation methods for co-products

Source	Allocation methods for co-products
The International Reference Life Cycle Data System (ILCD) Handbook: General Guide for Life Cycle Assessment- Detailed Guidance.	Allocation should be avoided by subdivision of unit processes or by substitution (system expansion): ‘If for the not required co-function functionally equivalent alternative processes / products are operated / produced in a sufficient extent, the not required co-function shall be substituted with the average market consumption mix of the processes or products that are superseded. Interpreting this means that straw, if used as feed stock for generating electricity/heat, is an addition to the existing biomass, renewable and fossil energy mix for energy generation. The emissions of the average fuel mix shall be credited to the crop (minus any straw processing and transport emissions). The crop alone will be attributed all the farming related emissions. If straw is ploughed into the soil, this could then be interpreted as a credit to the crop of GHG equivalent to the production, supply and use of the average mix of nitrogen fertilisers that is functionally equivalent to the mineral nitrogen benefit from the returned straw residue. For straw used as animal bedding or feed, this may be more complicated. The average mix of bedding sources or feeds that is functionally equivalent to straw may be harder to define. For this, a simplification is suggested: Either by determining physical causal relationships between inputs, and activities causing GHG emissions for allocation to the co-products or; Failing this (e.g. lack of data or practicality) a market value allocation is advised.

Source	Allocation methods for co-products
Audsley et al., 1998	A number of allocation methods are analysed in this study and a hierarchy of methods are proposed: 1. No allocation – emissions are attributed by further subdivision of processes. 2. No allocation – by substitution or system expansion 3. Allocation by physical causality (when co-products output can be varied – i.e. straw output can be reduced by incorporation) but only where realistic to practices. 4. Allocation by composition – a shared physical property in all co-products functions that is relevant to their reason for production (e.g. energy or protein). 5. Allocation by economic value
Life Cycle Inventories of Agricultural Production Systems. Data v2.0. Ecoinvent report No.15 (2007)	Allocation of crop emissions between grain and straw were based on economic value†. Sequestered carbon in the crop and straw is allocated on C content. For cereals it is assumed that 75% of the harvestable straw is harvested and 25% is left in the fields (for integrated and extensive Swiss cultivation) and 100% for organic production. OSR is not considered to be harvested. Only 65% of the straw is harvestable, so the total straw available is for integrated production and extensive is 49% and organic 65%, the remaining is residues left in the field. Data on the total straw to crop yield ratios were taken from Walther et al. (2001) (A Swiss German publication 'AGRAR Forschung'). †However for the data sets for selected typical European agricultural crops, straw co-products were not included.
Renewable Energy Directive - as interpreted by the UK for article 19.2	No emissions are allocated to agricultural crop residues and processing residues (or wastes). The RED rules consider these to have zero emissions until the point of their collection. A definition of differences between co-product and crop residues and wastes, with respect to straw, is not considered by AEA methodology.

Source	Allocation methods for co-products
Renewable Energy Directive	No GHG emissions are allocated to agricultural crop residues (including straw, paragraph 18, annex V) and processing residues (or wastes). The RED rules consider these to have zero emissions until the point of their collection. Allocation to co-products in the RED is by energy content (paragraph 17), specifically the proportion of the lower heating value of co-products. The LHV is for the entire (co-)product, not the dry fraction of it. Though allowance is given for the dry LHV as an adequate approximation for nearly-dry products. A co-product is defined as a substance that would 'normally be storable or tradable', but this is likely to refer to co-products from the biofuel production process stages, not at the farm gate. System expansion is only applied if an agricultural residue that is a by-product of the fuel chain being analysed is used to generate and export surplus electricity in a combined heat and power plant. Fossil emissions substituted by the electricity generated by crop residues are credited back to the fuel chain. This is a consequential approach given the impacts are due to an assumed change in non-system impacts – i.e. external electricity generation emissions. This probably only applies to situations where straw is used to generate energy as part of a biofuel production plant sent offsite, not, for example, straw simply sent directly from farms to a biomass fuelled power station for electricity generation.

Source	Allocation methods for co-products
UK Renewable transport fuels obligation methodology (Bauen et al., 2008)	A flexible approach is given by E4Tech, but this is mainly based on consequential, market-demand based methods rather than attributional system accounting and their rationale is focused on co-products at the biofuel conversion stages. Allocation is to be avoided by system expansion (substitution credits for existing products) otherwise economic allocation is used (proportional to the relative market value of co-products). Residues (straw) are considered as co-products in this methodology, but straw is not considered as a biofuel feedstock for the options for fuel chains in this (2008) methodology.
Greenhouse Gas Protocol – Draft Agricultural Protocol (unfinished) for farm-level inventories	The Draft Protocol states preferences for reporting product 'intensity ratios', physical allocation is preferred when: • A physical relationship amongst the products can be established and this relationship reflects their relative emissions contributions. • A change in the physical output of co-products is correlated to a change in the common process's emissions (e.g., if more co-product is produced, more emissions occur). • Prices change significantly or frequently over time (e.g., fluctuation in commodity crop prices); • Prices are not well-correlated with underlying physical properties and GHG emissions (e.g. for agricultural products with a high value, such as certain niche crops); • Companies pay different prices for the same product (due to different negotiated prices); or Economic allocation is preferred when: • A physical relationship amongst the products cannot be established or does not adequately reflect the relative emissions contributions.

Source	Allocation methods for co-products
	• The co-products would not be produced using the common process without the market demand for the main product and/or other valuable co-products • The co-products were a waste output that acquires value in the market place as a replacement for another material input (e.g., manure as a replacement for fertiliser). It is also suggested that 'for the purposes of using the economic allocation approach, companies should first establish a consistent policy for determining whether an output is a by-product or a co-product (e.g., based on their relative market value).'
WRI Product life cycle accounting and reporting standard 2011	A hierarchy of options are given: 1. To avoid allocation using process subdivision, redefining the functional unit, or using system expansion 2. Allocate emissions and removals based on underlying physical relationships between co-products 3. Economic allocation or another allocation method that reflects other relationships between the co-products The protocol requires the same allocation methods to be applied to similar inputs and outputs within the product's life cycle. The protocol provides examples – suggesting waste should not be allocated emissions (waste is defined in the guidance as a material with zero economic value). There is also provision for allocating removals to prevent double counting (only relevant to C in straw for long term use in materials, i.e. not used for feed).

Source	Allocation methods for co-products
PAS2050:2011	Hierarchy of preference – 1. Dividing unit processes into sub-processes to separate inputs and outputs 2. Crediting avoided emissions from production of the 'average products' displaced by the co-products 3. Supplementary requirements method 4. Allocation of net production GHG's in proportion to the economic value of co-products
PAS2050-1 Supplementary requirements for the application of PAS2050 to horticultural products	(8.2.1 PAS2050-1) As PAS2050:2011
The Agri-footprint method – framework version 1.0	• System expansion ONLY where avoided products can be defined unambiguously. • When the application (feed, food, fuel or material) is the same for each co-product and there is little difference between physical characteristics (energy, or protein content) then mass allocation is applied. • In all other cases, economic allocation is used by the Agri-footprint method (allocation fraction in proportion with relative revenue value of co-product).

Source	Allocation methods for co-products
DEFRA Project IS0205, Williams et al., 2006	Straw is allocated emission burdens by economic value prior to baling, relative to grain produced (0.05). Then emissions associated exclusively to straw (baling, transport etc.) are added after separately. Straw is given a negative GWP result at farm gate in the spreadsheet model, presumably for the carbon stored within it, although this is not confirmed in the reporting, and the spreadsheet model calculations are not easy to trace. From a commodity production perspective, a fraction of bread wheat is grown that does not meet the required quality criteria and becomes milled feed. This also allocates burdens on the basis of economic value.

4.1.9. Nitrous oxide emission methodology

Source	Nitrous oxide emission methodology
The International Reference Life Cycle Data System (ILCD) Handbook : General Guide for Life Cycle Assessment- Detailed Guidance.	No references were given to nitrous oxide emission methodology.
Audsley et al., 1998	Audsley et al. decide to follow the example of the Swiss Federal Office of Environment (BUWAL, 1994) by using a uniform emission factor of 3% of the total applied nitrogen converted to N_2O-N.
Life Cycle Inventories of Agricultural Production Systems. Data v2.0. Ecoinvent report No.15 (2007)	The emission methodology is adapted from the (1996) IPCC by Schmidt et al. (2000) (refers to a model; 'IULIA'). 1.25% N_2O-N is yielded from N inputs to soils, (organic and inorganic fertiliser, residues and BNF) after volatilised ammonia N is removed. This ammonia is said to be used to calculate further indirect N_2O emissions, but a reference to the methodology is not given. An estimate of 2.5% of the N lost as N_2O from leached nitrate is assumed (Schmidt et al., 2000).

Source	Nitrous oxide emission methodology
Renewable Energy Directive - as interpreted for the UK by AEA under article 19.2	The UK assessment of regional NUTS 2 cultivation emissions, following the RED, use IPCC 'tier 1' for most of the assessment for the regional defaults, but also in their sensitivity analysis use a tier 2 method (Stehfest and Bouwman, 2006) which accounts for regional variation in soils and climate. Ammonia emissions from AN and Urea differed from the fixed IPCC 2006 10% of N applied (an average of AN from tillage of 1.7% and, Urea 10% as NH_3-N) based on UK ammonia emissions inventory. EF used for ammonia N deposition to N_2O-N is 1% by N, the same as IPCC 2006. IPCC EF of 8 N_2O-N kg/ha emitted was used for cultivating peaty soils. Managed unfertilised grass (from JRC well to wheels, 2006) as background was removed from the anthropogenic sources of N_2O emission. Estimates of N inputs from residues did not follow IPCC 2006 but used other detailed assumptions such as ratio of farmer's straw yield to above ground biomass remaining (0.66 for cereals and assumed 0.5 for OSR). Estimates of N from root residues were taken from the literature and a model of root distribution developed by ADAS.
Renewable Energy Directive	Non-binding communications outlining methodologies refers to 2006 IPCC guidelines for National Greenhouse Gas Inventories, Volume 4, Chapter 11, taking in account both direct and indirect emissions. Rather than strict enforcement of a specific methodology, the option of all three tiers is given, though in the UK, currently, only a 'tier 1' approach is used.
UK Renewable transport fuels obligation methodology (Bauen et al., 2008)	The IPCC 2006 tier 1 approach is recommended. No qualification is given on the direct and indirect sources etc.

Source	Nitrous oxide emission methodology
Greenhouse Gas Protocol – Draft Agricultural Protocol (unfinished) for farm-level inventories	A review of models and approaches (IPCC 2006) are provided but no specific recommendations/requirements are given. Non CO_2 emissions from changes in carbon stocks should be reported (cultivation of peaty soils).
WRI Product life cycle accounting and reporting standard 2011	No direct references are given in this Protocol for estimating nitrous oxide emissions. However, in The Land Use, Land-Use Change, and Forestry Guidance for GHG Project Accounting, (from the same stable of protocols developed by the WRI) there is a suggestion for using IPCC 2006 methodology for GHG accounting.
PAS2050:2011	(7.8) Best method, subject to data quality rules, (see data quality requirements below) and chosen from either: 1) The highest tier from IPCC guidelines for National GHG inventories or 2) Highest tier approach used by the country the emissions are produced.
PAS2050-1 Supplementary requirements for the application of PAS2050 to horticultural products	Same as the PAS2050:2011
The Agri-footprint method – framework version 1.0	The nitrous oxide emission methodology uses emission factors from the Dutch national inventory reporting defaults for leached nitrogen and volatilized ammonia. Emission factor N sources conversion to ammonia are taken from a report by The Dutch National Institute for Public Health and the Environment. The 0.3 default for leaching is taken from the IPCC 2006 guidelines.

Source	Nitrous oxide emission methodology
DEFRA Project IS0205, Williams et al., 2006	The emissions methodology follows the 2004 UK national inventory interpretation of the 1997 IPCC methodology for nitrous oxide emission estimates. Leaching N, however, was not the default 0.3 used by IPCC tier 1 but was modelled with SUNDIAL, a model developed by Rothamsted Research, using various assumptions for characterised crop rotations (inorganic and organic with BNF clover leys).

4.1.10. Land use change

Source	Land use change
The International Reference Life Cycle Data System (ILCD) Handbook : General Guide for Life Cycle Assessment- Detailed Guidance.	CO_2 emissions from LUC shall follow the most recent IPCC default factors, unless more accurate specific data is available. The Handbook provides a worked example using IPCC default soil carbon (0-30cm) for UK set aside being put back into production for crops (Annex 13 p341). Land management and input factors from IPCC allow relative improvement in soil carbon stocks to be estimated. 'For loss/ binding of CO_2 in form of soil organic carbon, towards reaching the equilibrium of the land use after transformation, a default period of 20 years shall be assumed….For simplification, the total loss shall be assumed to occur linearly with time over the period until the about 90 % loss/ binding towards the new equilibrium has been reached'. '[where] more than one crop is harvested per year, the calculated inventory for that year shall be linearly allocated between the crops over the time of that year that they use the land; i.e. for simplification no further differentiation needs to be made between months earlier and later in that year.'
Audsley et al., 1998	A soil carbon stock change example is considered in this study for maize converted to grassland. The time frame for SOC transition to the new equilibrium was 50 years. Sequestration from straw and manure inputs are taken from references/models (Century) cited in the study over a 50 year period. This was annualised to give average tonnes C sequestered per year.

Source	Land use change
Life Cycle Inventories of Agricultural Production Systems. Data v2.0. Ecoinvent report No.15 (2007)	Land transformation is calculated from detailed inventories developed by the Ecoinvent for Swiss land use categories, and using averaged land uses for the Swiss arable context: ‘Carbon losses from soil and carbon dioxide released by burning wood residues from clear-cutting are classified as "carbon dioxide, land transformation". In line with the IPCC accounting rules, this elementary flow is treated like fossil CO_2 emissions in life cycle impact assessment methods’
Renewable Energy Directive - as interpreted by the UK for article 19.2	Carbon stock changes and other emissions from Land-use change are not included in this assessment of regional default GHG emissions.
Renewable Energy Directive	Land-use change refers to six land categories used by the IPCC tier 1 (forest land, grassland, cropland, wetlands, settlements and other land), plus a further category of perennial crops. Annualised CO_2 emissions from land use change are based on total carbon stock changes (soil and vegetation) as a result of conversion from a previous (reference) land use to biofuel feedstock cultivation, with a deviser of 20 years. Further guidance and defaults have been given in further communications from the EU.
UK Renewable transport fuels obligation methodology (Bauen et al., 2008)	Follows IPCC 2006 ‘tier 1’ method using default land use carbon stock estimates for biomass, soils and dead organic matter. • Carbon stock in biomass and deadwood/leaf litter immediately after land conversion is assumed to be zero. • All biomass carbon in crops is lost when annual crops are harvested for soil carbon stocks as default soils are mineral soils. • The stock change factors for management regime are neutral (i.e. these are not considered to change soil carbon stock).

Source	Land use change
Greenhouse Gas Protocol – Draft Agricultural Protocol (unfinished) for farm-level inventories	A linear fixed rate for carbon stock change amortized over a set period is required by the protocol. The periods should be region or country specific, but the default is 20 years, based on IPCC 2006. Historical LUC changes (within the 20 year period) would apply the fixed amortised rate to the cropped area.
WRI Product life cycle accounting and reporting standard 2011	‘Companies shall report the method used to calculate land-use change impacts, when applicable’ The protocol provides guidance on the use of methods for estimating GHG emissions from LUC for situations where previous land use change is known and when this is unknown. The carbon stock changes from LUC occurring within 20 years of the assessment period or a single harvest period (for forestry), are amortized evenly over 20 years to a fixed constant to apply to annual crops production.
PAS2050:2011	Allows for including more detailed methods through supplementary requirements, otherwise requires a list of defaults in Annex C or IPCC 2006 guidance. Land use change emissions are only included if change occurred within to 20 years prior to the current activity. Emissions are spread equally for each year within the 20 year period. Where land use timing is not known but less than 20 years prior to the assessment, land use change shall be assumed to occur either on the earliest demonstrable year or 01 January of the assessment year.

Source	Land use change
PAS2050-1 Supplementary requirements for the application of PAS2050 to horticultural products	As PAS2050:2011 but with supplementary requirements as follows: 1) PAS2050-1 gives a method for C loss with reference to the default climate and organic C by soil type from a published table (2.3) and assumes full tillage and medium input level from table 5.5 in IPCC guidance, (Vol 4). 2) For above ground carbon stocks – weighted average for existing forest types are provided in tables for a set of default above ground biomass and carbon fractions. These are taken from IPCC guidance. 3) Grassland and crops are assumed zero in above ground carbon stocks. Defaults for perennial crops are not documented in the supplementary requirements but are to be provided in a PAS2050-1 carbon calculator.
The Agri-footprint method – framework version 1.0	With regards to the uncertainty associated with the estimates of LULUC emissions, the method requires these emissions to be reported separately. An average sink of 403 kg CO_2eq Ha^{-1} yr^{-1} is assigned to natural land (C fossilisation in soils over time) which is accounted as lost from conversion to agricultural use. According to this method, regardless of the date of land use change, soil organic matter loss is assumed as a constant annual loss, resulting in 1,650 kg CO_2eq $ha^{-1}yr^{-1}$ in conventional cropping systems and 1,100 kg CO_2eq $ha^{-1}yr^{-1}$ in organic cropping systems. FAO data is required for the estimate of the loss of above ground biomass.
DEFRA Project	Land use change emissions are not included in the scope of the

Source	Land use change
IS0205, Williams et al., 2006	model. Production is assumed to be from existing land with no land use change carbon losses associated with cereals and oilseed production.

4.1.11. Carbon stores and soil emissions

Source	Carbon storage and soils
The International Reference Life Cycle Data System (ILCD) Handbook: General Guide for Life cycle Assessment- Detailed Guidance.	Land management and input factors from the IPCC methodology are suggested as a method of estimating sequestration/losses from land use where more detailed methods are unavailable. These are given in the ILCD guidance, (Annex 13). Transformation steps, where a new equilibrium in soil carbon stock is suggested to require sector specific guidance or product category rules, (p234, see footnote 156). Temporary storage of carbon in products (e.g. straw)
Audsley et al., 1998	Stock C change and resulting CO_2 emissions or sequestration from inputs and management practice were considered in the study with changes to the SOC equilibrium assumed over a 50 year transition period.
Life cycle Inventories of Agricultural Production Systems. Data v2.0. Ecoinvent report No.15 (2007)	The crop grains and straw co-products include carbon dioxide sequestered from the atmosphere in their inventory. (1.55 kg CO_2/kg DM for wheat, rye, barley grain and 1.61 for cereal straw, but 2.86 for rape seed).
Renewable Energy Directive - as interpreted by the UK for article 19.2	Emissions from cultivation of peaty soils or soil carbon sequestration from management changes do not appear to be included in AEA's methodology.
Renewable Energy Directive	Provision is made for emission savings from soil carbon sequestration via 'improved agricultural management'. This can only be taken into account 'if evidence is provided that the soil carbon has increased, or solid and verifiable evidence† is provided that it can reasonably be expected to have increased over the crops cultivation period' (Annex V, part C, point 1). 'Improved agricultural management' could include practices such as:

Source	Carbon storage and soils
	• Shifting to reduced or zero-tillage; • Improved crop rotations and/or cover crops, including crop residue management; • Improved fertiliser or manure management; • Use of soil improver (e.g. compost)'. The emission savings in terms of gCO_2eq/MJ can be calculated by using the land use change formula (point 7 Annex V, part C), replacing the divisor "20" by the period (in years) of cultivation of the crop under improved management. The time period is until crop maturity or 20 years, whichever is the earliest. Default factors are provided for the impact of management on soil carbon stock in 2009/28/EC decision on guidelines for the calculation of land carbon stocks, (Tables 2 and 3). Also, measurements are allowed: 'Measurements of soil carbon can constitute such evidence, e.g. by a first measurement in advance of the cultivation and subsequent ones at regular intervals several years apart. In such case, before the second measurement is available, increase in soil carbon would be estimated using a relevant scientific basis. From the second measurement onwards, the measurements would constitute the basis for determining the existence of an increase in soil carbon and its magnitude. Peaty soils 'For determining SOC, appropriate methods shall be used. Such methods shall take into account the entire depth of the organic soil layer as well as climate, land cover and land management and input. Such methods may include measurements'. It is made explicit that a change of management activities, tillage practice or manure input practice is not considered land-use change.

Source	Carbon storage and soils
UK Renewable transport fuels obligation methodology (Bauen et al., 2008)	Improved carbon storage is not included in the original 2008 methodology document by Bauen et al.
Greenhouse Gas Protocol – Draft Agricultural Protocol (unfinished) for farm-level inventories	The Agricultural Protocol has requirements that diverge from those in the Corporate Standard in relation to the reporting of biogenic CO_2 emissions and carbon sequestration (Table 1-3). In such cases, the Agricultural Protocol has primacy. Net fluxes to/from soil carbon stocks arising from changes in land use management are required to be reported. Net fluxes to/from biomass carbon stocks arising from changes in land use management in certain crop systems (woody perennials and SRC) are required to be reported. *Net CO_2 fluxes to/from the biomass associated with annual and perennial herbaceous crops should not be reported'. There is an option for short lived changes in carbon stocks (forest/grassland burning) to be reported in the reporting period or amortized over time, (this is not applicable for UK crops however).
WRI Product life cycle accounting and reporting standard 2011	These are included in the IPCC LUC defaults suggested in the LUC section. 'Companies may include management related soil carbon change only if they are able to reasonably estimate the emissions or removals, and reporting explicitly mentions that soil carbon is included.' The carbon stock change methodology is based on methodologies and guidelines given in the 2006 IPCC Guidelines for National GHG Inventories, Volume 4: Agriculture, Forestry,

Source	Carbon storage and soils
	and Other Land Use. The guide suggests that the most recent IPCC guidelines are used for generic activity data/emission factors unless sector or country specific data is available (peer-reviewed journals are mentioned as a source).
PAS2050:2011	Soil carbon stock change is excluded from the assessment as long as it is not associated with LUC, though provisions allow a different approach if supplementary requirements include one (PAS2050 clause 5.7).
PAS2050-1 Supplementary requirements for the application of PAS2050 to horticultural products	These supplementary requirements do not account for any additional methodologies to that of PAS2050:2011.
The Agri-footprint method – framework version 1.0	Emissions from the cultivation of peat soils use the 2010 Dutch national inventory methodology. The Agri- footprint method only gives default emissions for dairy cow grazing on peat soils, (since this is stated to be the only agricultural use of peat land in Holland): 19,040 kgCO_2eq ha^{-1}.
DEFRA Project IS0205, Williams et al., 2006	Soil carbon is not considered in the assessment methodology.

4.1.12. Data quality requirements

Source	Data quality requirements
The International Reference Life Cycle Data System (ILCD) Handbook: General Guide for Life Cycle Assessment- Detailed Guidance.	ILCD States that: Well-documented data and data sets should be preferred to allow judging the data appropriateness for use in context of the analysed system and to enable the (potential) critical reviewer to be able to perform an independent verification. ILCD also gives generic guidance in Appendix 12 on the principles of data quality based on time, geographical and technological representative data, along with guidance on completeness, precision and methodological appropriateness and consistency for LCA modelling. A set of respective data quality indicators are described, (p329) to reflect these requirements.
Audsley et al., 1998	No data quality rules were documented in this early study into how to harmonise methods for agricultural LCA's.
Life Cycle Inventories of Agricultural Production Systems. Data v2.0. Ecoinvent report No.15 (2007)	Ecoinvent has data quality scoring 1-5 categories in a so-called pedigree matrix, (from Pedersen, Weidema and Wesnaes 1996[24]). This includes criteria for reliability, completeness, temporal, geographical and technical correlation and, importantly, sample size.
Renewable Energy Directive - as interpreted by the UK for article 19.2	No data quality rules – this is an assessment, not a protocol.

[24] Pedersen Weidema B. and Wesnaes M. S. (1996) Data quality management for life cycle inventories – an example of using data quality indicators. *Journal of Cleaner Production*, **4**(3-4), pp. 167-174.

Source	Data quality requirements
Renewable Energy Directive	The BioGrace[25] project is attempting to harmonise the secondary data for emission factors for inputs. Specific data quality requirements are not given by the BioGrace project literature. RED only includes CO_2, CH_4 and N_2O and their GWP's of 1, 23 and 296 respectively.
UK Renewable transport fuels obligation methodology (Bauen et al., 2008)	For the default values, a group of international experts were consulted to define fuel chain steps for each biofuel and provide data and calculation steps for estimating GHG emissions for the worst, best and typical. These were checked by E4Tech for consistency with well to wheels studies (most likely JRC CONCAWE).
Greenhouse Gas Protocol – Draft Agricultural Protocol (unfinished) for farm-level inventories	General principles of relevance, completeness, consistency, transparency and accuracy are provided. No specific requirements are given in the draft protocol, although guidance is given on kinds of data and that companies should consult calculation tools to determine exact requirements (7.2). Guidance is given in 7.3 on prioritizing data collection on the grounds of various criteria (size, control, risk, stakeholders and sector guidance).

[25] www.biograce.net

Source	Data quality requirements
WRI Product life cycle accounting and reporting standard 2011	Includes carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, perfluorocarbons, and hydroflourocarbons emissions to, and removals from, the atmosphere. 100-year GWPs used to estimate GHG emissions and removals data to calculate the inventory results in units of CO_2 equivalents. ‘During the data collection process, companies shall assess the data quality of activity data, emission factors, and/or direct emissions data by using the data quality indicators’. ‘GHG accounting and reporting of a product inventory shall follow the principles of relevance, accuracy, completeness, consistency, and transparency.’ Relevance is further clarified as technological, geographical and temporal representativeness. Completeness is defined as ‘the degree to which the data are statistically representative of the process sites’. ‘Reliability: the degree to which the sources, data collection methods, and verification procedures used to obtain the data are dependable’. The guidance gives examples of using these qualitative criteria to assess the quality of activity data (as required) in a scoring matrix.
PAS2050:2011	Preferences are applied for time, geographically and technologically specific processes to the cereals and oilseed production processes. No quantitative criteria are given on these preferences: age, geographical or technological limits. Additionally, data, models and assumptions that are most accurate and precise (low variance) shall be given preference by

Source	Data quality requirements
	the PAS. There is also a requirement for completeness in terms of the coverage of at least 95% of the GHG emissions inventoried for the product.
PAS2050-1 Supplementary requirements for the application of PAS2050 to horticultural products	Directly references PAS2050, (clause 7.2) as summarised above.
The Agri-footprint method – framework version 1.0	The Agri-footprint method is fairly prescriptive regarding the use of default data sets and supporting methodology for emission estimates (Dutch NIR, IPCC Guidelines etc.)
DEFRA Project IS0205, Williams et al., 2006	No data quality rules – this is an assessment, not a protocol.

4.1.13. Primary data requirements

Source	Primary data requirement
The International Reference Life Cycle Data System (ILCD) Handbook: General Guide for Life Cycle Assessment- Detailed Guidance.	ILCD states: ‘Data that is averaged over several years may also be necessary in cases where a single year is not representative for the general, “current” situation. This applies in cases where data varies considerably among years. This could, for example, be the case for agricultural products, where, e.g. yield, the resulting nitrogen surplus and related emissions, pesticide amounts applied, etc. can differ considerably among years due to different meteorological conditions, disease incidents, and the like. ILCD also states that: Site or producer/provider specific data for the farming system should (not shall) be used, also supplier-specific data for the input products should be used. However the guide further allows (p 131) that: ‘Generic data of geographical mixes can be used also in parts of the foreground system (crop growing inventory data) if for the given case is justified as being more accurate, precise, and complete than available specific data’
Life Cycle Inventories of Agricultural Production Systems. Data v2.0. Ecoinvent report No.15 (2007)	The method takes secondary data for modelling agricultural products from statistical resources (FAO Stat, Eurostat and national statistics).
Renewable Energy Directive - as interpreted by the UK for article 19.2	As interpreted by the RTFO technical guidance for RED reporting of actual data. Primary data can be from one crop-growing season with data specific to an individual field or, average data for all fields of a particular crop grown on a farm. The UK regional assessment for cultivation emissions (under article 19.2 of the RED) use 5 year averages for yields, and fertilizer use for the crops listed above.

Source	Primary data requirement
Renewable Energy Directive	As interpreted by the RTFO technical guidance for RED reporting of actual data. Primary data can be from one crop-growing season with data specific to an individual field or, average data for all fields of a particular crop grown on a farm. The UK regional assessment for cultivation emissions (under article 19(2) of the RED) use 5 year averages for yields, and fertilizer use for the crops listed above.
UK Renewable transport fuels obligation methodology (Bauen et al., 2008)	Defaults can be used in conjunction with primary data (from operators), but co-dependency of some default variables (N input and yield) have to be controlled to prevent erroneous results; i.e. if only one input (e.g. yield) is altered disproportionately to the likely causal change in the other (e.g. N input left set at the default).
Greenhouse Gas Protocol – Draft Agricultural Protocol (unfinished) for farm-level inventories	The draft protocol 'Part 3 quality considerations and collecting primary data' is still to be written so could not be reviewed.
WRI Product life cycle accounting and reporting standard 2011	'Companies shall collect primary data for all processes under their ownership or control' (Control is defined as financial or operational. Financial control is further qualified by whether the company has the majority of risks or benefits associated with the operation's assets.
PAS2050:2011	Primary data is required from processes owned and operated or controlled by the organization implementing the PAS. Also primary data is required from suppliers that contribute greater than 10% where the organisations own GHG emissions are less than 10% of total emissions of the product. This excludes C sequestration.

Source	Primary data requirement
PAS2050-1 Supplementary requirements for the application of PAS2050 to horticultural products	As PAS2050 but includes the following supplementary requirements: 1) For annual crops, a minimum of 3 years of data is required/ suggested. Where unavailable, at least one year of data is required. 2) For crop cycles less than one year, data from min. of three recent full consecutive growing cycles are required. 3) For individual growers 7.3.1 of the supplementary requirement requires 100% sampling, (if product assessment requires multiple growers, a sampling protocol is given for sample population for data collection).
The Agri-footprint method – framework version 1.0	Dutch statistical sources are referenced by the methodology to give the average case for an agricultural commodities (inputs, yields etc.). Default fixed assumptions on emissions from retail; packaging and transport distances etc. for agri-commodities are given in the appendices.
DEFRA Project IS0205, Williams et al., 2006	Primary data were taken from national survey data (e.g. BSFP) but also assumptions were made by experts in farming practices. Research publications and agricultural data sources (Nix) were used to account for other emission estimates (from tractor operations, average manure application rates for crops etc.).

4.1.14. Secondary data requirements

Source	Secondary data requirement/ default data
The International Reference Life Cycle Data System (ILCD) Handbook: General Guide for Life Cycle Assessment- Detailed Guidance.	ILCD states: [Data which is not technologically representative] is justifiable only if this [does] not relevantly change the overall LCIA results compared to using fully representative data; otherwise the lower achieved representativeness shall be documented in the data set/ report. This is seemingly another rather paradoxical statement – since the representative data would need to be available to make this assessment. Also, the ILCD requires good geographical representativeness.
Audsley et al., 1998	Data was extrapolated from a variety of published industry and academic sources – no specifications for inventories of secondary data were documented in the study.
Life Cycle Inventories of Agricultural Production Systems. Data v2.0. Ecoinvent report No.15 (2007)	Fertiliser data is based on inventories adapted from Davis and Haglund (1999). Ecoinvent includes fossil CO_2 emission from urea. The CO_2 is bound in the production process but is released as a result of Urea application.
Renewable Energy Directive - as interpreted by the UK for article 19.2	RED suggests that default values should be defined for cultivation practices for each of the NUTS 2 areas (Nomenclature of Units Territorial for Statistics). Tractor fuel use for cultivation operations were estimated based on the assumption of tractor hours for operations from Nix and 2.40 kWh energy output per litre of fuel consumed for tractors fitted with engines up to 150 kW power output (based on US Nebraska test laboratory data 2010).

Source	Secondary data requirement/ default data
	Heavier soils and smaller fields increase the time required for ploughing and cultivation so weighting factors accounting for heavy medium and light soils and field efficiency were applied. It is assumed that minimum tillage and direct drilling reduces ploughing requirement by 50%. The Directive requires the use of the average emission intensity for electricity for a 'defined region'. It is suggested that this could be an average for the whole EU.
Renewable Energy Directive	The Directive requires the use of the average emission intensity for electricity for a 'defined region'. It is suggested that this could be an average for the whole EU. The Biograce project is producing a set of default emissions factors for inputs to biofuel production to harmonise the calculation methods [3].
UK Renewable transport fuels obligation methodology (Bauen et al., 2008)	A fixed set of default values, (worst, best and typical) for all inputs and fuel chain conversion processes is developed. Defaults are recommended to be conservative for inputs/processes contributing over 5% of the fuel chain emissions, or operators submit that which are under the 5% material contribution threshold. Conservative estimates are a policy tool to encourage reporting of actual primary data values. This may not be relevant for general carbon calculators for farmers where a typical may be more appropriate.
Greenhouse Gas Protocol – Draft Agricultural Protocol (unfinished) for farm-level inventories	Part 3: concerning scope 3 data quality - still to be completed. Scope 3 sources are optional when reporting in accordance with the GHG corporate standard.

Source	Secondary data requirement/ default data
WRI Product life cycle accounting and reporting standard 2011	'Companies shall collect data for all processes included in the inventory boundary'. An example is given in the guidance for options for the choice of GWP from the latest IPCC assessment report, or the SAR, following the UNFCC.
PAS2050:2011	Shall be used where primary data have not been obtained. It is in accordance with data quality rules, but preferences are given to competent sources (listing national government publications, UN publications or affiliated organizations and peer reviewed publications).
PAS2050-1 Supplementary requirements for the application of PAS2050 to horticultural products	'Shall be used where primary data have not been obtained', 'in accordance with data quality rules', but preferences are given to competent sources (listing national government publications, UN publications or affiliated organizations and peer reviewed publications)(7.4).
The Agri-footprint method – framework version 1.0	Ecoinvent V2.2 data is used for (scope 3) extraction, production and transport of energy carriers (fuels and electricity). Combustion data emissions are based on full oxidation of carbon content. Ecoinvent V2.2 data is used to calculate transport and packaging emissions. Fertiliser data is based on Davis and Haglund (1999).
DEFRA Project IS0205, Williams et al., 2006	Ecoinvent data were used for some of the inventory.

4.1.15. Uncertainty

Source	Handling variability and uncertainty
The International Reference Life Cycle Data System (ILCD) Handbook: General Guide for Life Cycle Assessment- Detailed Guidance.	‘ISO 14044:2006 defines precision as the “measure of the variability of the data values for each data expressed (e.g. variance)”. ‘ISO 14044:2006 does not define uncertainty, but uses the term in the sense of expressing the quantitative degree of the lack of precision, i.e. its (negative) measure, i.e. for the error’. Data quality indicators in the ILCD guidance suggest: ‘to differentiate between "variance" as stochastic measure of uncertainty and "variability" to capture processes and systems that have different LCI data under different, e.g. operation, conditions’.
Audsley et al., 1998	No approaches to uncertainty or sensitivity assessments were documented in the study.
Life Cycle Inventories of Agricultural Production Systems. Data v2.0. Ecoinvent report No.15 (2007)	For crop systems where a product is produced more than once (e.g. wheat is grown 2 times in the following rotation OSR- W –W – wB) the average input and yields are taken. Uncertainty ranges are given in many of the processes in the Ecoinvent database. These can be used by software for reporting uncertainty in system assessments using Monte Carlo analysis. Though the report did not publish a quantitative uncertainty assessment for Swiss, EU and US cereals, a qualitative data quality assessment is given using an uncertainty scoring system.
Renewable Energy Directive - as interpreted by the UK	Assessment time period and representativeness for primary data used for assessment calculations. The RTFO/RED is per batch of fuel so data is allowed from one crop growing season. The UK

Source	Handling variability and uncertainty
for article 19.2	assessment for regional cultivation emissions present an assessment of the uncertainty of the data used and also a sensitivity analysis for the estimate of nitrous oxide emissions using a more detailed modelling approach than the actual IPCC 'tier 1' method.
Renewable Energy Directive	Assessment time period and representativeness for primary data used for assessment calculations. The RTFO/RED is per batch of fuel so data is allowed from one crop growing season.
UK Renewable transport fuels obligation methodology (Bauen et al., 2008)	Uncertainty reporting is not part of the suggested methodology, though worst, best and typical values were part of the methodology for defaults.
Greenhouse Gas Protocol – Draft Agricultural Protocol (unfinished) for farm-level inventories	Intensity ratios 6.3 the suggestion is given for businesses, in the event of adverse weather events, should report emissions of expected yield, as well as actual yield. Although, intensity ratio reporting is optional.
WRI Product life cycle accounting and reporting standard 2011	The standard requires 'a qualitative statement on inventory uncertainty and methodological choices' (allocation methods, source of global warming potential (GWP) values used, calculation models etc.).
PAS2050:2011	Reassessment is required if the process is likely to alter the GHG emissions by 5% over 3 months (7.5). Data should be collected over sufficient time to allow an average to be calculated (assumed to be applied to emissions estimated from secondary sources and primary data).

Source	Handling variability and uncertainty
PAS2050-1 Supplementary requirements for the application of PAS2050 to horticultural products	Reassessment is required if the process is likely to alter the GHG emissions by 5% over 3 months (7.5). Data should be collected over sufficient time to allow an average to be calculated (assumed to be applied to emissions estimated from secondary sources and primary data).
The Agri-footprint method – framework version 1.0	Monte Carlo simulation of uncertainty is suggested, using normal distributions for inputs based on their mean and standard deviations. Where the standard deviations are not available, assumptions are given as to 2 standard deviations for the 'probable range' inputs data. If ranges are not available then defaults are given for St. dev of 20% for emission factors and 10% for all other inputs.
DEFRA Project IS0205, Williams et al., 2006	An overall summary of uncertainty associated with the commodity estimates of +/- 30% is reported. Uncertainly for specific commodities are not estimated.

4.2. Appendix B - Expert panel consultation questions

HGCA Draft Carbon Footprint Protocol – Expert Panel Consultation

[Copy of online survey text – font and format have been altered in transfer from original online survey version]

Dear expert panel member,

On behalf of the UK Home Grown Cereals Authority we would be most grateful if you could contribute your comments and judgements to the development of a cereal and oilseed crop GHG protocol by responding to this survey.

We would ask that your judgements be made within the context of the project's practical goals:

1. The primary goal is to enable levy payers to engage with GHG crop assessment;

2. A secondary goal is to set out a consistent, independent and transparent platform to allow levy payers to provide assessments to interested parties.

3. A final goal is to propose a protocol which can help growers make a practical difference.

The challenge is to develop a protocol (and related calculator) that will balance practicality with the best available options for farm level crop assessments, where greenhouse gas emission estimates for management options are backed by scientific data, as far as possible.

1. Defining the crop emissions reporting unit

Background

Our review of existing protocols and methods identified a number of units for reporting emissions in relation to crop production:

- By MJ of energy (for bioenergy reporting);
- By kg of protein (for product specific cereals);
- Mass (fresh weight);
- Mass (at ‘typical’ stored moisture level);
- By organisational boundary, (defined by organisational control, but augmented with GHG intensities per mass of crop);

In summary, there are a number of options for reporting, often depending on the crop’s end use. The protocol is aimed at engaging growers, and it is important to note that growers may not know exactly what end use their crops may serve.

1A. We have chosen to report estimated growing GHG emissions against one metric tonne of crop produced:

The growing emissions will be corrected to 1 metric tonne at the commercially appropriate stored moisture content:

- Cereal grain 14.5%
- Oilseeds 9 %

Do you agree or disagree with the reporting units outlined above?

Please tick the appropriate response:

I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - I am not qualified to answer this
○	○	○	○	○

Drying and storage emissions will be added to growing emissions after correction for moisture, (described later).

1A. Please give your comments below:

2. Product reporting group

Background

The GHG emissions profile of crops grown for broadly different functions are likely to vary for reporting due to different nitrogen requirements etc. Also yields and agronomy for winter and spring (and even autumn) varieties may differ.

As mentioned in the previous question, growers may not know exactly what the end use of their crops will be. However, benchmarking and comparisons are possibly a future goal of a protocol and related carbon calculator development.

Providing data for individual varieties would be impractical so we propose that the grower should be asked to conduct GHG assessments within the context of broad crop groups for reporting and future benchmarking requirements.

2A. We propose the following broad crop group categories:

- ○ nabim Group 1 - wheat for bread making
- ○ nabim Group 2 - wheat primarily for bread making but with other uses
- ○ nabim Group 3 - wheat for biscuit or non-bread baking etc.
- ○ nabim Group 4 - wheat for other uses - animal feed, biofuel etc.
- ○ Malting barley
- ○ Feed barley
- ○ Oilseed rape - food grade
- ○ Oilseed rape - industrial (including biofuels etc.).
- ○ Linseed
- ○ Food oats
- ○ Feed oats
- ○ Rye
- ○ Triticale

Please tick if you agree or add any comments or qualifications if you don't.

Please tick the appropriate response:

I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - I am not qualified to answer this
○	○	○	○	○

2A. Please give reasons or add comments:

2B. Should the reporting groups further distinguish between winter and spring varieties?
Please tick the appropriate response:

Yes	Uncertain	No
○	○	○

3. Defining the farm gate

Background

The reviewed literature gives few specific criteria and examples for defining the ‘farm gate’ production system boundary outlined in the HGCA project specification. Definitions we found for assessment boundaries are summarised below:

1. The point at which the product is transferred to a 3rd party

2. The point at which operational (physical) control is relinquished

3. The point at which financial control (ownership) is relinquished

4. Individual crop husbandry only to the point of harvest, not including drying or storage

5. Geographical farm gate but only of the arable system for a single crop, but including emissions from crop drying and storage

3. We have chosen to adapt the last definition with further qualifications below:

Emissions from grain drying and first storage shall be included whether stored on farm or in co-operative/merchant managed stores. Transport emissions from transfers between the farm to any offsite drying and first storage shall be included.

Do you agree with our proposed definition of the farm gate boundary?

Please tick the appropriate response:

I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
○	○	○	○	○

Qualifying details:

- GHG emissions from post-harvest activities, but before grain drying, will be included in the inventory then corrected to crop mass at the standard moisture content.
- GHG emissions associated with drying crops to the standard moisture levels will be based on secondary data, but the choice of drying technology used shall be relevant to the grower’s circumstances.
- GHG emissions incurred after the point of drying within the boundary such as transport and storage shall be added to the inventory after without any correction for moisture.
- Where grain drying occurs in two phases (e.g. drying may occur on farm and then further drying at grain merchants may be implemented) a single default drying operation shall be assumed.

Please add any suggestions for improvement or helpful queries regarding the proposed definition of ’farm gate'

4. Defining the cut-off criteria

Background

We have found that estimates of greenhouse gas emissions resulting from materials and activities supplied for crop production, (e.g. the manufacture of fertiliser and production of fuel), will be taken from different studies or data sources that are available. These studies report different levels of detail. Some studies may only report a single cumulative value, whilst other data sources may allow contributions to be separated from many different unit processes. These differences prevent the correct cut-off criteria being applied consistently to all of the contributory processes.

Therefore, applying cut-off criteria will be subject to the reported granularity of the secondary data that is available. Existing data sources may be also subject to the data available, and the judgement and discretion of the assessor.

Until more data sources become harmonised and made available, we recommend that GHG emissions from processes and activities should be included in the assessment boundary based on current data availability, expert opinion and practicality, and not subject to strict quantitative cut-off thresholds.

We propose that included and excluded processes shall be listed and described by the protocol, similar to the concept of descriptive product category rules: For included processes, estimates of their GHG emissions based on secondary data shall be subject to expert judgement of what is the most appropriate data available, in conjunction with the protocol's data quality requirements.

4.A. We propose that the HGCA protocol should not require specific quantitative cut-off criteria to define the detail of upstream sources of GHG's to exclude.

Requiring a mandatory cut-off threshold for emissions sources will be subject to the reported granularity of the data that is available for production of fertiliser, fuel, combustion and other processes. At present, the majority of data available are from different sources and studies where the detail of reporting is not equally transparent or likely to be consistent.

Please tick the appropriate response:

	I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - I am not qualified to answer this
Do you agree with this approach?	○	○	○	○	○

PCR's of varying quality were identified: GHG assessment of rapeseed oil (Japan); milled grain products (Sweden); and a generic framework protocol for PCR's of agricultural products, (Sweden). The reporting units and process coverage are outlined as well as reference to methods for the use of secondary data. These were not very detailed with regard to the growing stage, apart from a general requirement to include emissions from fuel and fertiliser production and use and nitrous oxide emissions from soils.

The Swedish framework suggests a 1% cut-off criteria for elementary flows, (LCA terminology for emissions leaving the system boundary, as defined by the study). Arguably there would also appear to be some ambiguity in defining what level of analysis could be interpreted to constitute a 'source' of GHG emissions in PAS2050.

'Unit process' and 'elementary flows' may be defined in LCA standards, but existing secondary data sources may be used which report aggregated results or data with limited transparency. For example, reported emissions data could be based only on mass balance of inputs and outputs for a whole fertiliser manufacturing installation or aggregated from many individual sub-processes in fertiliser manufacture. Transparency is important to understand whether the data includes or excludes transport or raw material extraction, steam credits and the use of energy sources not relevant for fertilisers manufactured for use in the UK etc.

4. Please give your comments or reasons below:

4B. Temporal cut off.

For consistency with other protocols we propose:

1. That the assessment of global warming impact for crop growing to the farm gate should be within a 100 year time period from production at the farm gate.
2. That the global warming potentials of greenhouse gases are within a 100 year period from being emitted.

(Please note even though we have combined these in one question here, we acknowledge there are different reasons for 1 and 2 within an assessment protocol)

Please tick the appropriate response:

I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
○	○	○	○	○

Product System:

Since this a farm gate assessment - we acknowledge that a 100yr boundary only affects longer term impacts arising from the crop growing stage. This may involve future requirements to include soil management impacts on soil carbon stock change etc. (see later questions). However, we include this primarily to conform to PAS2050 and other protocols which require a 100 year assessment boundary for product GHG life cycle assessments.

Greenhouse Gases:

Most literature follows the IPCC methodology for setting out the global warming potentials for greenhouse gases (GHG's). We propose that the protocol requires the latest GWP's as set out by the latest IPCC's assessment report (currently AR4 2007) based on estimates of the GHG's radiative forcing over a 100 year time period.

4b. Please add your comments:

5(i). Excluded Processes

<u>Background</u>

Our review of existing protocols and literature suggests there is some evidence that the processes such as fabrication and construction of farm buildings and machinery could contribute greater than 1% to farm gate cereal crop emissions. Emissions sources greater than 1% of the total GHG emissions are required to be included by PAS2050, yet this specification also explicitly excludes capital infrastructure from the assessment requirements.

We propose to exclude processes from the HGCA protocol on the grounds of

1. Consensus of existing protocols reviewed or;
2. That studies suggest that the activities are likely to make a negligible contribution or;
3. The primary data demanded would be unpractical for achieving the protocol goals.

Considering these points, we propose to exclude the following processes (below).

Please indicate whether you agree, disagree or consider the issue to be more complicated. If you disagree or suggest the grounds for exclusion are more complicated, please provide reasons.

5A. Production and supply of buildings and infrastructure

Please tick the appropriate response:

	I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
Exclude from the assessment	◯	◯	◯	◯	◯

5a. Please give your reasons below:

5B. Maintenance of buildings and infrastructure

Please tick the appropriate response:

	I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
Exclude from the assessment	◯	◯	◯	◯	◯

5b. Please give your reasons below:

5C. Production of agricultural machinery and equipment

Please tick the appropriate response:

	I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
Exclude from the assessment	◯	◯	◯	◯	◯

5c. Please give your reasons below:

5D. Maintenance of agricultural machinery and equipment

Please tick the appropriate response:

	I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
Exclude from the assessment	◯	◯	◯	◯	◯

5d. Please give your reasons below:

5E. The production and supply of pesticides

Please tick the appropriate response:

	I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
Exclude from the assessment	◯	◯	◯	◯	◯

5e. Please give your reasons below:

5F. Carbon dioxide removal (sequestration) from the atmosphere and storage of carbon in crops and straw.

Because the fate of carbon in straw and crops is complex and uncertain, we propose to exclude reporting biogenic carbon stored in crops and straw from the assessment inventory, (soil carbon is considered in later questions).

Please tick the appropriate response:

	I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
Exclude from the assessment	◯	◯	◯	◯	◯

Carbon sequestered from the atmosphere through photosynthesis is subsequently stored in crops and straw. At the farm gate assessment boundary, some LCA assessments would count carbon in crops and straw as a 'removal' of carbon, albeit likely to be a temporary one.

A proportion of the carbon within crops and straw, is likely to be degraded, combusted or metabolised and emitted back to the atmosphere, as GHG's, within the 100 year assessment boundary. Other fractions may be recycled and bound in soils, plants, animals and people etc.

Because the fate of carbon in straw and crops is complex and uncertain, we propose to exclude reporting biogenic carbon stored in crops and straw from the assessment inventory.

PAS2050:2011 and GHG protocols require significant GHG emissions and removals in each process to be accounted for in an inventory. However, due to the reasons outlined above, PAS2050 explicitly excludes carbon dioxide removals and emissions from assessment inventories if they are associated with food or feed products, or agricultural soils (excepting land use change).

5f. Please give your reasons below:

5G. Emissions from the production of seeds.

Please tick the appropriate response:

	I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
Exclude from the assessment	◯	◯	◯	◯	◯

5g. Please give your reasons below:

5H. The production, treatment and storage of manure, biosolids and compost within the control of a third party, (but not transport to site), that are used as organic fertilisers.

Please tick the appropriate response:

	I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
Exclude from the assessment	○	○	○	○	○

For the purposes of the protocol, and to avoid allocation as far as possible, we consider that these are by-products not co-products, and their production emissions should be attributed to their primary purpose - livestock production, mushroom production and waste treatment etc.

Though there are simple IPCC emission factors for storage of livestock manure, these may not be appropriate or robust. The research and assumptions surrounding emissions from manure and biosolids storage may require further attention, probably beyond the scope of the protocol review and prototype calculator. This uncertainty is another reason we are excluding this from the protocol boundary.

This exclusion also ignores arguments regarding 'reference systems' - quantifying emissions that would and wouldn't occur if these materials were not used by the grower.

The use of a reference system would appear to be aligned more with a consequential approach, which would require modelling the average reference system emissions to estimate the net 'change' from this to the current system. This is likely to be more subjective and complicate matters, especially for grower engagement.

Therefore, since this is a product based assessment not an assessment of larger infrastructural changes in relation to policy, we propose to keep consistently to an attributional approach.

5h. Please give your reasons below:

5I. Perfluorocarbons, hydroflourocarbons and sulphur hexafluoride

Please tick the appropriate response:

	I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
Exclude from the assessment	○	○	○	○	○

5i. Please give your reasons below:

5J. Human labour and related workforce transport or housing emissions.

Please tick the appropriate response:

	I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
Exclude from the assessment	○	○	○	○	○

5j. Please give your reasons below

5(ii) - Included processes

[Overleaf] is a schematic of the crop assessment boundary showing excluded and included processes along with a graphical representation of the recommended primary data that are required from the grower and secondary data from other sources.

'Tier 1' and 'tier 2' relate to where a grower may be able to modify secondary data categories to their farming context. The modification of secondary data primarily concerns the carbon calculator, rather than secondary data and methodological requirements to be published in the protocol.

We include on farm or local storage of delivered organic fertiliser, given it is nearer to the grower in terms of potential for management control, and arguably is an aspect that may be broadly analogous to off farm drying, which we propose to include in the assessment boundary.

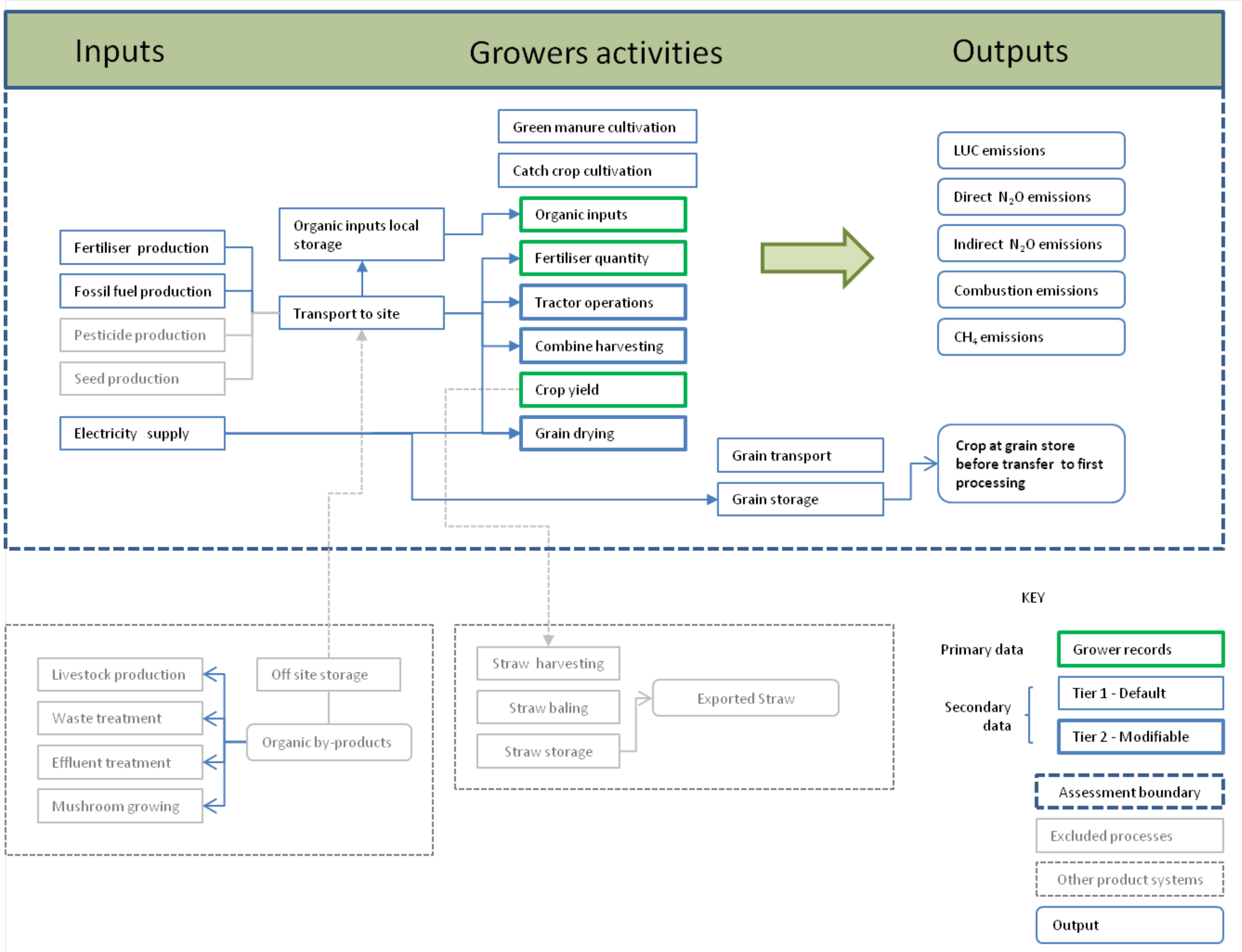
However, as mentioned in 5(i)H, we suggest that the basis for a robust methodology for GHG emission estimates from manure storage requires further research. It may be that a simple approach could be adopted in the interim for the purposes of demonstrating a prototype calculator.

5(ii) Do you agree with the schematic and the processes that have been included?

Please tick the appropriate response:

I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
○	○	○	○	○

Please give any comments or recommendations in the box below the schematic:


Inputs
Growers activities
Outputs
Green manure cultivation
Catch crop cultivation
Organic inputs local storage
Organic inputs
Fertiliser production
Fossil fuel production
Pesticide production
Seed production
Transport to site
Fertiliser quantity
Tractor operations
Combine harvesting
Crop yield
Electricity supply
Grain drying
LUC emissions
Direct N_2O emissions
Indirect N_2O emissions
Combustion emissions
CH_4 emissions
Grain transport
Grain storage
Crop at grain store before transfer to first processing
Livestock production
Waste treatment
Effluent treatment
Mushroom growing
Off site storage
Organic by-products
Straw harvesting
Straw baling
Straw storage
Exported Straw
KEY
Primary data
Grower records
Secondary data
Tier 1 - Default
Tier 2 - Modifiable
Assessment boundary
Excluded processes
Other product systems
Output

6. Attribution of GHG's from organic inputs

Background

The organic inputs identified in relation to crop growing are:

- Manure from livestock production
- Compost and other biosolids from waste treatment facilities or mushroom production
- Crop residues (from previous crops) and incorporated straw
- N-fixing legumes and other green manures

The GHG emissions associated with a) the production and b) the use of organic fertiliser may be attributed to both their source and the crops they benefit. The remainder or carry-over of the more recalcitrant fractions of nutrients from organic fertilisers could benefit subsequent crops over one or more years.

Manure, compost and biosolids	As outlined in 5(i)H, we propose that for simplicity, and also due to a lack of robust data, the upstream production and storage emissions for manure, compost and biosolids are attributed entirely to their primary product or service. Therefore we assume that allocation of any offsite production emissions to their 'by-products' used as organic fertilisers is conveniently avoided.
Straw and crop residues	For consistency we propose that where straw is incorporated, nitrous oxide emissions from straw nitrogen are attributed to the crop the straw originated from.
Green Manures and cover crops	We assume any green manure and cover crops are purposely grown for soil fertility to benefit crops; therefore, 100% of the green manure/cover crop cultivation emissions should be attributed to following crops in some way.

An active approach to soil nutrient management, following RB209, suggests farmers could reduce some mineral fertiliser requirements (and their associated GHG production burdens) when incorporating straw instead of exporting or using organic fertilisers. Although, some studies suggest quantifying the actual benefits and disbenefits to following crops by incorporating straw and manure are not straightforward.

We propose that any benefits of organic inputs should be demonstrated only in practice; i.e. in the growers actual crop yields and fertiliser use reflected in each crop GHG assessment etc.

6A. We propose that nitrous oxide emissions from the nitrogen in organic inputs should be attributed to the following crop on the basis of 'readily available nitrogen', not total nitrogen.

The definitions and default data on total nitrogen content and readily available nitrogen of organic manures, biosolids and compost shall be based on the most recent version of RB209 fertiliser manual - DEFRA.

Background

Though more sophisticated tools such as MANNER-NPK and PLANET are available for estimating crop available nutrients from manure inputs, these modelling approaches were considered too detailed for the purposes of a GHG protocol and carbon calculator.

Please tick the appropriate response:

	I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
	○	○	○	○	○

6a. Please comment below

6B.With reference to RB209, the unavailable organic nitrogen fraction of organic inputs is assumed to remain after the first crop. For the purposes of applying a methodology for estimating nitrous oxide emissions, we assume that 100% of the organic nitrogen fraction will be mineralised.

We propose for intermittent or periodic spreading of organic fertiliser, that nitrous oxide emissions from the recalcitrant nitrogen fraction should be attributed evenly to the crops grown in the same area over subsequent years, until the next manure application.

If organic fertiliser is applied before each crop, then the nitrous oxide yield will be estimated assuming mineral nitrogen equals the total nitrogen input (readily available N + unavailable N). The estimated emissions in this case should all be attributed to each following crop.

Background

Attributing the carry-over of the more recalcitrant organic fractions of nitrogen in biosolids, manures and green manures etc. to crops beyond the year of application is complex and subject to variables of leaching and subsequentcrop N uptake efficiencies etc. We propose to adopt a Dutch LCA methodology (following recommendations by Wegener Sleeswijk 1996, cited in Blonk et al., 2010) to simply divide the remaining fraction between the following series of crops in the cropping system in proportion to their area over the crop rotation period.

Please tick the appropriate response:

	I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
	○	○	○	○	○

6b. Please use this space for adding any further comments

6C. We propose that GHG emissions from processes required for growing green manures should be allocated to the next crop in proportion to the readily available nitrogen. The remaining production emissions should be attributed to following crops using the same method proposed for recalcitrant nitrogen (B).

Background

We acknowledge that green manures are not grown exclusively for their contribution to soil nitrogen supply for crops, but provide other benefits. However, allocating emissions on the basis of multi-functional benefits is complex. So for simplicity we propose using only nitrogen content.

Please tick the appropriate response:

I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
◯	◯	◯	◯	◯

6c. Please use this space for adding any further comments

6D. Due to the proposed boundary (reporting a single crop rather than for a crop system) and for consistency with the previous approaches, we propose attributing emissions from a crop's residues (including straw if incorporated) to that crop's emissions profile.

The total nitrogen in crop residues and straw is assumed to be mineralised for the purposes of applying methodology to estimate N_2O emissions.

Please tick the appropriate response:

I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
◯	◯	◯	◯	◯

6d. Please use this space for adding any further comments

7. Allocation between crops and straw

Background

Straw from crops may either be exported from the arable system for a variety of uses, or chopped and incorporated back into the soil. There does not appear to be an ideal solution for allocating growing emissions between crops and exported straw. The review highlights a number of ways in which the emissions associated with growing are shared between crops and straw if exported from the arable system. These are summarised below.

Option 1. All GHG emissions from crop growing are allocated 100% to the crop, essentially, straw is considered to be a by-product or waste residue from crop production, not a co-product.

Advantages	Disadvantages
• Avoids allocation (preference of ISO14040 etc.). • Consistent in time. • Consistent with attribution of organic inputs. • Crop growing is arguably the primary driver. • There is no large swing in a crop's emission profile if a grower ticks to export straw or not. • Simple/transparent. • Consistent with EU RED.	• Does not adequately reflect that straw has a value in the UK. • Straw sales may support the primary activity of crop growing, so should be acknowledged. • Effectively allows user of straw to claim a GHG neutral product, except for straw specific operations such as chopping, baling and transport.

Option 2. 100% of the production related GHG emissions are attributed to the crop, but the system is expanded so that substitution credits can be removed from this burden for the equivalent GHG emissions associated with products that are displaced by straw.

Advantages	Disadvantages
• Avoids allocation (preference of ISO14040 etc.). • Follows PAS and original RTFO C&S reporting.	• This is arguably more appropriate for assessment of changes in GHG emission relating to markets impacts for policy assessment, not attributional product assessment. • Unambiguosly identifying products that are substituted may be problematic (average of the market spread of substituted products, or a identifying a single marginal one?).

Option 3. GHG emissions from growing are allocated in proportion to energy content between crops and straw (if crops and straw are used for energy and straw is considered of value as a co-product, not a by-product or waste).

Advantages	Disadvantages
• Consistent in time. • Consensus with the RED.	• Doesn't satisfactorily reflect the primary product as the cause of emissions. • Doesn't reflect the function of the products. Energy is not the exclusive function of both crop and straw production.

Although, the RTFO sets a minimum threshold of >10% of the total market value as a condition before applying energy allocation based on a 3 year average market value.

Option 4. GHG emissions from growing are allocated simply in proportion to the mass split between the crop and straw.

Advantages	Disadvantages
• Consistent in time. • Simple/transparent.	• Doesn't satisfactorily reflect the primary product as the cause of emissions. • Doesn't reflect the function of the products.

Option 5. GHG emissions from growing are allocated between crop and straw in proportion to their economic value (perhaps based on a 3 year average as suggested in the RTFO).

Advantages	Disadvantages
• Reflects that straw has value and in some proportion may influence the overall reason for production - economic benefit. • Allows allocation for crops and co-products with very different end functions with one method.	• This is market based and variable, in time and regionally. • Changing GHG emission results based purely on external market conditions may not be conducive to grower engagement for aiding GHG mitigation. • Arguably this doesn't align with the attributional product approach required for product assessment. • If only applied to exported straw then this may exhibit a swing the in crop's GHG profile • Organic straw may have a different value, complicating crop GHG results.

Our proposed method is Option 1.

This is consistent with our proposed approach to attributing emissions from organic fertiliser production and incorporated straw. In the carbon calculator we may report results from both options 1 and 5 to demonstrate to growers that there is no definitive method.

Please tick your most preferred option for allocation to straw exported from the field.

Please tick **only one** of the following:

- ◯ **Option 1.** 100% of estimated GHG emissions from growing are attributed to the crop - no allocation to exported straw.
- ◯ **Option 2.** 100% of estimated GHG emissions from growing are attributed to the crop, but the production GHG emissions associated with any products that are substituted by straw are removed from the crop GHG burden.
- ◯ **Option 3.** Allocate growing emissions per hectare by proportion of energy content of straw and grain per hectare.

- ○ **Option 4.** Allocation of GHG emissions per hectare to crop and straw simply in the proportion to their harvested mass per hectare.
- ○ **Option 5**. Allocation of GHG emissions in proportion to their fixed 3 or 5 year UK average economic value for crops and straw, in field, at the point of separation.
- ○ Other, (please define in the comment box).
- ○ I will skip this question; this is not my area of expertise.

Make a comment on your choice here:

Notes

- Option 5 refers to market values, these could be derived from national data sources (based on DEFRA average cereal and straw prices to remove annual and regional variation). Assumptions would be required for removing respective baling, transport and drying costs from these values to obtain on field values, or other more appropriate data.
- The end use of straw may not be known by the grower. In some cases, third party contractors and merchants may deal with the removal and end use of straw.
- Energy allocation may be inappropriate if the straw use is animal bedding and the crop is grown for bread wheat etc. Having different allocations for end use and different results may also complicate matters for grower engagement.
- If growers tick to incorporate straw that has a commercial export value, it may have an implicit but less quantifiable benefit for soil fertility, i.e. inc. SOM, but another more pressing motive may also be to clear the straw quickly in preparation for the next crop.
- The impact on soil fertility from straw inputs would still be reflected in the GHG emissions of assessments, to some extent, if fertiliser use or ploughing fuel requirements of crops manifest as relatively lower as a result of straw input. Therefore growers choosing not to export straw could exhibit GHG reductions where attribution of P & K fertiliser mfr and fuel use to the crops is legitimately avoided.

7. Please use this space for adding any further comments

8. Soil carbon and land use change emissions

Background

Soil carbon sequestration from management of arable soils and also soil carbon losses from conversion of grassland or even forest land to arable crops are included in a number of the specifications and protocols for GHG assessment. These are categorised as:

(1) Land use change.
(2) Tillage change.

(3) Increase carbon input e.g. through manures, residues.

8A. We propose that emissions from any direct land use changes (1) should be included.

LUC can be estimated in a fairly simple manner based on the IPCC's methodology, where emissions from LUC could be linearly annualised over a 20 year period to allow attribution to an annual crop growing cycle. This is also referred to in a number of the existing protocols (PAS2050:2011 has default estimates for annual CO2 emissions).

Please tick the appropriate response:

I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
○	○	○	○	○

8a. Please give your reasons:

8B. We propose that the effects of tillage change should be excluded.

The permanence of sequestration, a long term increase in soil carbon storage, through low and no till practices is hard to guarantee. Built up soil organic carbon could be lost relatively rapidly with a change in regime to deep ploughing, for example.

Please tick the appropriate response:

I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
○	○	○	○	○

PAS2050:2011 excludes soil carbon changes that are not from land use changes. PAS2050 has a temporal boundary of 100 years for GHG product assessments, so following this, it may be remiss to suggest that sequestration may be permanent and to encourage low or no tillage practices where the net impacts on other GHG emissions are not fully understood.

8b. Please give your reasons:

8C. We propose that (3) - soil carbon sequestration from inputs - should be excluded in GHG crop inventory by the protocol.

Though the IPCC provides a simple management factor for manure inputs, more data intensive modelling approaches, which we suggest are beyond the practical goals of the HGCA protocol and calculator, probably would be required at the farm level.

There are also considerable uncertainties attached to estimating whether sequestration from inputs may actually be an additional removal of carbon dioxide, or just shifting the carbon storage location. Though a valid concern, this involves consideration of reference situations and is more appropriate for consequential, policy level assessment.

Due to these reasons we propose to exclude attributing local carbon sequestration due to organic inputs from the crop GHG inventory.

Additionality

The longer term benefits of straw incorporation and organic inputs on soil organic matter and soil fertility should be highlighted in the growers guide. Also, the growers guide should explain that although soil organic carbon (SOC) stock and fertility could also potentially reduce over time at a growers site if they shift to exporting straw or reducing organic inputs, from a global perspective, if diverted straw and organic by-products are eventually returned to soils elsewhere, this may not translate into net carbon loss (and GHG emissions).

Conversely, if manure inputs increase SOC in a growers fields it doesn't mean that additional sequestration is taking place compared to what would happen otherwise; exported straw as animal bedding or manure would likely end up in soil elsewhere.

The exception is where the fertiliser benefit of the diverted organic matter is not exploited by crops elsewhere, then, arguably, emissions for production of additional inorganic fertilisers may be needed, giving rise to a net GHG emission. But this indirect, consequential impact is hard to quantify.

In summary, quantifying GHG reductions for single crop GHG assessments due to increases on SOC may be challenged on the grounds that this may not lead to additional sequestration from a global perspective.

There would appear to be considerable uncertainty involved in estimating management impacts on soil carbon sequestration from organic inputs, since this depends on unambiguously defining the alternative fate of organic inputs, if not used by the grower. So we propose to exclude soil carbon sequestration from inputs from the GHG assessment protocol.

Please tick the appropriate response:

I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
○	○	○	○	○

8C. Please give your reasons or any additional comments:

8D. Carbon dioxide emissions from the draining of peat and cultivation of organic or peaty soils (histosols) can be estimated using IPCC land use and land use change ‘tier 1’ methodologies.

We think that the evidence base for the IPCC default method may require further refinement for application to farm level assessment.

We propose that methodologies to estimate emissions from organic soils will be dealt with separately with more focussed interaction. This will also have implications on whether to include default IPCC nitrous oxide emissions from peat soils, which relates to the oxidation of carbon from organic soils.

Please tick the appropriate response:

I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
○	○	○	○	○

8d. Please enter your comments below:

9. Primary data requirements

Background

Existing protocols do not give specific requirements on how representative farm data should be selected for GHG assessments. Only the draft horticultural supplementary requirements for PAS2050-1 gave rules for individual growers to use 100% of their fields for GHG estimates of open field horticultural crops.

Since cereals and OSR growers may operate farms with ten's to hundreds of fields extending over different soil types, a protocol for representing their average crops requires some rules or guidance for selecting primary crop growing data.

From the team's experience of the arable farming industry, we think that the kind of growers likely to follow a GHG protocol or use any associated online carbon calculators will be those that already use farm business software and/or have a good knowledge of the inputs and related yields of their fields for the various crops they grow. We suggest that a protocol and calculator should have a two tier approach:

1. A simple method which requires input from only one growing season
2. A more demanding method which requires an average for recorded yields and inputs over 3 crop growing seasons.

The two approaches should be augmented with general recommendations for selecting representative data in a grower's guide, rather than mandatory requirements. Guidance should provide measures to prevent bias, such as growers using data representative of their overall crop growing average, rather than selecting their best performing fields.

For processes such as grain drying and machinery fuel use where secondary data is considered more accurate or accessible than primary data, though perhaps is older or geographically less appropriate etc., we suggest that the protocol allows this data to be used in preference.

Please check the boxes where you agree with the proposed approach. Please add any comments if you don't agree, or any qualifications where necessary.

9A. We propose that primary data should be required that reflects GHG emissions for the average farm production of crops, reported within each broad crop group outlined previously. This would allow growers to report a fair and representative GHG assessment to interested parties.

Simple guidance should be given in the growers guide to prevent bias, e.g. 'cherry picking' by only reporting the best yielding fields etc.

Please tick the appropriate response:

I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
○	○	○	○	○

9a. Please add your reasons or any comments below:

9B. A scientifically robust sampling procedure to represent a typical crop from many fields over a number of seasons could be onerous, and potentially reduce practical engagement by growers with the protocol and calculator.

To strike a balance between the use of representative data and practicality, we do not recommend that the protocol includes mandatory requirements for calculating area, weighted arithmetic mean averages of yield and inputs, and selection of a statistically robust sample size of a grower's fields. We propose guidance should be given in the growers guide instead.

Please tick the appropriate response:

I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
○	○	○	○	○

9b. Please add your reasons or any comments below:

9C. For a simpler 'tier 1' assessment, the grower should be encouraged to use an estimated typical yield per hectare and inputs for the harvested crop in the most common soil type and husbandry used to grow the crop.

Please tick the appropriate response:

I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
○	○	○	○	○

9c.Please add your reasons or any comments below:

9D. For more detailed 'tier 2' assessments, the grower should be required to provide yield and fertiliser input data based on a minimum of 3 seasons growing records to obtain an average assessment representative of the grower.

Please tick the appropriate response:

I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
○	○	○	○	○

This should reduce seasonal variability due to the influence of climate.

9d-Please add your reasons or any comments below:

9E. For processes such as grain drying and machinery fuel use where secondary data is considered more accurate or accessible than primary data, though perhaps is older or geographically less appropriate etc., we suggest that the protocol allows this data to be used in preference.

Implemented in a carbon calculator for example, a 'tier 1' assessments fuel use data (litres per Ha) for field operations and grain drying may be fixed defaults taken from secondary sources. For 'tier 2' assessments fuel use for each operation shall be the same defaults but could be open for modification by the grower.

Please tick the appropriate response:

	I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
	◯	◯	◯	◯	◯

9e. Please add your reasons or any comments below:

9F. Primary data on the quantity of nitrogen applied and the type of fertiliser shall be mandatory, as shall primary data on crop yields.

Nitrogen input and yield are the most significant variable and interdependent. The growers guide and tool should emphasise this.

Please tick the appropriate response:	I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
	◯	◯	◯	◯	◯

9f. Please add your reasons or any comments below:

10. Secondary data quality requirements

Background

GHG estimates often heavily rely on the use of secondary data and estimates taken from LCA databases or other sources or studies, some from outside the UK (eg. Ecoinvent data etc.).

The specifications and protocols reviewed give broadly similar requirements for secondary data quality. In summary, the requirements are generally that data should be temporally, geographically and technologically appropriate to the assessment.

We propose that the protocol should also apply these criteria to secondary data. However, we have found that data availability is likely to limit all of these criteria being fulfilled for many data sources.

We propose that the protocol should require that data used for the HGCA crop assessment to be justified as being the best source available and should be described, in the context of the criteria below, in the appendices of the grower's guide, the data source referenced, and any methods of derivation.

Please state whether you agree with the criteria below:

Data quality should follow the requirements of PAS2050 (7.2) - interpreted with respect to crop production as below:

Please tick the appropriate response:	Yes	Uncertain	No
Accuracy preference: The secondary data used for defaults or replacing primary data should be justified, i.e. that it is likely to be more accurate or realistic than collecting primary data from growers.	○	○	○
Technology preference: The data should be based on technology that reflects the machinery and inputs (fertiliser etc) used in the UK, as far as is practical.	○	○	○
Age preference: The most recent secondary data sources should be preferred.This refers mainly with regard to emission factors and models (IPCC or otherwise).	○	○	○
Geographical preference: The choice of data sources should give preference to UK climate, energy mix and sources of data should prefer UK government publications and accepted international sources (IPCC) should be considered within the context of UK farm scale GHG assessment.	○	○	○
If data sources contravene these general requirements, these should be clearly communicated, and justification given.	○	○	○

Please add any further comments below:

11. Nitrous oxide emissions

Most GHG assessment protocols and specifications refer to the highest IPCC tier methods available for estimating nitrous oxide emissions from agriculture. The UK national inventory currently uses an adaptation of the IPCC 'tier 1' methodology. This fairly simple but is used for country level GHG reporting not farm scale assessments.

More detailed methodologies have been used for crop assessment at farm and regional level, but the more detailed mechanistic models require specialist knowledge to correctly apply contextual information and more demanding data requirements.

We propose a two tier approach for protocol: a simple IPCC 'tier 1' method and an intermediate approach which bridges the gap between geographically indistinct IPCC 'tier 1' method and detailed models. This tier 2 method is to be implemented using the prototype carbon calculator:

11A. We propose using the IPCC tier 1 methodology for nitrous oxide emissions for the HGCA tier 1 crop assessment.

Please tick the appropriate response:

	I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
	○	○	○	○	○

11B. We propose providing a more detailed tier 2 methodology for the protocol which requires selection from categories by growers regarding:

- **fertiliser type**
- **fertiliser application rate,**
- **crop type,**
- **categories of simple soil parameters (texture, organic carbon, drainage etc)**

This is based on empirical modelling by Bouwman et al., 2002.

Please tick the appropriate response:

I agree	I agree - with comments	I disagree - with reasons	It is complicated, see my comments	Pass - not my area of expertise
○	○	○	○	○

Bouwman, A.F., Boumans, L.J.M., Batjes, N.H., 2002. Modeling global annual N_2O and NO emissions from fertilized fields, Global Biogeochem. Cycles 16 (4), 1080, doi:10.1029/2001GB001812.

On behalf of the Home Grown Cereals Authority and the project team thank you for taking the time to respond to our questions.